space sciences

VOLUME 1
Space Business

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Pat Dasch, Editor in Chief

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Preface

Astronomers have studied the heavens for more than two millennia, but in the twentieth century, humankind ventured off planet Earth into the dark vacuum void of space, forever changing our perspective of our home planet and on our relationship to the universe in which we reside.

Our explorations of space—the final frontier in our niche in this solar system—first with satellites, then robotic probes, and finally with humans, have given rise to an extensive space industry that has a major influence on the economy and on our lives. In 1998, U.S. space exports (launch services, satellites, space-based communications services, and the like) totaled $64 billion. As we entered the new millennium, space exports were the second largest dollar earner after agriculture. The aerospace industry directly employs some 860,000 Americans, with many more involved in subcontracting companies and academic research.

Beginnings

The Chinese are credited with developing the rudiments of rocketry—they launched rockets as missiles against invading Mongols in 1232. In the nineteenth century William Congrieve developed a rocket in Britain based on designs conceived in India in the eighteenth century. Congrieve extended the range of the Indian rockets, adapting them specifically for use by armies. Congrieve's rockets were used in 1806 in the Napoleonic Wars.

The Birth of Modern Space Exploration

The basis of modern spaceflight and exploration came with the writings of Konstantin Tsiolkovsky (1857–1935), a Russian mathematics teacher. He described multi-stage rockets, winged craft like the space shuttle developed in the 1970s, space stations like Mir and the International Space Station, and interplanetary missions of discovery.

During the same period, space travel captured the imagination of fiction writers. Jules Verne wrote several novels with spaceflight themes. His book, *From the Earth to the Moon* (1865), describes manned flight to the Moon, including a launch site in Florida and a spaceship named Columbia—the name chosen for the Apollo 11 spaceship that made the first lunar landing in July 1969 and the first space shuttle, which flew in April 1981. In the twentieth century, Arthur C. Clarke predicted the role of communications satellites and extended our vision of human space exploration while

television series such as *Star Trek* and *Dr. Who* challenged the imagination and embedded the idea of space travel in our culture.

The first successful test of the V-2 rocket developed by Wernher von Braun and his team at Peenemünde, Germany, in October 1942 has been described as the "birth of the Space Age." After World War II some of the Peenemünde team under von Braun came to the United States, where they worked at the White Sands Missile Range in New Mexico, while others went to Russia. This sowed the seeds of the space race of the 1960s. Each team worked to develop advanced rockets, with Russia developing the R-7, while a series of rockets with names like Thor, Redstone, and Titan were produced in the United States.

When the Russians lofted Sputnik, the first artificial satellite, on October 4, 1957, the race was on. The flights of Yuri Gagarin, Alan Shepard, and John Glenn followed, culminating in the race for the Moon and the Apollo Program of the 1960s and early 1970s.

The Emergence of a Space Industry

The enormous national commitment to the Apollo Program marked a new phase in our space endeavors. The need for innovation and technological advance stimulated the academic and engineering communities and led to the growth of a vast network of contract supporters of the aerospace initiative and the birth of a vibrant space industry. At the same time, planetary science emerged as a new geological specialization.

Following the Apollo Program, the U.S. space agency's mission remained poorly defined through the end of the twentieth century, grasping at major programs such as development of the space shuttle and the International Space Station, in part, some argue, to provide jobs for the very large workforce spawned by the Apollo Program. The 1980s saw the beginnings of what would become a robust commercial space industry, largely independent of government programs, providing communications and information technology via space-based satellites. During the 1990s many thought that commercialization was the way of the future for space ventures. Commercially coordinated robotic planetary exploration missions were conceived with suggestions that NASA purchase the data, and Dennis Tito, the first paying space tourist in 2001, raised hopes of access to space for all.

The terrorist attacks on the United States on September 11, 2001 and the U.S. recession led to a re-evaluation of the entrepreneurial optimism of the 1990s. Many private commercial space ventures were placed on hold or went out of business. Commentators suggested that the true dawning of the commercial space age would be delayed by up to a decade. But, at the same time, the U.S. space agency emerged with a more clearly defined mandate than it had had since the Apollo Program, with a role of driving technological innovation—with an early emphasis on reducing the cost of getting to orbit—and leading world class space-related scientific projects. And military orders, to fill the needs of the new world order, compensated to a point for the downturn in the commercial space communications sector.

It is against this background of an industry in a state of flux, a discipline on the cusp of a new age of innovation, that this encyclopedia has been prepared.

Organization of the Material

The 341 entries in *Space Sciences* have been organized in four volumes, focusing on the business of space exploration, planetary science and astronomy, human space exploration, and the outlook for the future exploration of space. Each entry has been newly commissioned for this work. Our contributors are drawn from academia, industry, government, professional space institutes and associations, and nonprofit organizations. Many of the contributors are world authorities on their subject, providing up-to-the-minute information in a straightforward style accessible to high school students and university undergraduates.

One of the outstanding advantages of books on space is the wonderful imagery of exploration and achievement. These volumes are richly illustrated, and sidebars provide capsules of additional information on topics of particular interest. Entries are followed by a list of related entries, as well as a reading list for students seeking more information.

Acknowledgements

I wish to thank the team at Macmillan Reference USA and the Gale Group for their vision and leadership in bringing this work to fruition. In particular, thanks to Hélène Potter, Cindy Clendenon, and Gloria Lam. My thanks to Associate Editors Nadine Barlow, Leonard David, and Frank Sietzen, whose expertise, commitment, and patience have made *Space Sciences* possible. My thanks also go to my husband, Julius, for his encouragement and support. My love affair with space began in the 1970s when I worked alongside geologists using space imagery to plan volcanological field work in remote areas of South America, and took root when, in the 1980s, I became involved in systematic analysis of the more than 3,000 photographs of Earth that astronauts bring back at the end of every shuttle mission. The beauty of planet Earth, as seen from space, and the wealth of information contained in those images, convinced me that space is a very real part of life on Earth, and that I wanted to be a part of the exploration of space and to share the wonder of it with the public. I hope that *Space Sciences* conveys the excitement, achievements, and potential of space exploration to a new generation of students.

Pat Dasch
Editor in Chief

For Your Reference

The following section provides information that is applicable to a number of articles in this reference work. Included in the following pages is a chart providing comparative solar system planet data, as well as measurement, abbreviation, and conversion tables.

SOLAR SYSTEM PLANET DATA

	Mercury	Venus[2]	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Mean distance from the Sun (AU): [1]	0.387	0.723	1	1.524	5.202	9.555	19.218	30.109	39.439
Siderial period of orbit (years):	0.24	0.62	1	1.88	11.86	29.46	84.01	164.79	247.68
Mean orbital velocity (km/sec):	47.89	35.04	29.79	24.14	13.06	9.64	6.81	5.43	4.74
Orbital essentricity:	0.206	0.007	0.017	0.093	0.048	0.056	0.047	0.009	0.246
Inclination to ecliptic (degrees):	7.00	3.40	0	1.85	1.30	2.49	0.77	1.77	17.17
Equatorial radius (km):	2439	6052	6378	3397	71492	60268	25559	24764	1140
Polar radius (km):	same	same	6357	3380	66854	54360	24973	24340	same
Mass of planet (Earth = 1):[3]	0.06	0.82	1	0.11	317.89	95.18	14.54	17.15	0.002
Mean density (gm/cm ^{3}):	5.44	5.25	5.52	3.94	1.33	0.69	1.27	1.64	2.0
Body rotation period (hours):	1408	5832.R	23.93	24.62	9.92	10.66	17.24	16.11	153.3
Tilt of equator to orbit (degrees):	0	2.12	23.45	23.98	3.08	26.73	97.92	28.8	96

[1]AU indicates one astronomical unit, defined as the mean distance between Earth and the Sun (~1.495 x 10^8 km).
[2]R indicates planet rotation is retrograde (i.e., opposite to the planet's orbit).
[3]Earth's mass is approximately 5.976 x 10^{26} grams.

SI BASE AND SUPPLEMENTARY UNIT NAMES AND SYMBOLS

Physical Quality	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
Plane angle	radian	rad
Solid angle	steradian	sr

Temperature

Scientists commonly use the Celsius system. Although not recommended for scientific and technical use, earth scientists also use the familiar Fahrenheit temperature scale (°F). 1°F = 1.8°C or K. The triple point of H_2O, where gas, liquid, and solid water coexist, is 32°F.

- To change from Fahrenheit (F) to Celsius (C):
  °C = (°F-32)/(1.8)
- To change from Celsius (C) to Fahrenheit (F):
  °F = (°C x 1.8) + 32
- To change from Celsius (C) to Kelvin (K):
  K = °C + 273.15
- To change from Fahrenheit (F) to Kelvin (K):
  K = (°F-32)/(1.8) + 273.15

UNITS DERIVED FROM SI, WITH SPECIAL NAMES AND SYMBOLS

Derived Quantity	Name of SI Unit	Symbol for SI Unit	Expression in Terms of SI Base Units
Frequency	hertz	Hz	s-1
Force	newton	N	m kg s-2
Pressure, stress	Pascal	Pa	N m-2 =m-1 kg s-2
Energy, work, heat	Joule	J	N m =m2 kg s-2
Power, radiant flux	watt	W	J s-1 =m2 kg s-3
Electric charge	coulomb	C	A s
Electric potential, electromotive force	volt	V	J C-1 =m-2 kg s-3 A-1
Electric resistance	ohm	_	V A-1 =m2 kg s-3 A-2
Celsius temperature	degree Celsius	C	K
Luminous flux	lumen	lm	cd sr
Illuminance	lux	lx	cd sr m-2

UNITS USED WITH SI, WITH NAME, SYMBOL, AND VALUES IN SI UNITS

The following units, not part of the SI, will continue to be used in appropriate contexts (e.g., angtsrom):

Physical Quantity	Name of Unit	Symbol for Unit	Value in SI Units
Time	minute	min	60 s
	hour	h	3,600 s
	day	d	86,400 s
Plane angle	degree	°	(π/180) rad
	minute	'	(π/10,800) rad
	second	"	(π/648,000) rad
Length	angstrom	Å	10^{-10} m
Volume	liter	l, L	1 dm^3 = 10^{-3} m^3
Mass	ton	t	1 mg = 10^3 kg
	unified atomic mass unit	u (=m_a(^{12}C)/12)	≈1.66054 x 10^{-27} kg
Pressure	bar	bar	10^5 Pa = 10^5 N m^{-2}
Energy	electronvolt	eV (= e X V)	≈1.60218 x 10^{-19} J

CONVERSIONS FOR STANDARD, DERIVED, AND CUSTOMARY MEASUREMENTS

Length

1 angstrom (Å)	0.1 nanometer (exactly) 0.000000004 inch
1 centimeter (cm)	0.3937 inches
1 foot (ft)	0.3048 meter (exactly)
1 inch (in)	2.54 centimeters (exactly)
1 kilometer (km)	0.621 mile
1 meter (m)	39.37 inches 1.094 yards
1 mile (mi)	5,280 feet (exactly) 1.609 kilometers
1 astronomical unit (AU)	1.495979 x 10^{13} cm
1 parsec (pc)	206,264.806 AU 3.085678 x 10^{18} cm 3.261633 light-years
1 light-year	9.460530 x 10^{17} cm

Area

1 acre	43,560 square feet (exactly) 0.405 hectare
1 hectare	2.471 acres
1 square centimeter (cm^2)	0.155 square inch
1 square foot (ft^2)	929.030 square centimeters
1 square inch (in^2)	6.4516 square centimeters (exactly)
1 square kilometer (km^2)	247.104 acres 0.386 square mile
1 square meter (m^2)	1.196 square yards 10.764 square feet
1 square mile (mi^2)	258.999 hectares

MEASUREMENTS AND ABBREVIATIONS

Volume

1 barrel (bbl)*, liquid	31 to 42 gallons
1 cubic centimeter (cm^3)	0.061 cubic inch
1 cubic foot (ft^3)	7.481 gallons 28.316 cubic decimeters
1 cubic inch (in^3)	0.554 fluid ounce
1 dram, fluid (or liquid)	⅛ fluid ounce (exactly) 0.226 cubic inch 3.697 milliliters
1 gallon (gal) (U.S.)	231 cubic inches (exactly) 3.785 liters 128 U.S. fluid ounces (exactly)
1 gallon (gal) (British Imperial)	277.42 cubic inches 1.201 U.S. gallons 4.546 liters
1 liter	1 cubic decimeter (exactly) 1.057 liquid quarts 0.908 dry quart 61.025 cubic inches
1 ounce, fluid (or liquid)	1.805 cubic inches 29.573 mililiters
1 ounce, fluid (fl oz) (British)	0.961 U.S. fluid ounce 1.734 cubic inches 28.412 milliliters
1 quart (qt), dry (U.S.)	67.201 cubic inches 1.101 liters
1 quart (qt), liquid (U.S.)	57.75 cubic inches (exactly) 0.946 liter

* There are a variety of "barrels" established by law or usage. For example, U.S. federal taxes on fermented liquors are based on a barrel of 31 gallons (141 liters); many state laws fix the "barrel for liquids" as 31½ gallons (119.2 liters); one state fixes a 36-gallon (160.5 liters) barrel for cistern measurment; federal law recognizes a 40-gallon (178 liters) barrel for "proof spirts"; by custom, 42 gallons (159 liters) comprise a barrel of crude oil or petroleum products for statistical purposes, and this equivalent is recognized "for liquids" by four states.

Units of mass

1 carat (ct)	200 milligrams (exactly) 3.086 grains
1 grain	64.79891 milligrams (exactly)
1 gram (g)	15.432 grains 0.035 ounce
1 kilogram (kg)	2.205 pounds
1 microgram (μg)	0.000001 gram (exactly)
1 milligram (mg)	0.015 grain
1 ounce (oz)	437.5 grains (exactly) 28.350 grams
1 pound (lb)	7,000 grains (exactly) 453.59237 grams (exactly)
1 ton, gross or long	2,240 pounds (exactly) 1.12 net tons (exactly) 1.016 metric tons
1 ton, metric (t)	2,204.623 pounds 0.984 gross ton 1.102 net tons
1 ton, net or short	2,000 pounds (exactly) 0.893 gross ton 0.907 metric ton

Pressure

1 kilogram/square centimeter (kg/cm^2)	0.96784 atmosphere (atm) 14.2233 pounds/square inch (lb/in^2) 0.98067 bar
1 bar	0.98692 atmosphere (atm) 1.02 kilograms/square centimeter (kg/cm^2)

Major Business Milestones in U.S. History

Apr. 1820	Federal law allows settlers to purchase lands in western United States.
Dec. 1823	Monroe Doctrine established.
Mar. 1824	Supreme Court establishes federal authority over interstate commerce.
May, 1824	United States raises tariff on foreign goods.
May, 1828	Congress passes high import duty on foreign goods.
July, 1832	President Andrew Jackson vetoes Bank of U.S. rechartering.
Nov. 1832	South Carolina voids Tariff Acts of 1828, 1832.
Mar. 1833	Congress passes bill giving president power to enforce tariffs.
Sept. 1833	U.S. Treasury Secretary removes deposits from Bank of U.S.
Mar. 1834	Congress censures president over removal of funds from Bank of U.S.
June, 1834	Second Coinage Act changes silver/gold ratio, which undervalues silver.
Dec. 1835	United States becomes debt-free.
Feb. 1836	Bank of U.S. rechartered.
June, 1836	Congress passes Deposit Act requiring federal deposit bank in every state.
July, 1836	Payments for purchase of public land required in gold or silver.
May, 1837	Panic of 1837 triggers seven-year depression in the United States.
Aug. 1841	Congress passes new bankruptcy law.
Sept. 1841	President John Tyler vetoes bill to reestablish national U.S. bank.
July, 1846	Tariff reduced by Congressional action.
Jan. 1848	Gold rush era begins.

Sept. 1850	Land grants established to help pay for U.S. transcontinental railroad.
Aug. 1854	Congress reduces purchase price of federal lands.
Jan. 1855	First U.S. petroleum company is established.
Apr. 1857	Panic of 1857 triggers run on U.S. banks.
July, 1858	Gold discovered near Pike's Peak Colorado.
Aug. 1859	Pennsylvania site of major oil discovery.
May, 1862	Homestead Act establishes farming on public lands.
Feb. 1863	Congress passes National Banking Act.
June, 1864	Tariffs slashed by Congress.
Mar. 1865	Congress creates 10 percent tax on state bank notes.
Apr. 1866	Funding Act passed, creates conversion of securities into bonds.
July, 1866	Congress reduces Civil War taxes.
Mar. 1867	Congress passes Internal Revenue Act.
Feb. 1868	Congress suspends greenback retirement.
Mar. 1868	Congress cancels excise taxes.
July, 1870	Congress announces end of U.S. income tax in two years.
Feb. 1873	Coinage of silver dollars ends.
Sept. 1873	Five-year depression begins.
	U.S. Stock Exchange closes for ten days following stock collapse.
June, 1874	Amount of greenbacks in circulation is fixed.
Jan. 1875	Greenbacks can be redeemed in gold.
Jan. 1878	First U.S. commercial telephone exchange starts in Connecticut.
Jan. 1881	Western Union company is formed.
	Income tax declared unconstitutional.
Dec. 1886	American Federation of Labor is created in Columbus, Ohio.
Feb. 1887	Congress created Interstate Commerce Commission.
Oct. 1890	Tariff Act raises tariffs.
Apr. 1893	U.S. Treasury suspends issuance of gold certificates.
Jan. 1894	Treasury sells $50 million in bonds to resupply gold reserves.
Aug. 1894	Tariff Act creates two percent federal income tax.
Nov. 1894	United States issues additional $50 million in bonds to buy gold.
Feb. 1895	United States buys $65 million in gold.

July, 1897	United States raises tariffs to record levels.
June, 1898	War Revenue Act passed; establishes excise taxes.
Jan. 1901	Huge oilfield discovery in Texas.
May, 1901	Wall Street Panic over control of Northern-Pacific railroad.
June, 1901	J. P. Morgan consolidates U.S. Steel.
Jan. 1907	U.S. immigration reaches peak.
Oct. 1907	"Banker's Panic" sweeps banking industry, causing widespread failures.
Feb. 1908	Supreme Court rules Sherman Anti-Trust Act applies to labor unions.
Aug. 1909	Payne-Aldrich Tariff Act signed and reduces tariff rates.
June, 1910	Postal Savings System to pay interest of two percent.
May, 1911	Supreme Court orders break-up of Standard Oil.
Jan. 1913	Postal Service establishes Parcel Post.
Mar. 1913	Ford opens auto assembly line.
July, 1914	Stock Exchange closes as Europe slides into war.
Nov. 1914	Federal Reserve opens.
1915	Carrier Engineering is founded, creating commercial air conditioning.
Jan. 1915	Telephone service between New York and San Francisco begins.
Oct. 1915	U.S. banks loan $500 million to Great Britain and France.
Sept. 1916	Emergency Revenue Act doubles U.S. income tax rates.
Mar. 1917	Excess Profits Tax instituted.
Apr. 1917	Congress passes Emergency Loan Act to issue bonds for war effort.
Dec. 1917	Federal government assumes control of railroads.
Apr. 1919	Congress passes loan authorization to pay off war debt.
1920	Recession begins in United States following end of World War I.
Feb. 1920	Federal Reserve issues 7 percent discount rate.
June, 1924	Federal government reduces federal income tax rates.
Apr. 1923	Commercial air passenger service begins in United States.
July, 1928	Interest rates soar to record highs.
Feb. 1929	Federal Reserve refuses to support stock speculation.
Oct. 1929	Stock market prices plunge.
Nov. 1929	New York Stock Exchange reports record stock devaluation.

Dec. 1929	President Herbert Hoover signs income tax reduction bill.
June, 1930	Stock market reports additional steep value losses.
Dec. 1930	Bank of U.S. fails.
	Banks across United States close.
Sept. 1931	Bank panic closes 800 banks.
July, 1932	Dow Jones Industrial Average falls to record lows.
Dec. 1932	Treasury Certificates reach record low interest.
Feb. 1934	Congress votes on massive civil works and relief aid.
June, 1934	Congress creates Securities and Exchange Commission.
Feb. 1934	Congress votes to regulate crude oil.
Apr. 1935	Congress votes on work relief program for unemployed.
Aug. 1935	Congress votes on increases to income, inheritance, and gift taxes.
Jan. 1936	Congress imposes payroll tax.
May, 1938	Congress cuts corporate taxes.
June, 1939	IRS establishes minimum flat-rate corporate tax.
June, 1940	Federal taxes raised.
Oct. 1940	Corporate tax rate raised to 24 percent.
Sept. 1941	All federal taxes increased to fund increases in defense spending.
June, 1945	Federal reserve reduces gold reserve.
Nov. 1945	Revenue Act passed, slashes taxes raised during World War II.
July, 1946	Stock prices begin decline after years of growth.
Aug. 1948	Consumer Price Index peaks at record high values.
Aug. 1950	Federal Reserve Board urges end to inflationary loan practice.
Mar. 1954	Excise taxes slashed.
Aug. 1954	IRS changes federal tax code to allow greater depreciation.
Jan. 1955	United States shows full employment, increased consumer spending.
Aug. 1955	Congress raised minimum wage to $1.00 per hour.
Sept. 1957	Recession starts.
May, 1958	Largest peacetime business growth begins.
Jan. 1959	President Dwight D. Eisenhower endorses 52 percent hike in corporate tax rates.
May, 1961	Minimum wage raised to $1.25 per hour.
Oct. 1962	Congress passes Revenue Act allowing for investment tax credits.

Jan. 1963	President John F. Kennedy proposes major reduction in tax rates.
Nov. 1966	Congress suspends Investment Tax Credit.
Jan. 1967	President Lyndon B. Johnson proposes 6 percent surtax on income taxes.
June, 1968	Revenue Act adds 10 percent tax surcharge to federal taxes.
June, 1969	Prime lending rate reaches highest level of 8.5 percent.
	Consumer prices rise more than 6 percent since January.
Dec. 1969	Taxes reduced for poor and low income earners.
Mar. 1971	Social security benefits raised 10 percent.
Aug. 1971	President Richard M. Nixon takes United States off gold standard.
Jan. 1973	Wage and price controls instituted.
June, 1973	Minimum wage increased to $2.20 per hour.
Sept. 1973	Congress creates new ration: U.S. dollar to gold $42 per ounce.
Oct. 1973	Oil embargo begins.
Apr. 1974	End of wage and price controls.
Oct. 1974	President Gerald R. Ford proposes 5 percent income tax surcharge.
Dec. 1974	Federal Reserve reduces discount rate to 7.5 percent.
July, 1975	Social Security payments increased 8 percent.
Nov. 1977	Minimum wage raised to $3.35 per hour.
May, 1980	Leading Economic Indicators posts 4.8 percent drop, largest on record.
Dec. 1980	Prime lending rate reaches 21.5 percent, highest in history.
July, 1981	Congress passes Reagan tax cut plan.
Aug. 1982	Bull Market begins on Wall Street.
Sept. 1986	Congress passes tax reform act.
Oct. 1987	Stock market crashes 508 points in single day.
Oct. 1989	Minimum wage increased to $3.80 per hour.
Apr. 1991	Dow Jones Industrial Average breaks 3000.
Dec. 1995	Dow Jones breaks 5117.
July, 1997	Congress passes largest tax cut package in 16 years.
Oct. 1997	Dow Jones falls 554 points in one day.
Aug. 1998	Dow Jones falls 512 points in single day.
Sept. 1998	Congress passes $80 billion tax cut.
Oct. 1998	Federal Reserve cuts rate by 0.025 to 5 percent.
2000	Internet dot.com businesses blossom.

May, 2000	Federal Reserve reduces prime rate to 6.5 percent.
Jan. 2001	Federal Reserve reduces prime rate to 6 percent.
Mar. 2001	Prime rate dropped to 5.5 percent.
Apr. 2001	Prime rate dropped to 5 percent.
	Dot.coms collapse, technology stocks plummet.
May, 2001	Prime rate dropped to 4.5 percent.
June, 2001	Prime rate dropped to 4 percent.
Aug. 2001	Prime rate dropped to 3.5 percent.
Sept. 2001	Terrorist attacks against the United States devastate economy.
	Prime rate dropped to 3 percent.
Oct. 2001	Prime rate dropped to 2.5 percent.
Nov. 2001	Prime rate dropped to 2 percent.
Dec. 2001	Prime rate dropped to 1.75 percent.

Frank Sietzen, Jr.

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Milestones in Space History

c. 850 The Chinese invent a form of gunpowder for rocket propulsion.

1242 Englishman Roger Bacon develops gunpowder.

1379 Rockets are used as weapons in the Siege of Chioggia, Italy.

1804 William Congrieve develops ship-fired rockets.

1903 Konstantin Tsiolkovsky publishes *Research into Interplanetary Science by Means of Rocket Power*, a treatise on space travel.

1909 Robert H. Goddard develops designs for liquid-fueled rockets.

1917 Smithsonian Institute issues grant to Goddard for rocket research.

1918 Goddard publishes the monograph *Method of Attaining Extreme Altitudes.*

1921 Soviet Union establishes a state laboratory for solid rocket research.

1922 Hermann Oberth publishes *Die Rakete zu den Planetenräumen*, a work on rocket travel through space.

1923 Tsiolkovsky publishes work postulating multi-staged rockets.

1924 Walter Hohmann publishes work on rocket flight and orbital motion.

1927 The German Society for Space Travel holds its first meeting.

Max Valier proposes rocket-powered aircraft adapted from Junkers G23.

1928 Oberth designs liquid rocket for the film *Woman in the Moon.*

1929 Goddard launches rocket carrying barometer.

1930 Soviet rocket designer Valentin Glusko designs U.S.S.R. liquid rocket engine.

1931	Eugene Sänger test fires liquid rocket engines in Vienna.
1932	German Rocket Society fires first rocket in test flight.
1933	Goddard receives grant from Guggenheim Foundation for rocket studies.
1934	Wernher von Braun, member of the German Rocket Society, test fires water-cooled rocket.
1935	Goddard fires advanced liquid rocket that reaches 700 miles per hour.
1936	Glushko publishes work on liquid rocket engines.
1937	The Rocket Research Project of the California Institute of Technology begins research program on rocket designs.
1938	von Braun's rocket researchers open center at Pennemünde.
1939	Sänger and Irene Brendt refine rocket designs and propose advanced winged suborbital bomber.
1940	Goddard develops centrifugal pumps for rocket engines.
1941	Germans test rocket-powered interceptor aircraft Me 163.
1942	V-2 rocket fired from Pennemünde enters space during ballistic flight.
1943	First operational V-2 launch.
1944	V-2 rocket launched to strike London.
1945	Arthur C. Clarke proposes geostationary satellites.
1946	Soviet Union tests version of German V-2 rocket.
1947	United States test fires Corporal missile from White Sands, New Mexico.
	X-1 research rocket aircraft flies past the speed of sound.
1948	United States reveals development plan for Earth satellite adapted from RAND.
1949	Chinese rocket scientist Hsueh-Sen proposes hypersonic aircraft.
1950	United States fires Viking 4 rocket to record 106 miles from USS Norton Sound.
1951	Bell Aircraft Corporation proposes winged suborbital rocket-plane.
1952	Wernher von Braun proposes wheeled Earth-orbiting space station.
1953	U.S. Navy D-558II sets world altitude record of 15 miles above Earth.
1954	Soviet Union begins design of RD-107, RD-108 ballistic missile engines.
1955	Soviet Union launches dogs aboard research rocket on suborbital flight.

1956 United States announces plan to launch Earth satellite as part of Geophysical Year program.

1957 U.S. Army Ballistic Missile Agency is formed.

Soviet Union test fires R-7 ballistic missile.

Soviet Union launches the world's first Earth satellite, Sputnik-1, aboard R-7.

United States launches 3-stage Jupiter C on test flight.

United States attempts Vanguard 1 satellite launch; rocket explodes.

1958 United States orbits Explorer-1 Earth satellite aboard Jupiter-C rocket.

United States establishes the National Aeronautics and Space Administration (NASA) as civilian space research organization.

NASA establishes Project Mercury manned space project.

United States orbits Atlas rocket with Project Score.

1959 Soviet Union sends Luna 1 towards Moon; misses by 3100 miles.

NASA announces the selection of seven astronauts for Earth space missions.

Soviet Union launches Luna 2, which strikes the Moon.

1960 United States launches Echo satellite balloon.

United States launches Discoverer 14 into orbit, capsule caught in midair.

Soviet Union launches two dogs into Earth orbit.

Mercury-Redstone rocket test fired in suborbital flight test.

1961 Soviet Union tests Vostok capsule in Earth orbit with dummy passenger.

Soviet Union launches Yuri Gagarin aboard Vostok-1; he becomes the first human in space.

United States launches Alan B. Shepard on suborbital flight.

United States proposes goal of landing humans on the Moon before 1970.

Soviet Union launches Gherman Titov into Earth orbital flight for one day.

United States launches Virgil I. "Gus" Grissom on suborbital flight.

United States launches first Saturn 1 rocket in suborbital test.

1962	United States launches John H. Glenn into 3-orbit flight.
	United States launches Ranger to impact Moon; craft fails.
	First United States/United Kingdom international satellite launch; Ariel 1 enters orbit.
	X-15 research aircraft sets new altitude record of 246,700 feet.
	United States launches Scott Carpenter into 3-orbit flight.
	United States orbits Telstar 1 communications satellite.
	Soviet Union launches Vostok 3 and 4 into Earth orbital flight.
	United States launches Mariner II toward Venus flyby.
	United States launches Walter Schirra into 6-orbit flight.
	Soviet Union launches Mars 1 flight; craft fails.
1963	United States launches Gordon Cooper into 22-orbit flight.
	Soviet Union launches Vostok 5 into 119-hour orbital flight.
	United States test fires advanced solid rockets for Titan 3C.
	First Apollo Project test in Little Joe II launch.
	Soviet Union orbits Vostok 6, which carries Valentina Tereshkova, the first woman into space.
	Soviet Union tests advanced version of R-7 called Soyuz launcher.
1964	United States conducts first Saturn 1 launch with live second stage; enters orbit.
	U.S. Ranger 6 mission launched towards Moon; craft fails.
	Soviet Union launches Zond 1 to Venus; craft fails.
	United States launches Ranger 7 on successful Moon impact.
	United States launches Syncom 3 communications satellite.
	Soviet Union launches Voshkod 1 carrying three cosmonauts.
	United States launches Mariner 4 on Martian flyby mission.
1965	Soviet Union launches Voshkod 2; first space walk.
	United States launches Gemini 3 on 3-orbit piloted test flight.
	United States launches Early Bird 1 communications satellite.
	United States launches Gemini 4 on 4-day flight; first U.S. space walk.

United States launches Gemini 5 on 8-day flight.

United States launches Titan 3C on maiden flight.

Europe launches Asterix 1 satellite into orbit.

United States Gemini 6/7 conduct first space rendezvous.

1966 Soviet Union launches Luna 9, which soft lands on Moon.

United States Gemini 8 conducts first space docking; flight aborted.

United States launches Surveyor 1 to Moon soft landing.

United States tests Atlas Centaur advanced launch vehicle.

Gemini 9 flight encounters space walk troubles.

Gemini 10 flight conducts double rendezvous.

United States launches Lunar Orbiter 1 to orbit Moon.

Gemini 11 tests advanced space walks.

United States launches Saturn IB on unpiloted test flight.

Soviet Union tests advanced Proton launch vehicle.

United States launches Gemini 12 to conclude two-man missions.

1967 Apollo 1 astronauts killed in launch pad fire.

Soviet Soyuz 1 flight fails; cosmonaut killed.

Britain launches Ariel 3 communications satellite.

United States conducts test flight of M2F2 lifting body research craft.

United States sends Surveyor 3 to dig lunar soils.

Soviet Union orbits anti-satellite system.

United States conducts first flight of Saturn V rocket (Apollo 4).

1968 Yuri Gagarin killed in plane crash.

Soviet Union docks Cosmos 212 and 213 automatically in orbit.

United States conducts Apollo 6 Saturn V test flight; partial success.

Nuclear rocket engine tested in Nevada.

United States launches Apollo 7 in three-person orbital test flight.

Soviet Union launches Soyuz 3 on three-day piloted flight.

United States sends Apollo 8 into lunar orbit; first human flight to Moon.

1969 Soviet Union launches Soyuz 4 and 5 into orbit; craft dock.

Largest tactical communications satellite launched.

	United States flies Apollo 9 on test of lunar landing craft in Earth orbit.
	United States flies Apollo 10 to Moon in dress rehearsal of landing attempt.
	United States cancels military space station program.
	United States flies Apollo 11 to first landing on the Moon.
	United States cancels production of Saturn V in budget cut.
	Soviet lunar rocket N-1 fails in launch explosion.
	United States sends Mariner 6 on Mars flyby.
	United States flies Apollo 12 on second lunar landing mission.
	Soviet Union flies Soyuz 6 and 7 missions.
	United States launches Skynet military satellites for Britain.
1970	China orbits first satellite.
	Japan orbits domestic satellite.
	United States Apollo 13 mission suffers explosion; crew returns safely.
	Soviet Union launches Venera 7 for landing on Venus.
	United States launches military early warning satellite.
	Soviet Union launches Luna 17 to Moon.
	United States announces modifications to Apollo spacecraft.
1971	United States flies Apollo 14 to Moon landing.
	Soviet Union launches Salyut 1 space station into orbit.
	First crew to Salyut station, Soyuz 11, perishes.
	Soviet Union launches Mars 3 to make landing on the red planet.
	United States flies Apollo 15 to Moon with roving vehicle aboard.
1972	United States and the Soviet Union sign space cooperation agreement.
	United States launches Pioneer 10 to Jupiter flyby.
	Soviet Union launches Venera 8 to soft land on Venus.
	United States launches Apollo 16 to moon.
	India and Soviet Union sign agreement for launch of Indian satellite.
	United States initiates space shuttle project.
	United States flies Apollo 17, last lunar landing mission.

1973	United States launches Skylab space station.
	United States launches first crew to Skylab station.
	Soviet Union launches Soyuz 12 mission.
	United States launches second crew to Skylab space station.
1974	United States launches ATS research satellite.
	Soviet Union launches Salyut 3 on unpiloted test flight.
	Soviet Union launches Soyuz 12, 13, and 14 flights.
	Soviet Union launches Salyut 4 space station.
1975	Soviet Union launches Soyuz 17 to dock with Salyut 4 station.
	Soviet Union launches Venera 9 to soft land on Venus.
	United States and Soviet Union conduct Apollo-Soyuz Test Project joint flight.
	China orbits large military satellite.
	United States sends Viking 1 and 2 towards landing on Martian surface.
	Soviet Union launches unpiloted Soyuz 20.
1976	Soviet Union launches Salyut 5 space station.
	First space shuttle rolls out; Enterprise prototype.
	Soviet Union docks Soyuz 21 to station.
	China begins tests of advanced ballistic missile.
1977	Soyuz 24 docks with station.
	United States conducts atmospheric test flights of shuttle Enterprise.
	United States launches Voyager 1 and 2 on deep space missions.
	Soviet Union launches Salyut 6 space station.
	Soviet Soyuz 25 fails to dock with station.
	Soyuz 26 is launched and docks with station.
1978	Soyuz 27 is launched and docks with Salyut 6 station.
	Soyuz 28 docks with Soyuz 27/Salyut complex.
	United States launches Pioneer/Venus 1 mission.
	Soyuz 29 docks with station.
	Soviet Union launches Progress unpiloted tankers to station.
	Soyuz 30 docks with station.
	United States launches Pioneer/Venus 2.
	Soyuz 31 docks with station.

1979	Soyuz 32 docks with Salyut station.
	Voyager 1 flies past Jupiter.
	Soyuz 33 fails to dock with station.
	Voyager 2 flies past Jupiter.
1980	First Ariane rocket launches from French Guiana; fails.
	Soviet Union begins new Soyuz T piloted missions.
	STS-1 first shuttle mission moves to launching pad.
1981	Soviet Union orbits advanced Salyut stations.
	STS-1 launched on first space shuttle mission.
	United States launches STS-2 on second shuttle flight; mission curtailed.
1982	United States launches STS-5 first operational shuttle flight.
1983	United States launches Challenger, second orbital shuttle, on STS-6.
	United States launches Sally Ride, the first American woman in space, on STS-7.
	United States launches Guion Bluford, the first African-American astronaut, on STS-8.
	United States launches first Spacelab mission aboard STS-9.
1984	Soviet Union tests advanced orbital station designs.
	Shuttle Discovery makes first flights.
	United States proposes permanent space station as goal.
1985	Space shuttle Atlantis enters service.
	United States announces policy for commercial rocket sales.
	United States flies U.S. Senator aboard space shuttle Challenger.
1986	Soviet Union launches and occupies advanced Mir space station.
	Challenger—on its tenth mission, STS-51-L—is destroyed in a launching accident.
	United States restricts payloads on future shuttle missions.
	United States orders replacement shuttle for Challenger.
1987	Soviet Union flies advanced Soyuz T-2 designs.
	United States' Delta, Atlas, and Titan rockets grounded in launch failures.
	Soviet Union launches Energyia advanced heavy lift rocket.

1988	Soviet Union orbits unpiloted shuttle Buran.
	United States launches space shuttle Discovery on STS-26 flight.
	United States launches STS-27 military shuttle flight.
1989	United States launches STS-29 flight.
	United States launches Magellan probe from shuttle.
1990	Shuttle fleet grounded for hydrogen leaks.
	United States launches Hubble Space Telescope.
1992	Replacement shuttle Endeavour enters service.
	United States probe Mars Observer fails.
1993	United States and Russia announce space station partnership.
1994	United States shuttles begin visits to Russian space station Mir.
1995	Europe launches first Ariane 5 advanced booster; flight fails.
1996	United States announces X-33 project to replace shuttles.
1997	Mars Pathfinder lands on Mars.
1998	First elements of International Space Station launched.
1999	First Ocean space launch of Zenit rocket in Sea Launch program.
2000	Twin United States Mars missions fail.
2001	United States cancels shuttle replacements X-33 and X-34 because of space cutbacks.
	United States orbits Mars Odyssey probe around Mars.
2002	First launches of United States advanced Delta IV and Atlas V commercial rockets.

Frank Sietzen, Jr.

Human Achievements in Space

The road to space has been neither steady nor easy, but the journey has cast humans into a new role in history. Here are some of the milestones and achievements.

Oct. 4, 1957 The Soviet Union launches the first artificial satellite, a 184-pound spacecraft named Sputnik.

Nov. 3, 1957 The Soviets continue pushing the space frontier with the launch of a dog named Laika into orbit aboard Sputnik 2. The dog lives for seven days, an indication that perhaps people may also be able to survive in space.

Jan. 31, 1958 The United States launches Explorer 1, the first U.S. satellite, and discovers that Earth is surrounded by radiation belts. James Van Allen, who instrumented the satellite, is credited with the discovery.

Apr. 12, 1961 Yuri Gagarin becomes the first person in space. He is launched by the Soviet Union aboard a Vostok rocket for a two-hour orbital flight around the planet.

May 5, 1961 Astronaut Alan Shepard becomes the first American in space. Shepard demonstrates that individuals can control a vehicle during weightlessness and high gravitational forces. During his 15-minute suborbital flight, Shepard reaches speeds of 5,100 mph.

May 24, 1961 Stung by the series of Soviet firsts in space, President John F. Kennedy announces a bold plan to land men on the Moon and bring them safely back to Earth before the end of the decade.

Feb. 20, 1962 John Glenn becomes the first American in orbit. He flies around the planet for nearly five hours in his Mercury capsule, Friendship 7.

June 16, 1963 The Soviets launch the first woman, Valentina Tereshkova, into space. She circles Earth in her Vostok spacecraft for three days.

Nov. 28, 1964 NASA launches Mariner 4 spacecraft for a flyby of Mars.

Mar. 18, 1965 Cosmonaut Alexei Leonov performs the world's first space walk outside his Voskhod 2 spacecraft. The outing lasts 10 minutes.

Mar. 23, 1965 Astronauts Virgil I. "Gus" Grissom and John Young blast off on the first Gemini mission and demonstrate for the first time how to maneuver from one orbit to another.

June 3, 1965 Astronaut Edward White becomes the first American to walk in space during a 21-minute outing outside his Gemini spacecraft.

Mar. 16, 1966 Gemini astronauts Neil Armstrong and David Scott dock their spacecraft with an unmanned target vehicle to complete the first joining of two spacecraft in orbit. A stuck thruster forces an early end to the experiment, and the crew makes America's first emergency landing from space.

Jan. 27, 1967 The Apollo 1 crew is killed when a fire breaks out in their command module during a prelaunch test. The fatalities devastate the American space community, but a subsequent spacecraft redesign helps the United States achieve its goal of sending men to the Moon.

Apr. 24, 1967 Tragedy also strikes the Soviet space program, with the death of cosmonaut Vladimir Komarov. His new Soyuz spacecraft gets tangled with parachute lines during reentry and crashes to Earth.

Dec. 21, 1968 Apollo 8, the first manned mission to the Moon, blasts off from Cape Canaveral, Florida. Frank Borman, Jim Lovell and Bill Anders orbit the Moon ten times, coming to within 70 miles of the lunar surface.

July 20, 1969 Humans walk on another world for the first time when astronauts Neil Armstrong and Edwin "Buzz" Aldrin climb out of their spaceship and set foot on the Moon.

Apr. 13, 1970 The Apollo 13 mission to the Moon is aborted when an oxygen tank explosion cripples the spacecraft. NASA's most serious inflight emergency ends four days later when the astronauts, ill and freezing, splash down in the Pacific Ocean.

June 6, 1971 Cosmonauts blast off for the first mission in the world's first space station, the Soviet Union's Salyut 1. The crew spends twenty-two days aboard the outpost. During reentry, however, a faulty valve leaks air from the Soyuz capsule, and the crew is killed.

Jan. 5, 1972 President Nixon announces plans to build "an entirely new type of space transportation system," pumping life into NASA's dream to build a reusable, multi-purpose space shuttle.

Dec. 7, 1972 The seventh and final mission to the Moon is launched, as public interest and political support for the Apollo program dims.

May 14, 1973 NASA launches the first U.S. space station, Skylab 1, into orbit. Three crews live on the station between May 1973 and February 1974. NASA hopes to have the shuttle fly-

ing in time to reboost and resupply Skylab, but the outpost falls from orbit on July 11, 1979.

July 17, 1975 In a momentary break from Cold War tensions, the United States and Soviet Union conduct the first linking of American and Russian spaceships in orbit. The Apollo-Soyuz mission is a harbinger of the cooperative space programs that develop between the world's two space powers twenty years later.

Apr. 12, 1981 Space shuttle Columbia blasts off with a two-man crew for the first test-flight of NASA's new reusable spaceship. After two days in orbit, the shuttle lands at Edwards Air Force Base in California.

June 18, 1983 For the first time, a space shuttle crew includes a woman. Astronaut Sally Ride becomes America's first woman in orbit.

Oct. 30, 1983 NASA's increasingly diverse astronaut corps includes an African-American for the first time. Guion Bluford, an aerospace engineer, is one of the five crewmen assigned to the STS-8 mission.

Nov. 28, 1983 NASA flies its first Spacelab mission and its first European astronaut, Ulf Merbold.

Feb. 7, 1984 Shuttle astronauts Bruce McCandless and Robert Stewart take the first untethered space walks, using a jet backpack to fly up to 320 feet from the orbiter.

Apr. 9–11, 1984 First retrieval and repair of an orbital satellite.

Jan. 28, 1986 Space shuttle Challenger explodes 73 seconds after launch, killing its seven-member crew. Aboard the shuttle was Teacher-in-Space finalist Christa McAuliffe, who was to conduct lessons from orbit. NASA grounds the shuttle fleet for two and a half years.

Feb. 20. 1986 The Soviets launch the core module of their new space station, Mir, into orbit. Mir is the first outpost designed as a module system to be expanded in orbit. Expected lifetime of the station is five years.

May 15, 1987 Soviets launch a new heavy-lift booster from the Baikonur Cosmodrome in Kazakhstan.

Oct. 1, 1987 Mir cosmonaut Yuri Romanenko breaks the record for the longest space mission, surpassing the 236-day flight by Salyut cosmonauts set in 1984.

Sept. 29, 1988 NASA launches the space shuttle Discovery on the first crewed U.S. mission since the 1986 Challenger explosion. The shuttle carries a replacement communications satellite for the one lost onboard Challenger.

May 4, 1989 Astronauts dispatch a planetary probe from the shuttle for the first time. The Magellan radar mapper is bound for Venus.

Nov. 15, 1989 The Soviets launch their space shuttle Buran, which means snowstorm, on its debut flight. There is no crew onboard, and unlike the U.S. shuttle, no engines to help place it into orbit. Lofted into orbit by twin Energia heavy-lift boosters, Buran circles Earth twice and lands. Buran never flies again.

Apr. 24, 1990 NASA launches the long-awaited Hubble Space Telescope, the cornerstone of the agency's "Great Observatory" program, aboard space shuttle Discovery. Shortly after placing the telescope in orbit, astronomers discover that the telescope's prime mirror is misshapen.

Dec. 2, 1993 Space shuttle Endeavour takes off for one of NASA's most critical shuttle missions: repairing the Hubble Space Telescope. During an unprecedented five space walks, astronauts install corrective optics. The mission is a complete success.

Feb. 3, 1994 A Russian cosmonaut, Sergei Krikalev, flies aboard a U.S. spaceship for the first time.

Mar. 16, 1995 NASA astronaut Norman Thagard begins a three and a half month mission on Mir—the first American to train and fly on a Russian spaceship. He is the first of seven Americans to live on Mir.

Mar. 22, 1995 Cosmonaut Valeri Polyakov sets a new space endurance record of 437 days, 18 hours.

June 29, 1995 Space shuttle Atlantis docks for the first time at the Russian space station Mir.

Mar. 24, 1996 Shannon Lucid begins her stay aboard space aboard Mir, which lasts 188 days—a U.S. record for spaceflight endurance at that time.

Feb. 24, 1997 An oxygen canister on Mir bursts into flames, cutting off the route to the station's emergency escape vehicles. Six crewmembers are onboard, including U.S. astronaut Jerry Linenger.

June 27, 1997 During a practice of a new docking technique, Mir commander Vasily Tsibliyev loses control of an unpiloted cargo ship and it plows into the station. The Spektr module is punctured, The crew hurriedly seals off the compartment to save the ship.

Oct. 29, 1998 Senator John Glenn, one of the original Mercury astronauts, returns to space aboard the shuttle.

Nov. 20, 1998 A Russian Proton rocket hurls the first piece of the International Space Station into orbit.

Aug. 27, 1999 Cosmonauts Viktor Afanasyev, Sergei Avdeyev, and Jean-Pierre Haignere leave Mir. The station is unoccupied for the first time in almost a decade.

Oct. 31, 2000 The first joint American-Russian crew is launched to the International Space Station. Commander Bill Shepherd requests the radio call sign "Alpha" for the station and the name sticks.

Mar. 23, 2001 The *Mir* space station drops out of orbit and burns up in Earth's atmosphere.

Apr. 28, 2001 Russia launches the world's first space tourist for a week-long stay at the International Space Station. NASA objects to the flight, but is powerless to stop it.

Irene Brown

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Accessing Space

A

The task of placing satellites into **orbit** has proven formidable, and current technology dictates that rockets be used to access space. A rocket is a cylindrical metal object containing inflammable material, which, when ignited, propels the rocket to a significant height or distance. Rocket-powered vehicles are quite different from jet aircraft, in that jets use the atmosphere as a source of oxidizer (oxygen in the air) with which to burn the fuel. Rocket-propelled vehicles must carry along all propellants (both fuel and oxidizer).

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Pre-Space Age Rocketry Developments

Many centuries ago the Chinese first employed crude rockets using solidified propellants to scare their enemies with the resulting loud noises and flashing overhead lights. Later, rockets became popular for displays and celebrations. Early devices, however, were crude, used low-energy propellants, and were largely uncontrollable. It was not until the 1900s that major technological advances in rocketry were realized.

Around the turn of the twentieth century, Konstantin Tsiolkovsky, a Russian schoolteacher, discovered the fundamental relationship between the amount of propellant needed in a rocket and the resulting change in speed. This remains the most fundamental relationship of rocketry and is referred to as the "rocket equation." In the 1920s American physicist Robert H. Goddard designed and built the first liquid-propelled rocket motor and demonstrated its use in flight. This was a significant step toward the development of modern missiles and space launchers.

The onset of World War II (1939–1945) created a sense of urgency in advancing the development and deployment of long-range, rocket-propelled artillery projectiles and bombs. In both Germany and the United States major efforts were begun to create rocket-propelled guided bombs, that is, missiles. By 1944 operational V-2 missiles were being launched by Germany toward England. Although these were the first successfully guided bombs, they lacked good terminal guidance and usually missed their primary targets. They were, however, very effective as instruments of mass intimidation.

After the war, one group of German rocket engineers and scientists defected to the United States and another to the Soviet Union. Wernher von

The European Space Agency's fifth-generation Ariane rocket, shown here launching in October 1997, was capable of delivering an 18-ton satellite into a low Earth orbit.

Braun led the group that went to the United States. The mission of these scientists was to continue work on missile technology, and by the 1950s, the V-2 had been improved and transformed into a variety of missiles. In order to create an intercontinental ballistic missile (ICBM) that could travel several thousand miles, however, improved guidance systems and multistage booster designs were needed, and these two areas of technology became the focus of 1950s rocketry research. Precise guidance systems ensure accurate **trajectories** and precision targeting, while two-stage vehicles can overcome the pull of Earth's strong gravity and low-propellant energies to achieve great distances. These same technologies were needed for orbital launcher vehicles.

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

Rocketry Advances During the Late Twentieth Century Space Age

When the Soviets launched the first artificial satellite in 1957 (Sputnik 1), the United States quickly followed by modifying its ICBM inventory to create orbital launchers, and the "space race" between the two countries was on in earnest. By 1960 both the United States and the Soviet Union were producing launch vehicles at will. In 1961 President John F. Kennedy challenged America to send humans, before the end of the decade, to the surface of the Moon and return them safely. As amazing as it seemed at the time, two American astronauts, Neil Armstrong and Buzz Aldrin, walked on the Moon in July 1969. By the end of Project Apollo, in 1972, a total of twelve astronauts had walked on the lunar soil and returned safely to Earth, and the United States was well established as the dominant spacefaring nation.

During the 1960s and 1970s both the Soviet Union and the United States developed several families of space launchers. The Soviet inventory included the Kosmos, Proton, Soyuz, and Molniya, and the U.S. inventory included the Titan, Atlas, and Delta. In terms of the number and frequency of satellite launches, the Soviets were far more prolific, until the breakup of the Soviet Union in 1991. Whereas the Soviets focused on putting large numbers of relatively crude satellites in orbit, the United States focused on sophistication and reliability. Thus, the West was very successful in collecting a good deal more science data with fewer satellites.

Early in the 1970s President Richard Nixon approved the development of the Space Transportation System, better known as the space shuttle. This was to be a reusable system to replace all U.S. **expendable launch vehicles**. Thus, when the shuttle started flying in 1981, production lines for the Delta and Atlas boosters were shut down. They stayed shut down until the 1986 Challenger disaster.✶ At that point it became clear that expendables were still needed and would be needed for a long time to come. By 1989 the shuttle and several expendables were back in business. The three-year U.S. launch hiatus, however, permitted other countries to enter the commercial launcher business. The most prominent of these is the European Space Agency's launcher family, Ariane, which launches roughly 40 percent of the world's largest communications satellites. Other competitors in the marketplace include Russia, Ukraine, China, and Japan. Even Israel, Brazil, and India have been active in developing and launching small booster vehicles.

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

✶**On January 28, 1986, space shuttle Challenger was destroyed by a technical malfunction approximately 72 seconds after lift-off.**

The Future of Rocketry in the Twenty-First Century

As the twenty-first century begins, there are more than twenty families of expendable launchers from Europe and eight countries outside Europe. Nevertheless, there remains only one operational reusable vehicle, the space shuttle. The high cost of space access continues to propel the launch industry toward better solutions. Thus, new vehicles are expected to be developed in the future, including a few more expendables and a new generation of **reusables**. While the new expendables should offer some relief in terms of launch prices, reusable vehicles hold the promise for the significant cost reductions that are needed for extensive expansion of applications, such as space tourism. In pursuit of this objective, a half-dozen

reusables launchers that can be used many times before discarding companies are trying to develop a fully reusable vehicle. Some of them propose to build a single-stage system in which the entire vehicle travels from the launch pad all the way to orbit, separates from the satellite, and returns to the launch site. Others propose two-stage vehicles in which a booster/**orbiter** combination leave the launch pad together and return separately. By 2010, at least one of these systems could be operating. SEE ALSO Aldrin, Buzz (volume 1); Apollo (volume 3); Armstrong, Neil (volume 3); Goddard, Robert Hutchings (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Space Shuttle (volume 3); Tsiolkovsky, Konstantin (volume 3); von Braun, Wernher (volume 3).

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

Marshall H. Kaplan

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Advertising

In the early days of human spaceflight in the 1960s, public curiosity about astronauts was fueled by regular headlines in the media. Products selected for the space program were perceived to be exceptional, and promoters were quick to exploit this by playing up the fascination and mystery surrounding spaceflight. A crystallized, dehydrated, orange-flavored beverage called Tang was touted as "what the astronauts drink," and sales skyrocketed as the public clamored to have what the astronauts had. With the space age, thus, came space-themed advertising.

Consumers are bombarded daily with multimedia advertisements, coaxing people to buy, choose, or react to a myriad of products and services. Advertisers are hired to promote these products and services to specific markets based on a careful calculation of a target population's propensity to consume. To appeal to this possibility, advertisers strive to stay in the mainstream of the target audience in fashion, entertainment, food, and new technology by implanting a brand with a message that is crafted to be remembered by the recipient. Over the years, space themes have been used as a backdrop for many new products.

Before humans were orbiting Earth, space-themed advertisements were uncommon because the general public did not connect with outer space. Now, in the early twenty-first century, with discussion of futuristic orbiting hotels and launch adventure trips within the realm of technological possibility, space as a backdrop or theme for advertising is well-established.

Pepsi Cola launched a new advertising campaign from the Mir space station on April 25, 1996. This particular campaign unveiled a new version of Pepsi's logo.

Some fantastic concepts have been considered for advertising in space. For example, one firm considered using an Earth-based laser to beam messages onto the Moon. They soon realized this was impractical, however, because the images needed to be about the size of Texas to be visible to earthlings!

Pizza Hut, Inc., contracted with a Russian launch firm to affix a 9-meter-high (30-foot-high) new corporate logo on a Proton rocket carrying aloft a service module to the International Space Station and scheduled for launch in November 1999. Advertising the event prior to the launch date gave Pizza Hut international recognition, and the company expected 500 million people to watch the live televised event. The launch was planned to coincide with a release of Pizza Hut's transformed millennium image; the launch, however, was postponed for eight months because of technical problems.

Pepsi, the soft drink company, paid a large sum of money so that Russian cosmonauts would unveil a newly designed brand logo on a simulated "can" during missions to the Russian space station Mir in May 1996. The company has also pursued smaller scale promotional ventures in the U.S. space program since 1984.

NASA and other outer space agencies have researched the profitability of permitting advertising through the display of logos on space hardware, such as the International Space Station. While there is a market for such advertising, studies suggest that demand would not necessarily be sustained beyond the novelty of the first few paying customers.

Space.com, one of several space-related web sites that appeared in the dot-com boom of the late 1990s, derived significant revenue from advertising banners at the web site. Interestingly, the advertising content tended to relate to very down-to-Earth necessities—credit cards, cars, goods and services—and not space merchandise or otherworldly creations.

SEE ALSO Commercialization (volume 1); International Space Station (volumes 1 and 3); Mir (volume 3).

Len Campaigne

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Aerospace Corporations

For most of history, humankind has had to study space from on or near the surface of Earth. This meant that most of our knowledge was limited to what could be deduced from observations conducted through dust and light pollution and the distorting and degrading effects of Earth's atmosphere. No **in situ** study or direct analysis of materials from space (except for studies of **meteorites**) was possible. These conditions changed drastically with the development of space technology. First machines, then humans, were able to enter space, beginning a new era in space study and exploration. This era has grown to include the exploitation of space for public and private purposes. Designing, building, and operating the systems that make this possible is the role of aerospace corporations of the twenty-first century.

in situ in the natural or original location

meteorite any part of a meteoroid that survives passage through Earth's atmosphere

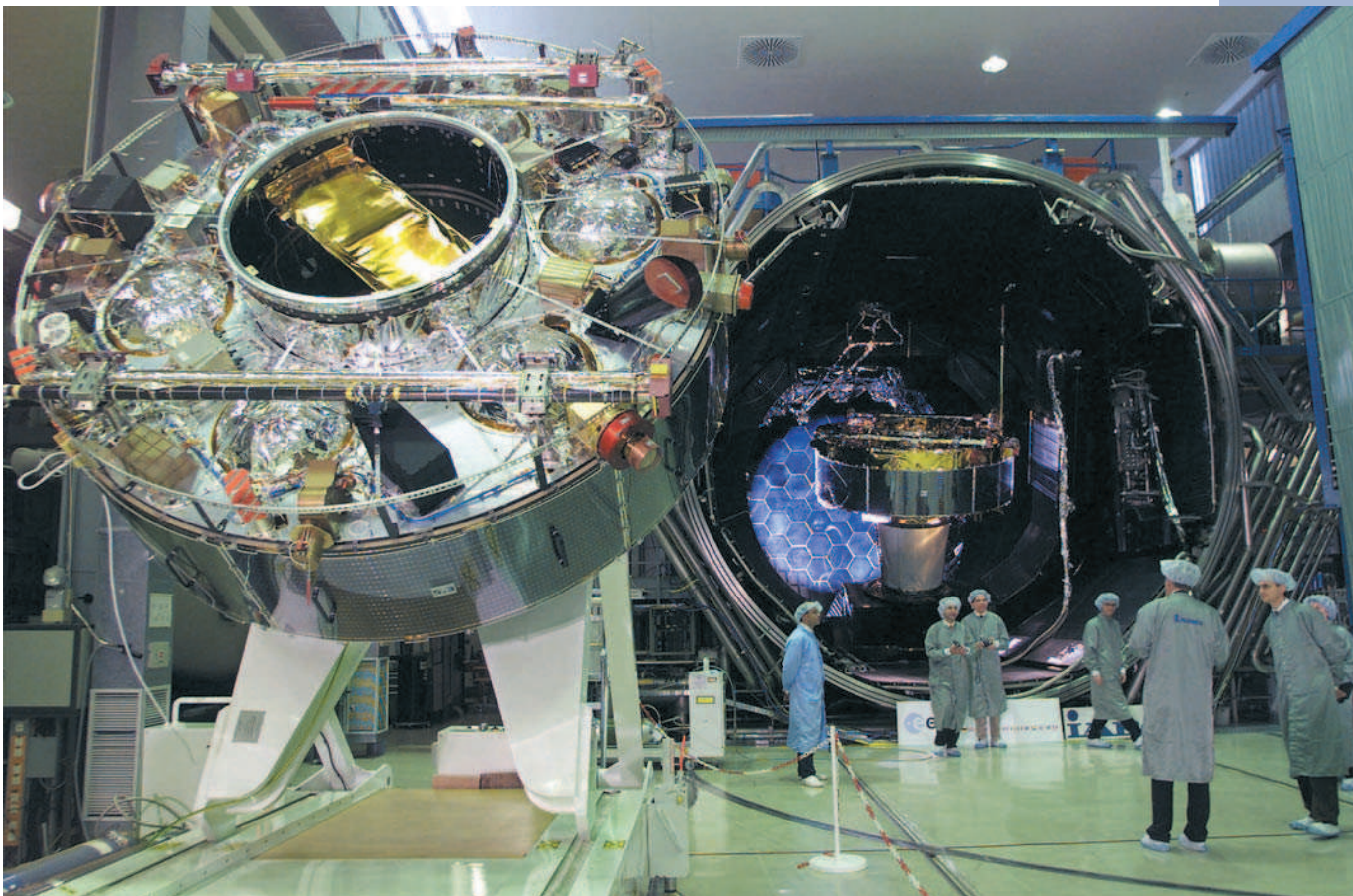
Historical Overview

The characteristics of aerospace corporations and the current structure of the aerospace industry result from the numerous political and economic forces that have created, shaped, and reshaped it. The first of these forces, and the one responsible in large part for creating the aerospace industry, was the Cold War. As World War II came to a close, the uneasy alliance between Russia and the United States began to disintegrate. Leaders on both sides sought to achieve a military advantage by capturing advanced German technology and the scientists and engineers who developed it. This included the German rocket technology that created the V-2 missile, the first vehicle to enter the realm of space.

This competition was a precursor to the space race between the two superpowers, the United States and Russia. That competition began in earnest on October 4, 1957, when the Soviet Union launched the 184-pound Sputnik, Earth's first artificial satellite, into an **orbit** 805 kilometers (500 miles) above Earth. This demanded a response from the U.S. Department of Defense (DoD) and intelligence and scientific communities.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

To develop the systems needed to engage in this competition, the U.S. government established contracts with existing aircraft and aeronautics com-



panies. Martin Aircraft was the manufacturer of the B-26 Marauder, a World War II bomber. Its corporate successor, Martin Marietta, developed the Titan rocket that was used first as an intercontinental ballistic missile (ICBM) during the Cold War. The rocket was later modified to boost two astronauts in **Gemini** capsules into orbit during the space race. (Long after the end of the space race, the Cold War, and many years of storage, the Titan II ICBMs are being refurbished and modified for use as space launch vehicles to place DoD satellites into space.) The government turned to Pratt & Whitney, an aircraft engine manufacturer, to develop the first liquid hydrogen-fueled engine to operate successfully in space. It was used on the Surveyor lunar lander, the Viking Mars lander, and the Voyager outer-planet **flyby** missions. A derivative of this engine is used in the second stage of the Delta III satellite launch rockets.

The intelligence community was also interested in using space technology. The United States' first space-based overhead **reconnaissance** program, CORONA, began flight in 1959. It, too, relied on established companies. Lockheed, a prominent aircraft manufacturer, developed the launch vehicle's upper stage. Eastman Kodak (now Kodak) produced special film that would function properly in space and low-Earth-orbit (LEO) environments. General Electric designed and manufactured the recovery capsule to protect exposed film as it was deorbited and re-entered Earth's atmosphere for airborne capture and recovery.

The DaimlerChrysler automotive group contributes to the European Aeronautic Defence and Space Company's development by manufacturing Cluster II satellites.

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

reconnaissance a survey or preliminary exploration of a region of interest

The government's interest in, and contracts for, space systems also created new companies. TRW resulted from efforts to build the Atlas missile and the Pioneer I spacecraft, the first U.S. ICBM and satellite, respectively. Currently, commercial involvement in the aerospace industry is growing, but government involvement continues to be significant.

Space Systems Overview

Each space system is composed of a collection of subsystems, often grouped into segments. Typical groupings are the launch segment; the space segment; the ground, or control, segment; and the user segment. The launch segment includes the equipment, facilities, and personnel needed to place elements of the system into space. The space segment includes the spacecraft, other equipment, and personnel that are placed into space. The ground, or control, segment includes the equipment, facilities, and personnel that control and operate the spacecraft as it performs its mission. The user segment includes the equipment, facilities, and personnel using the products of the space system to accomplish other purposes. Aerospace corporations✶ are the source of virtually all of the equipment and facilities that these segments require. Moreover, these corporations frequently train or provide personnel to operate and maintain them.

✶In 2002, the leading U.S. aerospace corporations included Boeing, Hughes, Lockheed Martin, TRW, Raytheon, Orbital Sciences Corporation, and Spectrum Astro.

The Launch Segment. The most visible activity associated with space missions is usually the launch of the space elements of the system. Television and film coverage has often featured footage of the space shuttle with its large boosters gushing fire and smoke as it rises slowly into the sky. The launch vehicle and upper stages, along with the facilities, equipment, and team at the launch site and associated range, are part of the launch segment. The two U.S. aerospace corporations that provide the most frequently used large launch vehicles are the Boeing Company (Delta) and Lockheed Martin Corporation (Atlas and Titan). The United Space Alliance, which manages and conducts space operations and maintenance of the National Aeronautics and Space Administration's (NASA) Space Transportation System (space shuttle), is a joint venture between Boeing and Lockheed Martin.

Other companies that provide launch systems include Orbital Sciences Corporation, which manufactures and operates small launch systems, the Pegasus (an air-launched rocket capable of placing more than 1,000 pounds in LEO), and the Taurus (a small rocket launched from a "bare" pad to minimize operating costs). Sea Launch is an international partnership that launches Russian-made Zenit boosters from a floating, oceangoing platform. Boeing, a 40 percent partner, manufactures the **payload fairing**, performs spacecraft integration, and manages overall mission operations. RSC Energia (Russia) provides the third stage, launch vehicle integration, and mission operations. KB Yuzhnoye/PO Yuzhmash (Ukraine) provides the first two Zenit stages, launch vehicle integration support, and mission operations.

payload fairing structure surrounding a payload and designed to reduce drag

Since the mid-1990s the industry has seen a number of newcomers, many with partially or fully reusable systems but so far without any space launches. These companies include Kistler Aerospace Corporation, Beal Aerospace Technologies, and several others with launchers using unique approaches, such as Rotary Rocket Company, Kelly Space and Technology, and Pioneer Rocketplane.

Most launch vehicles use liquid propellants, but some use motors with solid fuels. The large, white strap-on boosters straddling the rust-orange main fuel tank of the space shuttle are solid-fuel boosters, as are the strap-on motors used with the Atlas, Delta, and Titan. In addition, most upper stages that are used to propel systems to high orbits or even into **interplanetary trajectories** are also solid-fuel systems. Thiokol Corporation, Pratt & Whitney, and others make many of these motors.

The Space Segment. The space segment consists of all the hardware, software, and other elements placed into space. Examples include spacecraft that orbit Earth, such as NASA's Tracking and Data Relay Satellite, or an interplanetary probe, such as the **Cassini mission** to Saturn. Spacecraft used by humans, such as the space shuttle **orbiter** and the International Space Station, are also included. Even the smallest spacecraft are complex machines. They must operate with limited human interaction for long periods of time, in a very hostile environment, and at great distances. Designing, manufacturing, and testing these spacecraft can be very demanding and requires many specialized facilities and an experienced staff.

Some of the established leaders in this segment include Hughes Aircraft Company, Boeing, Lockheed Martin, and TRW. Hughes is the primary manufacturer of communications satellites. Boeing is a major developer of spacecraft for the Global Positioning System (GPS), a space-based navigation system operated by the DoD.✶ Lockheed Martin's heritage includes support for missions studying every planet in the solar system (so far excepting Pluto). TRW has been a key contractor for spacecraft such as Pioneer I, the Chandra X-ray Observatory, and the Defense Support Program ballistic missile warning satellites.

Relative newcomers to this segment include Spectrum Astro and Orbital Sciences Corporation. Spectrum Astro worked with NASA's Jet Propulsion Laboratory to develop Deep Space I, a new technology demonstrator. They are teamed with the University of California, Berkeley, to design and develop the **spacecraft bus** and to integrate and test the **payload** of the High Energy Solar Spectroscopic Imager (HESSI) spacecraft. HESSI will investigate the physics of particle acceleration and energy release in solar **flares**, observing X rays and **gamma rays**. Orbital Sciences Corporation designs and manufactures small, low-cost satellites for LEO, medium Earth orbit (MEO), and **geosynchronous** Earth orbit (GEO) missions. They have developed, built, and launched more than seventy satellites delivering communications, broadcasting, imagery, and other services and information.

The Ground, or Control, Segment. The ground, or control, segment is probably the least glamorous and least public element of any space system. Although it lacks the showmanship of a launch or the mystique of traveling through space, it is critical to mission success. This segment consists of all the hardware, software, and other elements used to command the spacecraft and to **downlink**, distribute, and archive science and spacecraft systems status data. This segment serves as a combined control center and management information system for the mission. Aerospace corporations build and often operate these systems.

Lockheed Martin Federal Systems manages a team of subcontractors to support the Air Force Satellite Control Network. This network provides

LIQUID VS. SOLID FUELS

Liquid fuels generally provide more energy than solid fuels and are easier to control. Liquid fuel engines can be throttled up and down during a flight. Solid fuels are easier to handle. They do not give off toxic vapors or require extreme cooling during storage and pre-launch operations.

interplanetary trajectories the solar orbits followed by spacecraft moving from one planet in the solar system to another

Cassini mission a robotic spacecraft mission to the planet Saturn scheduled to arrive in July 2004, when the Huygens probe will be dropped into Titan's atmosphere while the Cassini spacecraft studies the planet

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

✶The Global Positioning System consists of 24 satellites that orbit over 10,000 miles above Earth.

spacecraft bus the primary structure and subsystems of a spacecraft

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

flares intense, sudden releases of energy

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

downlink the radio dish and receiver through which a satellite or spacecraft transmits information back to Earth

command-and-control services for many DoD and other government space programs. Harris was responsible for the development, integration, and installation of the command, control, and communications system for the U.S. Air Force's Defense Meteorological Satellite Program (a DoD weather satellite). Orbital Sciences Corporation has been involved in the construction of most of the world's major nonmilitary imaging satellite ground stations. Orbital's commercial satellite ground stations are used to receive, process, archive, and distribute images of Earth acquired by remote-imaging satellites.

The ground/control segment functions are often similar for different space programs. For this reason, cost savings from combined, multifunctional ground/control systems can be significant. Lockheed Martin leads NASA's Consolidated Space Operations Contract to help combine operations for many of the current and planned space science missions.

The User Segment. Although all segments of a space system are necessary, the user segment is the most important. It is here that the mission of a space program is achieved. The user segment consists of all the hardware, software, and other elements required to make use of the data. A very public example of user segment equipment is the GPS receiver. Many of these units are sold to campers, hikers, boaters, and others who desire an easy and accurate means of determining their location. The user segment is also where science data are processed, formatted, and delivered to the scientists and other investigators for study and analysis. The U.S. Geological Survey's Earth Resources Observation Systems (EROS) Data Center near Sioux Falls, South Dakota, is a major scientific data processing, archive, and product distribution center for spacecraft, shuttle, and aerial land sciences data and imagery. Data are processed into usable formats and made available to researchers and other users. Many aerospace corporations perform further processing and formatting of EROS data to generate information for sale.

Cross-Segment Approaches

Most aerospace corporations design, develop, and operate facilities and equipment in more than one segment. Often a specific space program will have one aerospace corporation serve as a lead or prime contractor, managing or integrating the work of many other companies. The International Space Station provides an excellent example. Boeing is the prime contractor of a space station team that includes a number of partners. Major U.S. teammates and some of their contributions include: Lockheed Martin, providing **solar arrays** and communications systems; Space Systems/Loral, providing batteries and electronics; Allied Signal, providing **gyroscopes** and other navigational gear; Honeywell, providing command and data systems as well as **gimbal motors**; and United Technologies, providing pumps and control valve assemblies.

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

gimbal motors motors that direct the nozzle of a rocket engine to provide steering

One of the newest and more unusual competitors spanning all segments is SpaceDev. SpaceDev is a commercial space exploration and development company for small, low-cost, commercial space missions, space products, and affordable space services. It offers fixed-price missions using proven, off-the-shelf components and an inexpensive mission design approach.

Other Industry Roles

In addition to designing, developing, and operating space systems in and across the various segments, some aerospace corporations perform more focused roles, such as providing systems engineering and other technical assistance or producing subsystems, components, and parts for systems. Many of these corporations are not as readily recognized as other members of the aerospace industry.

Systems Engineering and Technical Assistance. Systems engineering and technical assistance (SETA) is a role performed by a number of aerospace corporations. As a SETA contractor, an aerospace corporation may develop, review, analyze, or assess concepts and designs for space missions, programs, and systems. Typically, SETA contractors do not provide hardware for the programs they support. Instead, they provide valuable expertise and a viewpoint independent of those manufacturing the system's components. For example, Raytheon ITSS Corporation is the technical support contractor to the U.S. Geological Survey's EROS Data Center discussed previously. Science Applications International Corporation provides a variety of SETA services to NASA, the DoD, and some commercial space programs. Dynamics Research Corporation and OAO Corporation are examples of other companies that provide SETA support to NASA, the DoD, and aerospace prime contractors.

Parts, Components, or Subsystems Providers. Another role for an aerospace corporation is that of parts, components, or subsystems provider. This category encompasses the greatest number of aerospace corporations. Many of these corporations provide a broad range of subsystems and components and may also manufacture complete spacecraft. Others specialize in a specific type of space hardware, software, or service. Space products from Ball Aerospace and Technologies Corporation include antennas, fuel cell systems, mirrors, pointing and tracking components (such as star trackers), and reaction/momentum wheels. Malin Space Science Systems designs, develops, and operates instruments to fly on unmanned spacecraft. Thermacore Inc. works on heat pipes for space applications. These pipes are used to move heat from one location to another with little loss in temperature. Analytical Graphics, Inc., produces a commercial computer program, Satellite Tool Kit, which possesses extensive space mission and system analysis and modeling capabilities.

Nonaerospace Corporations

Many corporations that support aerospace programs are not commonly recognized as members of the aerospace industry. Kodak, a world-famous film and camera manufacturer, has been involved with aerospace almost since the beginning. Kodak developed the special film used in CORONA's orbiting cameras to photograph Soviet missile sites, air and naval bases, and weapons storage facilities. Its charge-coupled device image sensors were used on NASA's Mars Pathfinder Rover, which visited Mars in 1997. Today, Kodak manufactures digital cameras used from space to capture images of Earth's surface. These images are of value to scientists, farmers, and many others. IBM, another well-known corporation, supports many aerospace programs. During the 1999 space shuttle mission that returned John Glenn to space, twenty IBM ThinkPads (notebook computers) were onboard.

BACK FOR MORE

John Glenn was the first American to orbit Earth. In February of 1962 he piloted a Mercury capsule, Friendship 7, during a 3 orbit, 4 hour and 55 minute flight. In 1998, when he was 77 years old, Glenn returned to orbit on the space shuttle Discovery.

Other "unsung heroes" of aerospace include insurance and finance companies that are growing in importance as the primary revenue source for aerospace corporations shifts from government to the commercial sector. SEE ALSO GETTING TO SPACE CHEAPLY (VOLUME 1); INSURANCE (VOLUME 1); LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); LAUNCH VEHICLES, REUSABLE (VOLUME 1); NAVIGATION FROM SPACE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4); SATELLITE INDUSTRY (VOLUME 1).

Timothy R. Webster

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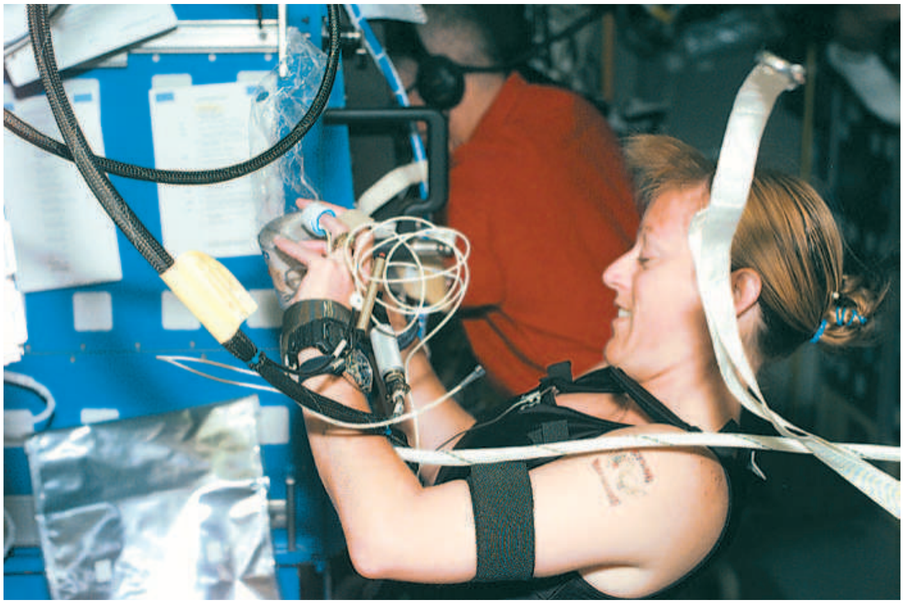
Aging Studies

Soon after entry into space, physical changes occur within the human body, and these changes become more severe and diverse as flight duration increases. When in space, humans experience early signs of a decrease in blood volume and red cell mass, aerobic capacity, endurance, strength, and muscle mass. Moreover, there is a reduction of bone density in the lower limbs, hips, and spine, and in the absorption of calcium through the gut. Visual-spatial orientation and eye-hand coordination are also affected.

When humans return to Earth's gravity, this reduction in physical fitness manifests itself through the body's inability to maintain the blood pressure control necessary to prevent fainting. This inability occurs because the heart and blood vessels are less responsive. Balance, gait, and motor coordination are also severely affected. Similar but less-intense symptoms occur during and after complete bed rest.

Bed Rest Studies

Researchers study bed rest to understand the mechanisms that bring about these symptoms, and to develop preventive treatments. Both astronauts and men and women volunteers for these bed rest studies recover, with the speed of recovery being proportional to the duration of the flight or the bed rest. Research into the mechanisms that contribute to these symptoms has



Astronaut Kathryn P. Hire undergoes a sleep study experiment in the Neurolab on the space shuttle Columbia. Bed rest studies are used to examine the physical changes that occur during human spaceflight.

pointed to the variety of ways humans use Earth's gravity to promote stimuli the body needs to maintain normal physiology.

In space, where the influence of gravity is negligible, the load we normally feel on Earth from our weight is absent. Exercise, such as walking, is ineffective, because we are not working against the force of gravity. Signals to the parts of our nervous system that control blood pressure from changing position (such as standing or lying down) are also absent, and we can no longer sense what is up and what is down.

Bed rest studies have been conducted to determine the minimum daily exposure to gravity's stimuli needed to maintain normal physiology. This research indicated that a change in posture from lying down to upright—a total of two to four hours of being upright so gravity pulled maximally in the head-to-toe direction—at least eight to sixteen times a day could prevent the decline in blood pressure control, aerobic capacity, blood volume, and muscle strength. As little as thirty minutes a day of walking at a pace of three miles per hour prevented the increased loss of calcium produced by bed rest. These results suggested that intermittent exposure to gravity in space, as provided by a **centrifuge**, may be an effective way to keep astronauts healthy on long trips.

centrifuge a device that uses centrifugal force caused by spinning to simulate gravity

sedentary lifestyle a lifestyle characterized by little movement or exercise

atrophy condition that involves withering, shrinking or wasting away

Are the Effects of Aging Irreversible?

The similarity of the set of symptoms resulting from going into space to those associated with aging is striking. In the elderly, these symptoms have been assumed to be part of the normal course of aging and therefore irreversible. Space and bed rest research argues against this assumption. Research indicates that the symptoms of aging are due to an increasingly **sedentary lifestyle** rather than aging and are thus also reversible in the elderly. In the mid-1990s, Maria Fiatarone and her coworkers reported that weight training and nutritional supplements reversed muscle and bone **atrophy** of aging in people aged seventy-three to ninety-eight.✶

✶John Glenn's second trip to space in 1998 at the age of seventy-seven on shuttle mission STS-95 helped increase understanding of the effects of a healthy lifestyle on aging.

It remains to be seen if space will also help us understand the more fundamental mechanisms of aging. Preliminary research suggests cell cycle and cell death may be affected. But it will only be through the conducting of experiments long enough to explore life span and chromosomal and genetic mechanisms that these questions will be answered. SEE ALSO Careers in Space Medicine (volume 1); Glenn, John (volume 3).

Joan Vernikos

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AIDS Research

Since 1985 the National Aeronautics and Space Administration (NASA) has supported fundamental studies on the various factors that affect protein crystal growth processes. More than thirty principal investigators from universities throughout the United States have investigated questions such as why crystals stop growing, what factors cause defect formations in growing crystals, and what influence parameters such as protein purity, temperature, pH (a solution's degree of acid or base properties), protein concentration, and fluid flows exert around growing crystals.

The majority of these studies were conducted in Earth-based laboratories, with a limited number of experiments performed on U.S. space shuttle flights. The purpose of the space experiments is to determine the effect that a **microgravity** environment has on the ultimate size and quality of protein crystals. This research was propelled by the need to improve success rates in producing high-quality crystals to be used for X-ray **crystallography** structure determinations. X-ray crystallography involves exposing a protein crystal to powerful X-ray radiation. When this occurs, the crystal produces a pattern of diffracted spots that can be used to mathematically determine (using computers) the structure of the protein (i.e., the positions of all the atoms that comprise the protein molecule).

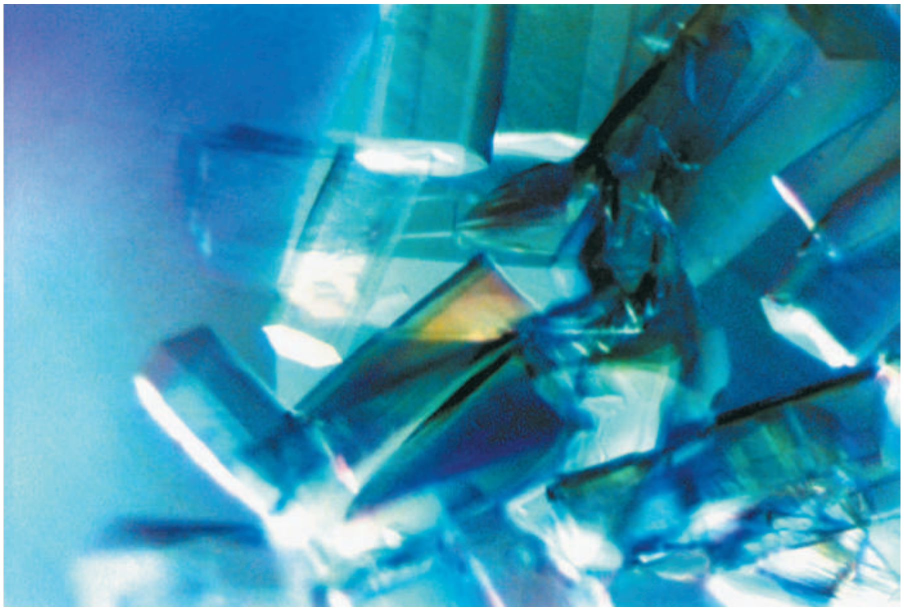
microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

crystallography the study of the internal structure of crystals

Structure-Based Drug Design

The three-dimensional structure of a protein is useful because it helps scientists understand the protein's function in biological systems. In addition, most known diseases are based on proteins that are not working properly within the human body or on foreign proteins that enter the body as part of harmful bacteria, viruses, or other pathogens. The three-dimensional structure of these disease-related proteins can aid scientists in designing new pharmaceutical agents (drugs) that specifically interact with the protein, thereby alleviating or lessening the harmful effects of the associated diseases.

This method of designing new and more effective pharmaceuticals, known as structure-based drug design, was used to develop many of the new-generation AIDS drugs. These drugs were developed using Earth-grown



Studies indicate that space-grown crystals, such as these HIV Reverse Transcriptase crystals, are larger and better ordered than comparable Earth-grown crystals.

crystals. There are, however, a number of other protein targets in the HIV virus as well as in most other pathogens that have yet to be crystallized. Attempts to grow crystals large enough and of sufficient quality are often unsuccessful, thereby preventing the use of structure-based drug design.

On Earth, when crystals begin to grow, lighter molecules float upward in the protein solution while heavier molecules are pulled down by gravity's forces (a process known as buoyancy-induced fluid flow). This flow of solution causes the protein to be swept to the surface of the crystal where it must align in a very perfect arrangement with other protein molecules. It is believed that the rapid flow of solution causes the protein molecules to become trapped in misalignments, thereby affecting the quality of the crystal and, eventually, even terminating crystal growth.

Crystal Growth in Microgravity

In a microgravity environment, these harmful flows are nonexistent because gravity's influence is minimal.✶ Thus, the movement of protein molecules in microgravity is much slower, caused only by a process known as random diffusion (the inherent vibration of individual molecules). It is believed that the lack of buoyancy-induced fluid flows (as occurs on Earth) creates a more **quiescent** environment for growing crystals. The protein molecules have sufficient time to become more perfectly ordered in the crystal before being trapped by additional incoming molecules.

✶The gravity level on the space shuttle equals one-millionth of that existing on Earth.

quiescent inactive

The scientific community is divided about the role that microgravity can play in improving the size and quality of protein crystals. In addition, the excessive cost of performing experiments in space has caused scientists to question the value of these experiments. Proponents of the space protein crystal growth program are optimistic that the longer growth times that will be available on the International Space Station will significantly improve microgravity success rates for producing crystals of significantly higher quality. SEE ALSO Careers in Space Medicine (volume 1); Crystal Growth (volume 3); Microgravity (volume 2); Zero Gravity (volume 3).

Lawrence J. DeLucas

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Aldrin, Buzz

American Astronaut and Engineer
1930–

Buzz Aldrin, along with Neil Armstrong, became the first humans to land on the Moon.

On July 20, 1969, Edwin "Buzz"✶ Aldrin and his fellow astronaut Neil Armstrong became the first humans to land on another world: Earth's Moon. This achievement is arguably the technological high-water mark of the twentieth century.

✶Aldrin's sister nicknamed him "Buzz," and it is now his legal name.

Aldrin's passion for exploration and quest for excellence and achievement began early in his life. Born on January 20, 1930, in Montclair, New Jersey, Aldrin received a bachelor of science degree from the U.S. Military Academy in 1951, graduating third in his class. After entering the U.S. Air Force, Aldrin earned his pilot wings in 1952.

As an F86 fighter pilot in the Korean War, Aldrin flew sixty-six combat missions. He later attended the Massachusetts Institute of Technology (MIT), where he wrote a thesis titled "Guidance for Manned Orbital Rendezvous." After his doctoral studies, Aldrin was assigned to the Air Force Systems Command in Los Angeles.

Aldrin's interest in space exploration led him to apply for a National Aeronautics and Space Administration tour of duty as an astronaut. Aldrin was selected as an astronaut in 1963. The research expertise in the new field of space rendezvous he had acquired during his studies at MIT were applied in the U.S. Gemini program.

On November 11, 1966, Aldrin, with James Lovell, flew into space aboard the two-seater Gemini 12 spacecraft. On that mission the Gemini astronauts rendezvoused and docked with an **Agena** target stage. During the linkup Aldrin carried out a then-record 5.5-hour space walk. Using handholds and foot restraints while carefully pacing himself, Aldrin achieved a pioneering extravehicular feat in light of the many difficulties experienced by earlier space walkers.

Agena a multipurpose rocket designed to perform ascent, precision orbit injection, and missions from low Earth orbit to interplanetary space. It also served as a docking target for the Gemini spacecraft

Aldrin's unique skills in developing rendezvous techniques were tested again in July 1969. Aldrin and his fellow Apollo 11 astronauts, Neil Armstrong and Mike Collins, were the first crew to attempt a human landing on the Moon. Once in lunar orbit, Armstrong and Aldrin piloted a landing craft, the Eagle, to a safe touchdown on the Moon's Sea of Tranquility. After joining Armstrong on the lunar surface, Aldrin described the scene as "magnificent desolation." They explored the landing area for two hours, setting up science gear and gathering rocks and soil samples. The two astronauts then rejoined Collins for the voyage back to Earth.

Aldrin returned to active military duty in 1971 and was assigned to Edwards Air Force Base in California as commander of the Test Pilots School. He retired from the U.S. Air Force as a colonel in 1972. Aldrin is a spokesman for a stronger and greatly expanded space program. He still advances new ideas for low-cost space transportation and promotes public space travel. Aldrin continues to spark new ideas for accessing the inner solar system. One of his concepts is the creation of a reusable cycling spaceship transportation system linking Earth and Mars for the routine movement of people and cargo.

Aldrin has written several books, sharing with readers his experiences in space. As a cowriter, Aldrin has authored science fiction novels that depict the evolution of space exploration in the far future. SEE ALSO Apollo (volume 3); Armstrong, Neil (volume 3); Gemini (volume 3); NASA (volume 3); Space Walks (volume 3).

Leonard David

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Artwork

Astronautics owes much of its existence to the arts. On the one hand, literary works by authors such as Jules Verne (1828–1905) were directly responsible for inspiring the founders of modern spaceflight; on the other hand, artists such as Chesley Bonestell (1888–1986)✶ made spaceflight seem possible. When Bonestell's space art was first published in the 1940s and early 1950s, spaceflight to most people still belonged in the realm of comic books and pulp fiction. Bonestell, working with such great space scientists as Wernher von Braun, depicted space travel with such vivid reality that it suddenly no longer seemed so fantastic. Emerging as it did when the United States was first taking an interest in astronautics, these paintings went a long way toward encouraging both public and government support.

✶The artwork in this article is courtesy of Bonestell Space Art.

Space Art Comes of Age

Since Bonestell's time, there have been many other artists who have specialized in space art, though even in the early twenty-first century there are probably fewer than a hundred who work at it full-time. Some have been able to develop specialties within the field. Robert McCall and Pat Rawlings, for example, devote themselves to rendering spacecraft, while others, such as Michael Carroll and Ron Miller, concentrate on astronomical scenes, including views of the surface of Mars✶ or the moons of Saturn. Some artists are interested in how we are going to explore space, while others are more interested in what we are going to find once we get there.

✶Go to Volume 4's article on Terraforming to see Michael Carroll's rendering of a "Blue Mars."

Speculative artwork, such as this depiction of spacecraft assembly in Mars orbit, can make the theoretical seem possible.

Although most space artists have a background in art, either as gallery artists or commercial artists, there are some notable exceptions. William K. Hartmann (b. 1939), for example, is a professional astronomer who happens to also be an excellent painter. He is able to combine his artistic talent with his expert knowledge of astronomy. Only a very few space artists have ever flown in space. Alexei Leonov, a Russian cosmonaut who was also the first man to walk in space, is a very fine painter who took drawing supplies with him into orbit. Vladimir Dzhanibekov is another cosmonaut who has translated his experiences in space onto canvas. Of the American astronauts, only one has had a serious interest in art. Alan Bean, who walked on the Moon in 1969, has devoted himself since retiring from the astronaut corps to painting and has become extraordinarily successful depicting scenes from his experiences in the Apollo program.

Beyond Aesthetics

The artists who specialize in astronomical scenes perform a very valuable service. In one sense, they are like the artists who re-create dinosaurs. By taking astronomical information and combining this with their knowledge of geology, **meteorology**, and other sciences, as well as their expertise in light, shadow, perspective, and color, they can create a realistic landscape of some other world. Most often these are places that have never been visited by human beings or unmanned probes. In other instances, an **orbiter** or a spacecraft on a **flyby** mission may have already taken photographs of a moon or planet. In this case, the artist can use these photos to create an impression of what it might look like to stand on the surface. Since it can be very difficult to interpret orbital photos—which look down on their subjects—paintings like these are very useful in helping to understand what the features actually look like.

meteorology the study of atmospheric phenomena or weather

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

Into the Twenty-First Century

Until recently, most space artists worked in the same traditional materials, such as oil paint, acrylics, and watercolors, as other artists and illustrators. Many space artists now also use the computer to either enhance their traditionally rendered work or to generate artwork from scratch. Don Davis (b. 1952)✶, one of the twenty-first century's best astronomical artists, no longer works with brushes at all, choosing instead to work exclusively on a computer. There are advantages, both technically and aesthetically, to both methods but it is very unlikely that the computer will ever entirely replace traditional tools. It is the wise artist, however, who is at least familiar with computer techniques.

Saturn's rings, as seen from the upper reaches of the planet's atmosphere.

✶Don Davis's artwork can be seen in the Volume 2 article "Close Encounters" and Volume 4's article on "Impacts."

An International Genre

There are space artists, both professional and amateur and both women and men, working in almost every nation. Indeed, one of the first great artists to specialize in the field, and who helped create it, was a French artist named Lucien Rudaux (1874–1947), who created beautiful space paintings in the 1920s and 1930s. Rudaux set a standard not exceeded until Bonestell published his first space art in the 1940s. Ludek Pešek (1919–1999), a Czechoslovakian expatriate who lived in Switzerland, was probably the best and most influential space artist to follow Bonestell. Pešek illustrated a dozen books with paintings of the planets that looked so natural and realistic it seemed as though they must have been done on location. David A. Hardy (b. 1936) of Great Britain is as adept at depicting spacecraft as he is landscapes of other worlds.

Notable women artists include Pamela Lee, who is highly regarded for her meticulously rendered depictions of astronauts at work, and MariLynn Flynn, who creates planetary landscapes in the tradition of Bonestell and Pešek. The membership roster of the International Association of Astronomical Artists, an organization of space artists, includes people from Germany, Armenia, Sweden, Japan, Russia, Canada, Belgium, and many other countries, all united by their mutual interest in space travel, astronomy, and art. SEE ALSO BONESTELL, CHESLEY (VOLUME 4); LITERATURE (VOLUME 1); MCCALL, ROBERT (VOLUME 1); RAWLINGS, PAT (VOLUME 4); VERNE, JULES (VOLUME 1); VON BRAUN, WERNHER (VOLUME 3).

Ron Miller

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Augustine, Norman

Space Industry Leader
1935–

Norman R. Augustine was chairman and chief executive officer (CEO) of Lockheed Martin Corporation prior to his retirement in 1997. Augustine

Norman Augustine served as chief executive officer of Lockheed Martin, a well-respected and established aerospace firm, before retiring in 1997.

was undersecretary of the army in the administration of President Gerald R. Ford in 1975, having previously served as assistant secretary of the army for President Richard M. Nixon in 1973. Augustine held a variety of engineering assignments during his career. In 1958, following his graduation from Princeton University with both bachelor's and master's degrees in engineering, Augustine joined Douglas Aircraft Company as program manager and chief engineer. In 1965 he was appointed assistant director for defense research and engineering in the Office of Secretary of Defense and then was named vice president for advanced programs and marketing for LTV Missiles and Space Company.

After joining Martin Marietta Corporation in 1977, Augustine was promoted to CEO and then chairman in 1987 and 1988, respectively. Following the formation of Lockheed Martin from the 1995 merger of Martin Marietta and Lockheed Corporation, he initially served as Lockheed Martin's president before becoming CEO and chairman in 1996.

In 1990 Augustine played a major role in defining the issues facing the U.S. space industry as head of President George H. W. Bush's Space Task Force. The group's report called for substantial increases in U.S. space spending, as well as setting new national goals in space exploration. The administration responded to the report in part by announcing a series of advanced space goals. However, funding for the projects was not supported by Congress, and the initiatives were abandoned.

Augustine has written several books, including *Augustine's Laws* (1990), a humorous chronicle of his experiences in defense contracting. He received the Distinguished Service Medal of the Department of Defense four times, the Defense Meritorious Service Medal, the Army Distinguished Service Medal, the Air Force Exceptional Service medal, and ten honorary degrees. SEE ALSO LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); MARKET SHARE (VOLUME 1).

Frank Sietzen, Jr.

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B

Barriers to Space Commerce

remote sensing the act of observing from orbit what may be seen or sensed below Earth

Space commerce exists in the early twenty-first century as a $100 billion industry. It consists primarily of firms providing commercial telecommunication and **remote sensing** services using satellites, as well as the manufacture and launch of those satellites. Space commerce also includes many organizations that provide products and services (including satellites, satellite services, launch, operations, and research) to government agencies in support of national civil and military space programs. Finally, a small number of firms provide other space services on a commercial basis, including space station access, on-orbit experimentation using a commercial module carried on space shuttles, and the launch of ashes for "burial" in space.

After key barriers to space commerce have been overcome, profit can be made through the development of new spacecraft, such as this theoretical depiction of a lunar freighter, which would be used in transport.

Efforts by space advocates, aerospace firms, and government agencies to further expand space commerce generally focus on extending the scope of commercial space activities beyond today's space telecommunications by fostering new space industries. Ongoing ventures propose expanding space services into new realms: high bandwidth Internet connectivity, on-orbit research and manufacturing, entertainment, education, power, and even routine space tourism. It is often asserted that the development of these industries is hindered by economic and policy barriers, and that these barriers can be overcome with appropriate government policy or industry initiatives.

SECONDARY INDUSTRIES ENABLED BY SPACE

Many secondary industries are enabled by space assets and capabilities, such as television broadcasting, weather forecasting, tracking and navigation using satellites, and many types of voice and data communication.

Economic Barriers to Entry

There are three major economic barriers to the growth of space commerce: the cost of entry, the risk associated with space activities, and the cost of transportation. These factors are closely interrelated.

The Cost of Entry. Space is an expensive business. The cost of manufacturing and launching a routine telecommunications satellite exceeds $150 million. The cost to establish a new capability, such as a reusable launch vehicle or an on-orbit manufacturing facility, is likely to be in the multibillion dollar range. The need to acquire a very high level of start-up capital✶ creates a barrier to entry into the space industry, especially for small and/or start-up firms.

✶**The high level of capital required to establish a new capability is needed to build facilities, develop and test hardware and software, staff up with a specialized engineering team, and ultimately get to orbit.**

High Risk Factors. The risks associated with space activities also increase the difficulty of entering the business. Risks arise from both technical factors and market factors. Technical risks exist because space systems are complex, often requiring new technology, and because space activities occur in a hazardous, challenging, and distant environment where maintenance and repair are expensive and may not be possible.

Market risks arise because in many cases the services being offered are new and it is difficult to predict what the customer response will be. In addition, complex systems and new technology make managing costs a challenge, which can negatively affect prices. Finally, for some space services, cheaper terrestrial alternatives may be developed. These risks are exacerbated by the timing and schedule associated with space projects. Major system expenditures have to be made years prior to the beginning of operations and, as a result, financing costs are high and the time frame for achieving a return on investment is fairly long.

The Cost of Transportation. Many in the industry characterize the high cost of transportation—typically expressed as the price per pound or kilogram to orbit—as the primary economic barrier, based on the premise that significantly reduced transportation costs to **orbit** would make new space business activities financially feasible. In theory, this would then lead to increased launch rates, which would further reduce launch costs, and this cycle would help reduce costs of entry. This basic logic—reduce the cost of getting to space and space commerce will grow rapidly—underlies many government and industry efforts to foster space commerce. The development of reusable commercial launch vehicles, for example, is generally supported by the contention that reusing vehicles (as opposed to using a vehicle only once, as is the case with today's commercial rockets) will ultimately provide lower costs to orbit. **Reusable launch vehicles** will, however, be expensive to develop. The costs and benefits of reusable launch vehicles will be a major issue for space commerce in the coming years.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

Government Policy

Government policies affect space commerce and, in the minds of many industry observers, create the greatest barriers. Government barriers to commercial space come in two varieties: areas where government regulation and oversight are perceived as restrictive or inappropriately competitive (i.e., the government should do less in order to foster space commerce) and areas where government policies and actions are perceived as insufficiently supportive (i.e., the government should do more in order to foster space commerce).

Export/import restrictions, safety and licensing regulations, and launch range use policies are examples of areas that have been criticized as too restrictive. This has led to some reforms. For example, in 1984 a single licensing entity for commercial launch services was created in the U.S. Department of Transportation, so that commercial launch service providers were relieved of the requirement to interact with more than a dozen government agencies in order get permission to launch. However, other policy barriers still exist. In the United States, for instance, export/import controls aimed at limiting the transfer of valuable or sensitive technology to other countries affect U.S. commercial satellite and launch firms competing in international markets.

Sometimes government agencies, in their conduct of space activities, are viewed as competing with industry. These concerns typically arise from government operation of systems or programs for which there is a commercial demand. For example, the space shuttle launched commercial satellites in the 1980s, but it no longer competes with expendable launch providers for these customers. Concerns may also emerge regarding systems or programs operated directly by government agencies, when they could be operated by industry. In the 1990s, the daily operation and management of the space shuttle were contracted out to an industry consortium.

Government policies generally express the intent to support commercial space. However, space advocates often criticize the implementation of this intent as inadequate. They seek government policies that will support commercial space, such as the government procuring commercial launch services rather than conducting government launches (an area in which the United States has made significant progress), undertaking technology development programs to reduce the risks to industry associated with advanced space concepts, serving as an anchor customer for new ventures, and providing loan guarantees, tax credits, and other financial incentives to space firms.

The impact of government policy and activities on space commerce should be viewed in a balanced way. All spacefaring nations have implemented some level of supportive government policy. While efforts to eliminate barriers to space commerce result in media attention and high-visibility policy discussion, it is important to note that many government policies have in fact been enabling space commerce. For example, government agencies have borne a significant proportion of the development costs of the major commercial launch vehicles worldwide. In the United States, Russia, and China, many vehicle families began as government launch systems that were eventually privatized; in Europe and Japan, commercial launchers were developed as government activities. Government agencies provide access to launch facilities and support new technology development and programs to reduce technology risks. Government acquisition of satellites and launch vehicles provides important economies of scale to manufacturing and launch firms. Intense international competition in space commerce has raised the issue of the fairness of different levels of government support for commercial space activities and given rise to international agreements ✶ aimed at leveling the playing field.

WILL LOWER LAUNCH COSTS LEAD TO A SPACE BOOM?

Is it true that space commerce will boom if launch costs are significantly reduced? No one knows for sure. There have been several analyses that have assessed the demand for launch services by proposed space businesses (on-orbit manufacturing, space tourism, and so on) as a function of lower launch prices.

The most widely used data come from a study conducted in the mid-1990s by six large aerospace companies in conjunction with the National Aeronautics and Space Administration. The "Commercial Space Transportation Study" projected that if launch prices were reduced from modern levels of $4,000 to $10,000 per pound (depending on the destination orbit) to less than $500 to $1,000 per pound, there could be significant growth in launch activity.

✶ **For more information on these agreements, see the Volume 1 article "Careers in Space Law."**

Conclusions

Barriers to space commerce are both economic and policy-based. The costs and risks of space activities create barriers to entry and limit the viability of new space industries. Despite the increasing commercial focus of space activities, government expenditures and policies will continue to have a major impact on space commerce. The greatest potential impact of government policies will arise from expenditures to reduce the costs of access to space, most likely through the development of reusable launch vehicles. The magnitude of this impact, even if launch costs drop dramatically, is difficult to predict. This uncertainty about potential benefits may inhibit government and industry willingness to commit significant resources to fostering new space markets. Finally, decision-making in both government and industry regarding space commerce will be increasingly shaped by international competition. SEE ALSO Accessing Space (volume 1); Burial (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Legislative Environment (volume 1); Remote Sensing Systems (volume 1); Reusable Launch Vehicles (volume 4); Space Tourism, Evolution of (volume 4); Tourism (volume 1).

Carissa Bryce Christensen and Deborah Pober

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Burial

The first space burial took place on April 21, 1997, when the cremated remains (cremains, or ashes) of twenty-four people were launched into Earth orbit. The Houston-based company Celestis, Inc. performed this historic space memorial service. Approximately seven grams of ashes from each individual were placed into a lipstick-sized flight capsule. Each capsule was inscribed with the person's name and a personal message. The capsules were then placed in the memorial satellite—a small satellite about the size of a coffee can. The memorial satellite was launched into space aboard a commercial rocket and placed into Earth orbit.

Celestis has continued to launch a memorial satellite every year since 1997. Many families choose the space burial because their loved ones had wanted to travel in space in their lifetimes. Each successive satellite has included more individuals as news has spread of this unique space-age service.

As of this writing, Celestis is the only company in the world launching ashes into space. The high cost of getting goods into Earth orbit (thus the small amount of ashes actually launched) and the strict regulations and permits necessary to conduct this novel business have helped to limit competition. In addition, as the space memorial service itself is new and unusual, it requires increased public knowledge and acceptance for the industry to grow.

Factors that encourage the growth of space memorials include the rising numbers of cremations worldwide. According to the Cremation Association of North America, almost seven million cremations a year take place in industrialized nations, and that number is increasing. Canada experienced a 25 percent increase in cremations from 1996 to 2000, and the United States had a 24 percent increase in the same time period. Presently, 45 percent of all deaths in Canada, 26 percent of all deaths in the United States, and almost all deaths in Japan (99 percent) lead to cremation.

There are several reasons for the increase of cremations over burials. The 1995 Wirthlin Report, sponsored by the Funeral and Memorial Information Council, states that one-fourth of survey respondents would choose cremation because it is less expensive than a traditional burial. The next rea-

A TRUE SPACE BURIAL

On July 31, 1999, the Lunar Prospector spacecraft finished its mission of mapping the Moon and was directed by NASA scientists to impact the Moon's surface. Aboard the spacecraft were the ashes of noted planetary geologist Eugene Shoemaker, the codiscoverer of the comet Shoemaker-Levy 9. The crash of the Lunar Prospector essentially buried Shoemaker's ashes on the Moon, where they remain today.

These lipstick-sized capsules contain cremated remains. Celestis, Inc. pioneered spaceflight memorials whereby a commercial rocket would carry and deposit this small payload in outer space.

son cited, by 17 percent of the respondents, was for environmental considerations—cremations use less land, which could be better used, for example, for agriculture to feed the world's population.

One might wonder about the space environment and all the memorial satellites in orbit—are they a type of orbital debris cluttering space? The memorial satellites do not remain in **orbit** forever. They are eventually drawn by gravity back to Earth, where they burn up harmlessly in the atmosphere. SEE ALSO Roddenberry, Gene (volume 1); Space Debris (volume 2).

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Charles M. Chafer and Cynthia S. Price

Internet Resources

Celestis, Inc. <http://www.celestis.com>.

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Business Failures

Many companies have built successful businesses sending television programs, computer data, long-distance phone calls, and other information around the world via satellite. Satellites are able to send information to people across an entire continent and around the world. Orbiting high above Earth, a satellite can simultaneously send the same information to a vast number of users within its coverage area. In addition, satellites are not affected by geography or topography and can transmit information beyond the reach of ground-based antennas. This characteristic, in particular, attracted entrepreneurs eager to make a profit by using satellites to provide telephone service for people who live or work in remote locations or in developing nations that have underdeveloped terrestrial communications systems.

A Chinese Long March 2C rocket carrying two U.S.-made Iridium satellites launches on March 26, 1998.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Failures in the Satellite Telephone Industry

But while some satellite systems have proven successful by offering advantages not matched by ground-based systems, the satellite telephone business has had a more difficult time. This difficulty is in part because cellular telephone companies greatly expanded their reach while the satellite systems were being built. Cellular systems use ground-based antennas, and it is generally much less expensive to use a cellular phone than to place a call with a satellite phone.

Two satellite telephone companies were forced into bankruptcy in mid-1999 because of limitations in their business plans, and because the communications business evolved while the companies were still in development. One of the companies, Iridium LLC, began service in 1998. The firm, however, could not attract enough customers to pay back the $5 billion it had borrowed to place sixty-six satellites in **orbit** to provide a global satellite phone system that would work anywhere on Earth. In late 2000, the newly formed Iridium Satellite LLC purchased the Iridium satellite system and associated ground systems for $25 million, a fraction of its original cost. Iridium Satellite soon began selling Iridium phone service at much lower prices than those of its predecessor.

Another satellite phone company, ICO Global Communications Ltd., had to reorganize and accept new owners, who bought the company at a large discount. ICO found it difficult to raise money from lenders after the failure of Iridium. ICO evolved into New ICO and developed a new, more diversified business plan that was not limited to satellite phone service. As of early 2002, New ICO had not yet started commercial service.

A third satellite phone venture, Globalstar LP, also ran into financial difficulty shortly after beginning commercial operations in 2000, and the company filed for bankruptcy protection in February 2002. Two other firms, Constellation Communications Inc. and Ellipso Inc., were unable to raise enough money to build their planned satellite phone systems.

The Reasons for the Difficulties

Iridium, ICO, and Globalstar ran into trouble because of the high cost of building a satellite system compared to the relatively low cost of expanded multicontinent cellular service, which relies on less expensive ground-based antennas. Satellites are expensive to build, and a complete satellite system can take years to complete. In addition, rockets can cost tens of millions of dollars to launch and they sometimes fail, requiring companies to buy insurance in case a rocket fails and destroys the spacecraft it was supposed to take into orbit.

These costs helped make satellite telephone systems much more expensive to use than cellular systems, while at the same time cellular networks were rapidly expanding the amount of territory for which they provided coverage. The cost difference, combined with the rapid growth of cellular networks, helped reduce the size of the potential market for satellite phone service during the very time that systems such as Iridium's were being developed.

In addition, satellite telephones are bigger and costlier to buy than cellular phones, and they must have an unobstructed view of the sky in order to work. Cellular phones, by contrast, work even indoors. These disadvantages further hurt the satellite phone industry.

Not all satellite phone companies have been unsuccessful. One, Inmarsat Ltd., has run a strong business providing mobile voice and data services for more than twenty years. But Inmarsat uses just a few satellites in **geostationary orbit** to serve most of the world, whereas Iridium, ICO, and Globalstar designed their systems around relatively large fleets of spacecraft located much closer to Earth. Such low- or medium-Earth orbit systems are intended to reduce the satellite delay associated with geostationary satellites, but they are also more costly and complex to build and operate.

geostationary orbit a specific altitude of an equatorial orbit, where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

The Related Failures of Launch Vehicle Makers

In addition to costing investors billions of dollars, the satellite phone industry's difficulties also deflated the hopes of several companies hoping to build a new series of launch vehicles designed to carry satellites into space. For example, Iridium and Globalstar each have several dozen satellites in their systems, and the expectation that the companies would have to replenish those spacecraft after several years helped inspire several firms to propose reusable rocket systems to launch new satellites.

The satellite phone systems in service in the early twenty-first century were launched using conventional rockets, which carry their **payloads** into space and then are discarded. Reusable rockets are intended to save money by returning to Earth after transporting a load into orbit and embarking on additional missions. But uncertainty about the satellite phone industry's future hurt the prospects of companies such as Rotary Rocket Co., Kistler Aerospace Corp., and Kelly Space & Technology Inc., which had looked to the satellite phone industry as a key source of business. Short of funds from investors, these firms have yet to develop an operational launch vehicle. SEE ALSO COMMUNICATIONS SATELLITE INDUSTRY (VOLUME 1); FINANCIAL MARKETS, IMPACTS ON (VOLUME 1); INSURANCE (VOLUME 1); LAUNCH VEHICLES, REUSABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4).

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Samuel Silverstein

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Business Parks

Humans have been doing business in orbit since the early 1960s, with "business" loosely defined in this context as any useful activity. Trained specialists, within the safety of small orbiting spacecraft, studied the Earth below and the heavens above. They conducted medical tests to see how their bodies responded to weightlessness. They did experiments on various materials to see how the lack of gravity affected their interactions. They studied the growth and behavior of plants and small animals. This early orbital activity would become the seed of today's space stations, which in turn may lead to tomorrow's space business parks.

Precursors to Space-Based Business Parks

For serious work, more spacious, dedicated orbiting laboratories were needed. The Soviets launched a series of Salyut stations beginning in 1971.

Astronaut Charles "Pete" Conrad Jr. completes an experiment activity checklist during training for a Skylab mission. Space business parks may include modules the size of Skylab.

The American Skylab, built from the casing of a leftover Saturn I booster, was launched in 1973 and was staffed in three missions of twenty-eight, fifty-nine, and eighty-four days.

Through the 1980s and 1990s, the National Aeronautics and Space Administration (NASA) used the space shuttle orbiter's **payload bay** to conduct orbital observations and experiments for periods of up to two weeks. Commercially built SpaceHab modules and the European-built Spacelab, both riding in the payload bay, allowed scientists to conduct more serious work. Meanwhile, the Soviet's historic Mir space station grew from a single module to an ungainly but productive complex.

payload bay the area in the shuttle or other spacecraft designed to carry cargo

Scientists experimented, **synthesizing** chemicals, crystals, and proteins impossible to produce in full gravity. Through such experiments it is possible that scientists might discover products valuable enough to warrant orbiting factories.

synthesis the combination of different things so as to form new and different products or ideas

Orbit is "the" place to do some useful things with proven economic impact: create global communications grids; monitor the atmosphere, weather, oceans, and changing land-use patterns; and search for unsuspected submarine and subterranean features. Much of this has been accomplished with automated satellites. Human activities in orbit have been directed at investigating the effects of **microgravity** on humans, animals, plants, and inanimate substances. Astronauts have also launched, retrieved, and repaired satellites and deep-space probes. The International Space Station (ISS) is being built to ramp up all these activities to the next level. Open for business with a crew of three, ISS's final design configuration would allow for a crew of seven. Further expansion of the current design is possible.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Elements of Business Parks in Space

Orbit is also an ideal place to service satellites, refuel probes on deep-space missions, and assemble large spacecraft and platforms too big to launch whole. For these activities humans will need: a fuel depot with the capacity to scavenge residual fuel, robotic tugs to take satellites to higher orbits and fetch them for servicing, a well-equipped hangar bay in which to perform such services safely under optimum lighting, and a personnel taxi for spacecraft parking nearby.

Supporting humans in space requires a growing mix of services to keep labs busy, bring people to orbit and back, supply equipment and parts, resupply consumables, and handle wastes. These are all businesses that can be provided more effectively at less cost by for-profit enterprises, given proper incentives. Physically, the ISS is similar to Mir in being a government-built metal maze. Operationally, the ISS could host considerable entrepreneurial activity.

A favorable climate of legislation, regulation, and taxation will foster such development. Privatizing American contributions could lead the way in this international endeavor. NASA could be mandated to use commercial providers for additional modules not in the original final design of the ISS as well as for the transfer of cargoes between orbits.

The ISS could evolve into a business park. As more people live and work aboard the ISS, additional quarters will be needed for visiting scientists, policymakers, and journalists. A modular six-berth "hotel" could grow with

The International Space Station, where astronauts live and conduct research for significant stretches of time, is the next step towards realizing integrated business parks in orbit.

demand. An open-door policy would welcome private individuals who had paid for or won their fares and who had passed physical and psychological tests.

berth space the human accommodations needed by a space station, cargo ship, or other vessel

Along with **berth space**, demand will grow for adequate recreation and relaxation "commons." A voluminous sports center, built in a shuttle external tank or large inflatable structure (sphere, cylinder, or torus), could be subsidized by naming rights and paid for by television advertising. Zero-G space soccer, handball, wrestling, ballet, and gymnastics might command respectable audiences on Earth. The first players will be regular staff, but telecasting these events would feed the demand among would-be tourists.

As on-location service providers join the action, they too will need residential and recreational space. As the population grows, treating and recycling wastes in-orbit will become more attractive. This will help build the know-how needed for future Moon and Mars outposts.

Managing a Growing Space Business Park

The operating agency should be a marina/port authority–type entity, acting as park "developer," anticipating growth and demand. The expansion of the station's skeletal structure and power grid must be planned, along with additional piers, slips, and docking ports. Haphazard growth can lead to an early dead end!

Clustering activities—scientific, commercial, industrial, and tourist—will aim at creating a critical mass of goods and services providers, including frequently scheduled transportation. If collective station keeping proves feasible, a station-business park could expand to include co-orbiting satellite clusters, orbiting Earth in formation. Laboratories may choose to relocate to such parks for isolation from unwanted vibrations.

If microgravity experiments identify products that could be profitably mass-produced in orbit, manufacturing complexes may develop. Raw materials mined on the Moon or the asteroids could be processed at orbiting industrial parks into building materials and manufactured goods. These products will not be aimed at consumers on Earth, where they would not be able to compete on price. Instead, they will feed the construction and furnishing of ever-more orbiting labs, business parks, factories, and tourist resorts. If Earth-to-orbit transportation costs remain high, space-sourced goods could have a cost advantage for orbital markets. This need to support increasing activities in Earth orbit will in turn support mining settlements on the Moon and elsewhere.

The Mir, deactivated and then recommissioned, had taken the lead in encouraging for-profit space activities, including tourism. Unfortunately, the Russian Space Agency decided to end its operation, and the aging space station re-entered Earth's atmosphere in 2001.

Given favorable changes in climate, bursts of commercial and business activity could vitalize the ISS core complex. The ISS is now in a high-inclination Earth orbit, an orbit chosen for its ease of access as well as to allow observation of most populated landmasses on Earth. Such orbits, however, are not optimum as staging points for higher **geosynchronous** orbit or deep space. Rising demand for such crewed services should lead to another depot-business park in **equatorial orbit**. Business and tourist activities in orbit are emerging from these tiny seeds. The future for business parks in orbit is bright. SEE ALSO Commercialization (volume 1); Habitats (volume 3); Hotels (volume 4); TransHab (volume 4).

Peter Kokh

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

equatorial orbit an orbit that lies in the same plane as Earth's equator

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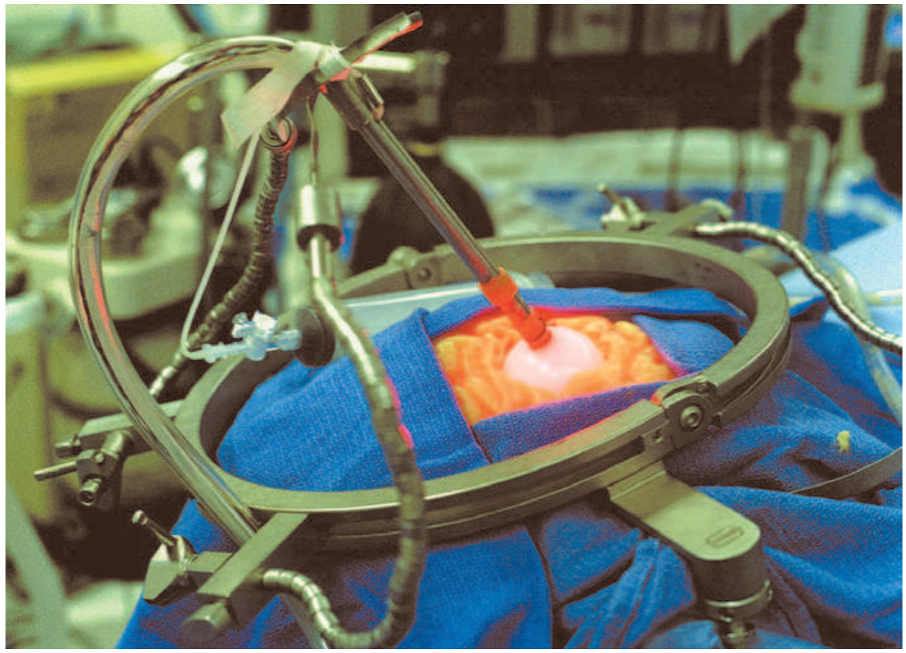
Cancer Research

The potential use of the **microgravity** environment for inroads in cancer research is both important and promising. Research opportunities are broad and will include many areas of examination for investigators who are trained in both basic and clinical sciences. As one example, studies have shown that mammalian **cell culture** conducted in a manner that does not allow cell settling as a result of gravitational forces holds promise in the propagation of three-dimensional tissue **cellular arrays** much like those that normally comprise tissue specimens in the intact body. The space shuttle and the International Space Station have only a minute fraction of the gravitational force present on Earth. Culture of tissues with a three-dimensional architecture on these research platforms provides a unique and powerful opportunity for

microgravity the condition experienced in free-fall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface



NASA's light-emitting diode (LED) developed out of a need for a light that could promote plant growth in space. Surgeons now use LED technology in cancer treatments involving surgery.

cell culture a means of growing mammalian (including human) cells in the research laboratory under defined experimental conditions

cellular array the three-dimensional placement of cells within a tissue

convection the movement of heated fluid caused by a variation in density; hot fluid rises while cool fluid sinks

X-ray diffraction analysis a method to determine the three-dimensional structure of molecules

studies of anti-cancer drug action with a more complex and natural tissue ultrastructure than can be attained in terrestrial laboratories.

Even the production and analysis of new anticancer drugs may be conducted in a superior manner in microgravity. Studies already conducted on the space shuttle have shown that, in at least some instances, superior crystal growth can be achieved in microgravity when compared to crystals grown on Earth. This success primarily is the result of a lack of liquid **convection** currents in microgravity that subsequently leads to a quieter liquid environment for a gradual and more orderly growth of crystals. The quality of crystal products is an important feature in the determination of the three-dimensional structure of the molecules by **X-ray diffraction analysis**. Until the three-dimensional structure of new and existing anti-cancer compounds is established, the design of superior candidates for cancer treatment is severely hampered.

It is generally recognized that cancers arise in the body more often than clinically troublesome cancer diseases occur. In many cases the primary cancer growth is restricted in further development and the victim's immune system plays an important role in limiting cancer progression, sometimes even eradicating the cancer cells altogether. It seems that the mammalian immune system may not function as efficiently in the microgravity environment when compared to Earth.

On one hand, a weakened immune response to infectious diseases and cancer could present a serious obstacle for space travelers of the future. On the other hand, a compromised immune system in microgravity, and a subsequent increased efficiency of tumor progression, may provide a valuable test bed for research on the immune system with regard to cancer development. The microgravity environment, where immune function is less efficient, may also provide an excellent opportunity to develop and assess new chemotherapeutic measures that can strengthen the host's immune response.

Of course, there are biomedical applications well beyond cancer research since the progression of many diseases may reflect a compromised immune function.

The life-threatening radiation exposure away from the protective atmosphere of Earth, and the ensuing increase in cancer cell development, is more than a casual concern for long-distance space travel. The means to protect space travelers from increased radiation will be necessary before such adventures are common.✶ SEE ALSO AIDS RESEARCH (VOLUME 1); LIVING IN SPACE (VOLUME 3); MADE IN SPACE (VOLUME 1); MEDICINE (VOLUME 3); MICROGRAVITY (VOLUME 2).

✶In 2002 NASA announced an expanded 10-year program to study space radiation issues.

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Career Astronauts

In the future, passenger flight into space is likely to become as routine as air travel. In the early twenty-first century, however, opening up the space frontier is the duty of a select cadre of highly trained individuals. In the United States, the early pioneering days of human spaceflight gave rise to individuals with what author Tom Wolfe called the "right stuff." These individuals were tough-as-nails experimental aircraft test pilots. They were critical to getting America's human spaceflight program, quite literally, off the ground. During the 1960s, and continuing through the 1970s, a unique corps of astronauts flew in the U.S. **Mercury**, **Gemini**, **Apollo**, and Skylab programs.

Today, after some forty years of human sojourns into **low Earth orbit** and to the Moon, roughly 400 people have departed Earth, heading for orbit. Beginning in 1981, a majority of these individuals have been boosted there courtesy of a U.S. space shuttle. Space travel has come a long way, from the early single-person "capsule" to the winged flight of a space shuttle.

Mercury the first American-piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963.

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Types and Duties of NASA Astronauts

The National Aeronautics and Space Administration (NASA) recruits pilot astronaut candidates and mission specialist astronaut candidates to support the space shuttle and International Space Station programs. Persons from both the civilian sector and the military services are considered. Applicants for the NASA Astronaut Candidate Program must be citizens of the United States.✶

✶Readers interested in an astronaut career may request an application package by writing to: NASA Johnson Space Center, Attn: AHX/Astronaut Selection Office, Houston, Texas 77058.

Pilot astronauts serve as both space shuttle commanders and pilots. During flight the commander has onboard responsibility for the vehicle, crew, mission success, and the safety of the flight. The pilot assists the commander

Since astronaut Buzz Aldrin's historic steps on the lunar surface in July 1969, more than 400 people—astronauts, cosmonauts, and even "space tourists"—have ventured into space.

in controlling and operating the vehicle. In addition, the pilot may assist in the deployment and retrieval of satellites using the **remote manipulator system**, in extravehicular activities (**spacewalking**), and in other **payload operations**.

remote manipulator system a system, such as the external Canada2 arm on the International Space Station, designed to be operated from a remote location inside the space station

spacewalking moving around outside a spaceship or space station, also known as extravehicular activity

payload operations experiments or procedures involving payload or "cargo" carried into orbit

Mission specialist astronauts, working with the commander and pilot, have overall responsibility for the coordination of shuttle operations in the areas of crew activity planning, consumables usage, and experiment and payload operations. Mission specialists are required to have detailed knowledge of shuttle systems, as well as detailed knowledge of the operational characteristics, mission requirements and objectives, and supporting systems and equipment for each **payload** element on their assigned missions. Mission specialists perform space walks, use the remote manipulator system to handle payloads, and perform or assist in specific experiments.

Space shuttle crews have demonstrated that operation and experimental investigations in space are a challenging endeavor. A basic shuttle crew normally consists of five people: the commander, the pilot, and three mission specialists. On occasion, additional mission specialists, **payload specialists**, or other crewmembers are assigned. The commander, pilot, and mission specialists are NASA astronauts.

An exciting new era of space exploration is underway with the building of the International Space Station (ISS). The development of this orbital facility has been called the largest international scientific and technological endeavor ever undertaken.

The ISS is designed to house six to seven people, and a permanent laboratory will be established in a realm where gravity, temperature, and pressure can be manipulated in a variety of scientific and engineering pursuits that are impossible in ground-based laboratories. The ISS will be a test bed for the technologies of the future and a laboratory for research on new, advanced industrial materials, communications technology, and medical research.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

payload specialists scientists or engineers selected by a company or a government employer for their expertise in conducting a specific experiment or commercial venture on a space shuttle mission

Requirements for Applicants

What minimum requirements must an individual meet prior to submitting an application for astronaut status at NASA?

For a mission specialist astronaut candidate, an individual must have a bachelor's degree from an accredited institution in engineering, a biological or physical science, or mathematics. The degree must be followed by at least three years of related, progressively responsible, professional experience. An advanced degree is desirable and may be substituted for part or all of the experience requirement (a master's degree is considered equivalent to one year of experience, while a doctoral degree equals three years of experience). The quality of the academic preparation is important. Individuals must also pass a NASA Class II space physical, which is similar to a military or civilian Class II flight physical, and includes the following specific standards:

- Distance visual acuity: 20/200 or better uncorrected, correctable to 20/20, each eye
- Blood pressure: 140/90 measured in a sitting position
- Height: between 148.6 and 193 centimeters (58.5 and 76 inches)

The minimum requirement for a pilot astronaut candidate is a bachelor's degree from an accredited institution in engineering, a biological or physical science, or mathematics. An advanced degree is desirable. The quality of the academic preparation is important. At least 1,000 hours pilot-in-command time in jet aircraft is necessary. Flight test experience is highly desirable. Applicants must pass a NASA Class I space physical, which is similar to a military or civilian Class I flight physical, and includes the following specific standards:

- Distant visual acuity: 20/70 or better uncorrected, correctable to 20/20, each eye
- Blood pressure: 140/90 measured in a sitting position
- Height: between 162.6 and 193 centimeters (64 and 76 inches)

Screening and Training

Beyond the initial application requirements, NASA's astronaut selection involves a rigorous screening process designed to cull the best and brightest from those who are applying. In fact, in July 1999, a NASA call for astronauts produced more than 4,000 applicants. A mere 3 percent made the first cut. From there, further screening by the Astronaut Selection Board led to a final twenty candidates.

Those who make the grade as astronaut trainees are located at NASA's Lyndon B. Johnson Space Center in Houston, Texas. The selected applicants are designated astronaut candidates and undergo a one- to two-year training and evaluation period during which time they participate in the basic astronaut training program. This effort is designed to develop the knowledge and skills required for formal mission training upon selection for a flight. During their candidate period, pilot astronaut candidates must maintain proficiency in NASA aircraft.

As part of the astronaut candidate training program, trainees are required to complete military water survival exercises prior to beginning their flying studies and become scuba qualified to prepare them for spacewalking training. Consequently, all astronaut candidates are required to pass a swimming test during their first month of training. They must swim three lengths of a 25-meter (82-foot) pool without stopping, and then swim three lengths of the pool in a flight suit and tennis shoes. The strokes allowed are freestyle, breaststroke, and sidestroke. There is no time limit. The candidates must also tread water continuously for ten minutes.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

parabolic trajectory trajectory followed by an object with velocity equal to escape velocity

To simulate **microgravity**, astronaut candidates board the infamous "Vomit Comet," a converted KC-135 jet aircraft. Flown on a **parabolic trajectory**, this airplane can produce periods of microgravity for some twenty seconds. Akin to an airborne version of a roller coaster, the parabolic maneuvers are repeated up to forty times a day. Those riding inside the aircraft experience microgravity similar to that felt in orbital flight, although in short bursts.

One very important note: Selection as a candidate does not ensure selection as an astronaut. Final selection is based on the satisfactory completion of the one-year program.

Salaries

Salaries for civilian astronaut candidates are based on the federal government's general schedule pay scales for grades GS-11 through GS-14 and are set in accordance with each individual's academic achievements and experience. Selected military personnel are assigned to the Johnson Space Center but remain in an active duty status for pay, benefits, leave, and other similar military matters. SEE ALSO Astronauts, Types of (volume 3); KC-135 Training Aircraft (volume 3); Mission Specialists (volume 3); NASA (volume 3); Payload Specialists (volume 3).

Leonard David

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Careers in Business and Program Management

One of the most interesting and potentially exciting trends in space exploration in the late twentieth and early twenty-first century has been the move towards the privatization and commercial exploitation of space. Privatization refers to the transfer of operations from the government or public agency to private sector management. Several organizations have suggested that many aspects of the U.S. space program's involvement in the International Space Station (ISS) and all Space Transport System (shuttle) operations should be privatized. The commercial exploitation of space has been a key topic of interest since the space program began. Commercialization and privatization of space go hand-in-hand, but the words have somewhat different meanings.

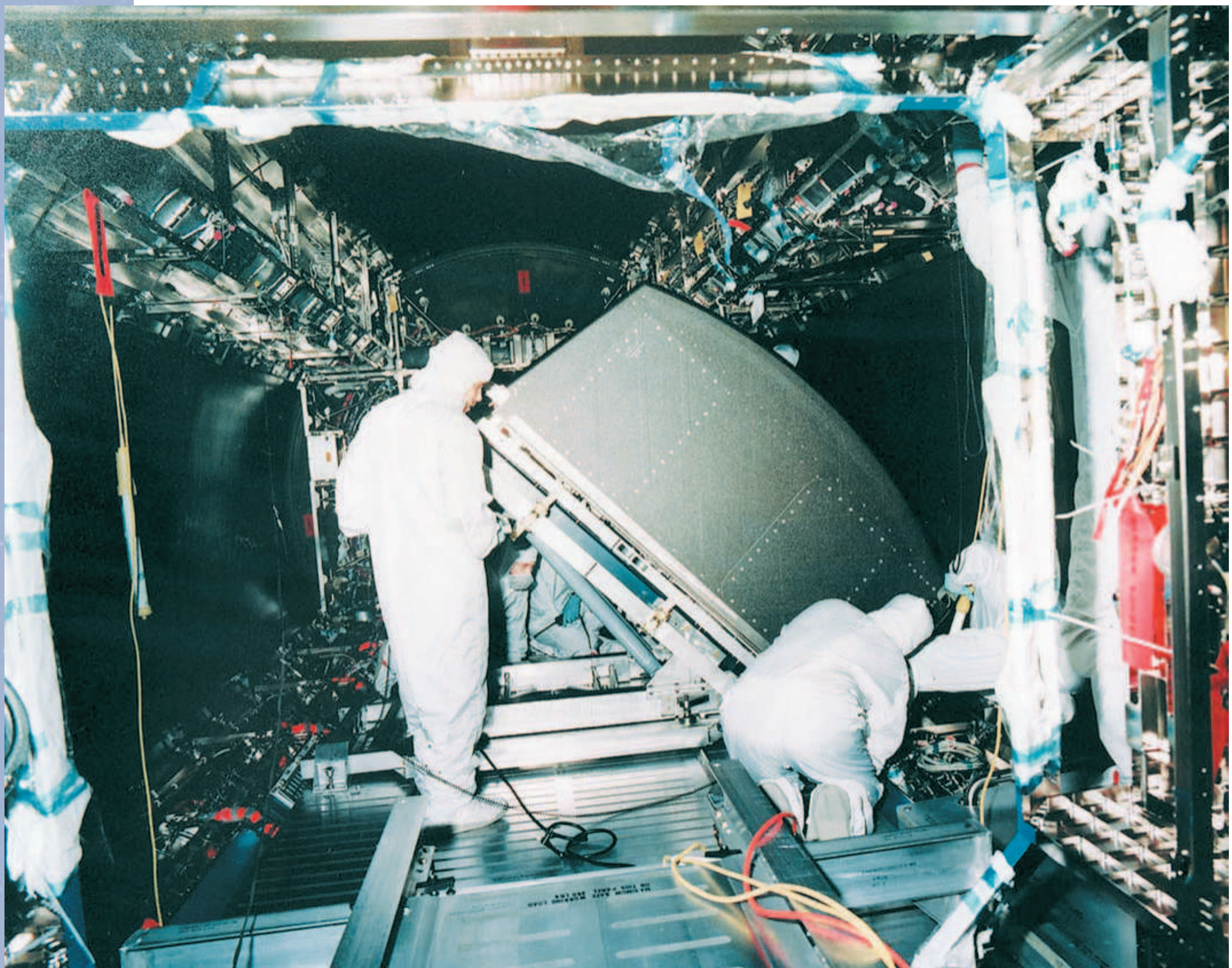
"Commercialization of space" is the term used by the National Aeronautics and Space Administration (NASA) and the U.S. Department of Commerce to describe the technology transfer program, where technologies developed by NASA are transferred to the private sector. The term is also used to describe purely private ventures that seek to use space as a resource for making a profit. This includes satellite delivery systems, asteroid mining, space-waste disposal, space tourism, and medical or commercial uses of the ISS. One of the earliest satellites launched was a giant balloon named Echo, which was used as a test of satellite communications. In the early twenty-first century, the space around Earth is filled with orbiting communications satellites, mostly owned and operated by private industry.

The commercialization of space offers new opportunities for private enterprise. While the large aerospace corporations continue to dominate the industry, several companies have been formed in recent years with the intention and stated goal of commercially exploiting space. Many former astronauts, and former NASA scientists and engineers, have moved on to these companies, suggesting that people with knowledge of space exploration consider privatization and commercial development of space enterprise the way of the future.

Careers in Aerospace

Individuals well suited for a career in aerospace tend to enjoy figuring out how things work; math and science; solving puzzles, especially mechanical puzzles; building flying model rockets, model airplanes, or trains; learning new things; and working with computers. There are several different ways to prepare for a career in aerospace, including taking plenty of math and science courses in high school. For those interested in design, research, or development of new aerospace systems, a college degree is desirable, preferably in engineering or science, but not necessarily aerospace engineering. After completing a degree, many seek a job in the aerospace or related industry and immediately apply for on-the-job training for specialized aerospace fields. Because jobs in the aerospace industries are very competitive, enlisting in one of the armed forces and applying for specialized training or even flight school are also recommended.

For the most part, everything that flies in the air or that orbits Earth is made by an aerospace industry. The aerospace industry is one of the largest employers in the United States, with over 750,000 employees. The aero-



The aerospace industry is one of the largest employers in the United States. Here, Boeing technicians install the first of 24 system racks into the U.S. laboratory module for the International Space Station at the Marshall Space Flight Center in Huntsville, Alabama.

space industry works very closely with the federal government on many projects. National defense and space exploration together account for over three-fourths of aerospace industries production. The aerospace industry hires more than 20 percent of the scientists and engineers in the United States.

It is almost impossible to get a job in the aerospace industry without a high school diploma. However, there are many different opportunities for employment in the aerospace industry, at many different levels from high school graduates to persons with advanced degrees in science, mathematics, and engineering. At whatever level a person is employed, special training or skill preparation is required. Administrative assistants working in the aerospace industry must be able to handle the complex technical language used by the industry. Union workers must be trained in the special manufacturing techniques used in aircraft and spacecraft, including ceramics, fiber composites, and exotic metals. Many workers must obtain a security clearance including extensive background checks.

Many companies hire more electrical engineers, mechanical engineers, and computer specialists than aerospace engineers. Also in high demand are materials scientists (to develop new alloys and composites), civil engineers (for site design and development), and chemical engineers (to study new fuels). Companies also hire safety engineers, manufacturing engineers (to help design efficient manufacturing processes), test and evaluation engineers, and quality control engineers.

A technical degree or advanced degree is not essential to work in the aerospace industry. Many jobs do not require a degree at all. Engineers and scientists represent less than one-third of the workforce. The remaining two-thirds are nontechnical support personnel. In production companies that primarily manufacture hardware, the proportion of engineers and technicians may be as low as 10 to 15 percent.

The large portion of employees at a typical aerospace company includes 10 to 20 percent professional employees, such as managers, salespeople, and contract administrators. Mechanics, electricians, and drafters are another 5 to 10 percent of the employees. The remainder include human resource specialists, engineering records employees, secretaries, and assembly line workers.

Aerospace Program Management

The aerospace industry has managed some of the largest, most expensive, and complex projects ever undertaken by humans. Projects such as the Apollo missions, with the goal of landing humans on the Moon within a decade, and the ISS involved thousands of people working all over the globe on different aspects of the project who had to all come together at the right time and place. Learning to manage such huge projects requires excellent technical comprehension and outstanding management abilities.

Some people have blamed NASA's management approach to the "faster, better, cheaper" series of "Discovery" class missions for the spectacular failures of the Mars Climate Orbiter and Mars Polar Lander. Former NASA administrator Daniel Goldin has commented that in the 1990s NASA dramatically increased its number of missions and decreased the time for each, while at the same time reducing the size of its staff. This resulted in less experienced program managers who received insufficient training and mentoring.

The lack of qualified managers has led to the development of specialized training in program management. Programs in space-related industries have traditionally been managed by scientists or engineers who learned to manage programs while on the job, or by former astronauts or others working in the aerospace industry. Although this approach has led to some spectacular successes in the space program, it has also led to some notable failures.

In response to criticism and recent failures of NASA in particular and the aerospace industry in general, the National Academy of Sciences recently completed a study and published a white paper with a suggested new design for program management. While the report specifically addresses human exploration of space and a potential Mars mission, its principles are applicable to any large-scale endeavor. The report grouped its recommendations into three broad areas.

The first recommendation made by the study group was that scientific study of specific solar system objects be integrated into an overall program of solar system exploration and science and not be treated as separate missions of exploration simply because of the interest in human exploration. All scientific solar system research would be grouped into a single office or agency.

The second recommendation made in the report was that a program of human spaceflight should have clearly stated program goals and clearly stated priorities. These would include political, engineering, scientific, and technological goals. The objectives of each individual part of a mission would have clearly stated priorities. These would be carefully integrated with the overall program goals.

The last recommendation made by the study group was that human spaceflight programs and scientific programs should work with a joint program office that would allow collaboration between the human exploration and scientific components. As a model, the study group suggested the successful Apollo, Skylab, and Apollo-Soyuz missions. SEE ALSO CAREER ASTRONAUTS (VOLUME 1); CAREERS IN ROCKETRY (VOLUME 1); CAREERS IN SPACE LAW (VOLUME 1); CAREERS IN SPACE MEDICINE (VOLUME 1); CAREERS IN WRITING, PHOTOGRAPHY, AND FILMMAKING (VOLUME 1).

Elliot Richmond

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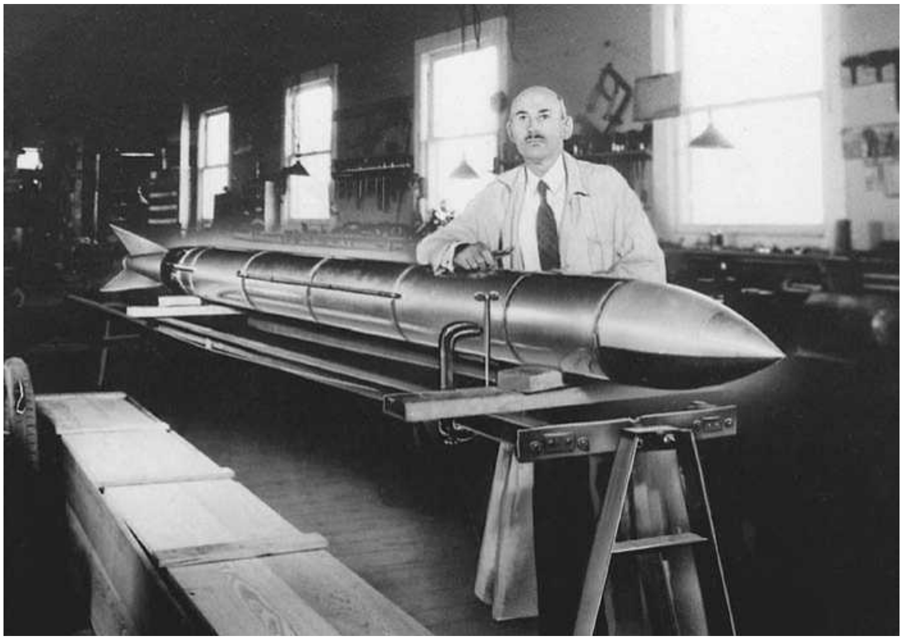
Careers in Rocketry

Three important developments during the first half of the twentieth century laid the foundation for both modern rocketry and careers within the field. The first was the inspired scientific and engineering work performed by Robert H. Goddard on solid propellant rockets, and subsequently on liquid propellant rockets, during the years 1915 through 1942. Remembered as the "Father of Modern Rocketry," Goddard was a physics professor at Clark University in Massachusetts. Working mostly alone, with limited



Robert Goddard, one of America's first rocket scientists, poses with one of his rockets at Roswell, New Mexico in 1938.

funds, he built and launched experimental solid and liquid propellant rockets and established the physical principles that enabled future rocket development to proceed.

The second event took place in Germany in the early 1930s. Goddard's work generated little interest in the United States, but it excited a small organization of young German rocket enthusiasts called *Verein Zur Forderung Der Raumfahrt* (VFR). One of the leaders of that group was Wernher von Braun, who ultimately helped the United States in the space race against the Soviet Union to place men on the Moon. The VFR built successful experimental liquid propellant rockets and captured the interest of the German army. VFR members were then assigned to develop a long-range **ballistic** missile that could deliver bombs to London. This huge effort ultimately resulted in the development of the V-2 rocket, which caused great devastation when it was used during World War II (1939–1945). In the space of a few months, over 1,300 V-2s were launched toward England. Technologically, the V-2 was an impressive development. It formed the prototype for most of the liquid-fueled rockets that were built over the next fifty years.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

The third important development was the atomic bomb and the onset of the Cold War between the Soviet Union and the United States. This occurred immediately after the conclusion of World War II in 1945. Using V-2 technology, both nations embarked on enormous efforts to develop ballistic missiles that could deliver atomic bombs to any target. Coincidentally, that effort helped develop rockets capable of carrying **payloads** into space.

payloads the cargo carried into orbit by a space vehicle, usually a scientific experiment, satellite, or space station module

Rocket Development

Professionals in the field of rocketry work on two general types of rockets: liquid propellant and solid propellant. Each type has applications where it is best suited. A third type, called a hybrid, combines a solid fuel with a liquid **oxidizer**. At the beginning of the twenty-first century, hybrids were in

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

early development by the National Aeronautics and Space Administration (NASA).

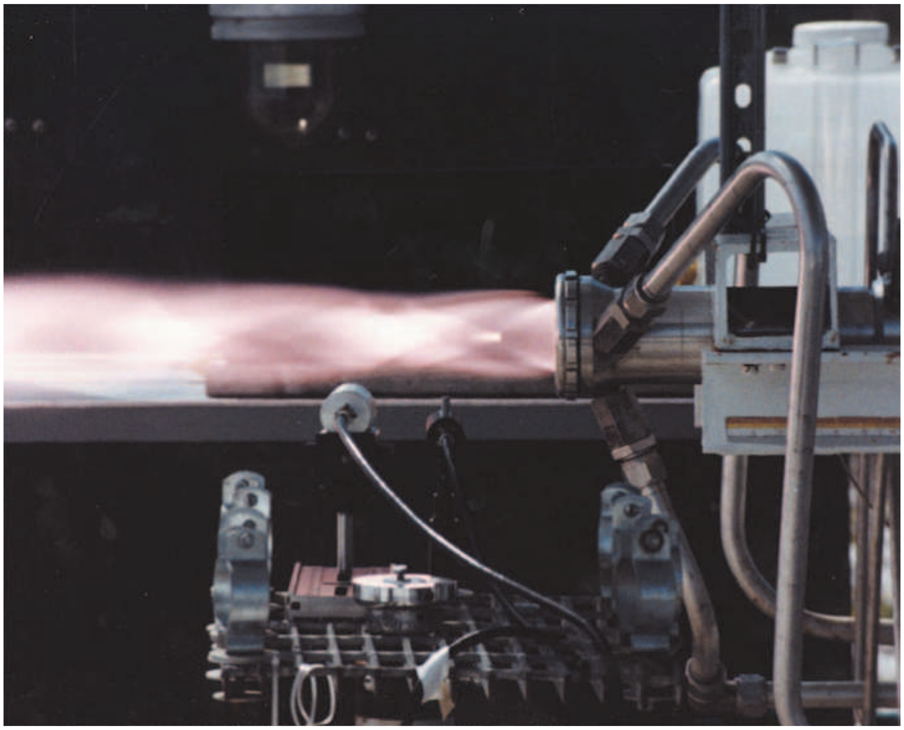
Liquid propellant rockets are generally preferred for space launches because of their flexibility of operation and better performance. For instance, the engines can be shut off and restarted, and the thrust can be throttled. On the other hand, solid propellant rockets have some tactical advantages. They do not require propellant loading on the launch pad, and they can be stored for long periods. Liquid propellant and solid propellant rockets can be used jointly to advantage in such cases as the Space Transportation System, better known as the space shuttle. The shuttle is initially boosted by two solid motors, working in tandem with the shuttle's liquid-fueled engines. Other liquid rockets that employ solid propellant boosters are the Delta, Titan IV, and Atlas space launchers.

The design and development of a rocket always begins with a requirement. That is, what is the nature of the mission that it is going to perform? The requirement could be established by the military, by NASA, or by a commercial enterprise concerned with exploiting opportunities in space. For the military, such a requirement might be a communications or spy satellite. For NASA it might be a spacecraft to Jupiter or a Mars lander. For commercial enterprises, the requirement usually centers on communications satellites or Earth-observation spacecraft.

As an example of the work involved in the field of rocketry, consider what happens when NASA comes up with a new requirement, and no existing rocket is capable of handling the mission. An entirely new rocket design is needed. Working to the requirements, a team of designers and systems engineers synthesize several different concepts for the new rocket, which, like all rockets, basically consists of a propulsion system, propellant tanks to hold the propellant, guidance and electronics equipment to control and monitor the rocket in flight, structure to hold the parts together, and miscellaneous components, valves, and wiring needed to make the rocket function. An advanced rocket that could complete the mission in a single stage might be included in the investigations, as well as various arrangements of two or more stages. In this phase of work, coordination with rocket engine and electronics systems manufacturers begins. Working together, the designers, engineers, and manufacturing professionals determine what is available, or what would need to be developed to make a particular concept work. Then the various concepts are compared in what are called trade studies, to determine which one can be built with the least cost, with the least risk, and on time, with the additional consideration of operational costs. Eventually each team will submit its best technical proposal and business plan, and subsequent evaluations and negotiations with NASA will culminate in placing a development contract with the winner.

Professions in Rocketry

Looking back to the beginnings of rocketry, Goddard served the functions of inventor, scientist, engineer, machinist, and test engineer, all combined into one. Modern design, development, manufacture, and operation of rockets require a broad array of professionals, including: mechanical, chemical, electronics, and aerospace engineers; thermodynamicists; aerodynamics and structural designers and analysts; manufacturing and tooling engineers; sys-



The design and development of a rocket is always guided by the nature of the mission that it is supposed to perform, and it is carefully tested to ensure its suitability.

tems engineers; project engineers; and test engineers. Rocketry is now heavily computer oriented, so persons preparing for a career in this field should become proficient in computer-aided analysis, design, and manufacturing.

The Future of Rocketry

As the twenty-first century unfolds, rocketry is still in its infancy, and there are many important areas in which professionals will be needed in the field in the future. It is too expensive to travel to space, and technology must be directed toward reducing space launch costs. One way this could occur is with the development of intercontinental ballistic travel. The development of a rocket engine that can operate on air and fuel will make this possible. With this innovation, hundreds of daily flights across continents can be envisioned. Travel to space in similar vehicles will be economical. In space travel, we can forecast nuclear propulsion, particularly if it turns out that water on the Moon can be readily mined. Nuclear steam rockets will then become common. Pulse plasma rockets, huge butterfly-shaped rockets that collect electrical energy from the Sun, will also be used. Ultimately, for travel to distant star systems, the tremendous energy available in particle annihilation will be applied in propulsion. Practical containers for **antimatter** may be impossible to achieve. But the secret may be to use antimatter as fast as it is generated—a challenge for rocketeers of the twenty-first century. SEE ALSO Goddard, Robert Hutchings (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Nuclear Propulsion (volume 4); Reusable Launch Vehicles (volume 4); Rocket Engines (volume 1); Rockets (volume 3); Space Shuttle (volume 3); von Braun, Wernher (volume 3).

Edward Hujsak

antimatter matter composed of antiparticles, such as positrons and antiprotons

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Careers in Space Law

Attorneys have been involved in space law since the early 1960s, when the legal community started addressing many rules and regulations relating to outer space activities. Space law practice deals with the legally related behavior of governments and private individuals who have interacted in some manner with outer space.

Issues that Space Lawyers Address

Many situations requiring legal expertise crop up in the world of space. Space lawyers rely on already established space law but still enter into uncharted territory. An example of such an undefined area that affects what space attorneys do is the designation of where space begins. The Outer Space Treaty and most of the other international conventions do not define the boundary between Earth's atmosphere and outer space. Another dilemma confronting space lawyers is the many provisions of the treaties, such as the ban on claims of sovereignty and property rights in space as well as the prohibition against military operations in outer space.

Generally speaking, space law attorneys handle two areas of outer space law:

- International space law, which governs the actions of countries as they relate to other states.
- Domestic space law, which governs actions within the state.

The Five Core Space Treaties

Space attorneys conduct most of their legal activities in keeping with space treaties, which resulted from the establishment of the United Nations Committee on the Peaceful Uses of Outer Space in 1958. Many countries have ratified five major international treaties and conventions, which guide space law attorneys in international and domestic space law.

The first major space treaty was the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (known as the Outer Space Treaty). This treaty addresses many liability issues that attorneys would be involved in litigating. Countries that did not ratify the 1972 Liability Convention may still be legally obligated to abide by this treaty.

The 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space (known as the Rescue Agreement) was the next major treaty. Attorneys play an important role with respect to this treaty by providing counsel to government and public organizations concerning rescue and recovery efforts.

This was followed by the 1972 Convention on International Liability for Damage Caused by Space Objects (known as the Liability Convention). One of the biggest concerns space attorneys deal with regarding these five treaties is the issue of liability. Therefore, space law practice is to a great extent involved with such issues. Among the issues space law attorneys currently handle is damage caused by spacecraft and satellites, as well as indirect effects such as causing pollution in outer space that adversely affects Earth. In the future, as private tourism expands into space and private citizens go into outer space for pleasure, a very strong interest will arise in liability provisions and indemnification through the insurance industry.

Specifically, the Liability Convention requires payment of damages making restitution for "loss of life, personal injury or other impairment of health, or loss or damage to property of States or of persons, natural or juridical, or property of international governmental organizations" (Liability Convention, Article 1). A "launching state" is explicitly defined as a state that launches or procures the launching of a space object or a state from whose territory or facility a space object is launched, regardless of whether the launch was in fact successful.

The 1976 Convention on Registration of Objects Launched into Outer Space (known as the Registration Convention) requires adherence to regulations regarding the tracking of all spacecraft and satellites. Attorneys counsel organizations on how to comply with these requirements.

The final major space treaty was the 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (known as the Moon Agreement). The United States has not ratified this treaty, but legal counsel still needs to be aware of its ramifications, especially when working with ratifying countries on joint projects. SEE ALSO LAW (VOLUME 4); LAW OF SPACE (VOLUME 1); LEGISLATIVE ENVIRONMENT (VOLUME 1).

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Careers in Space Medicine

Outer space has a very different environment from that of Earth. The atmosphere, radiation, and gravity levels are so drastically varied that several adjustments are made to protect astronauts from the deadly effects of the space environment on the human body. In particular, gravitational effects are not well controlled and the effects of long-term exposure to **microgravity** are unknown.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Several experiments have already indicated that major biological changes begin in the human body within minutes of spaceflight. For example, when

When in space, humans experience decreased aerobic capacity, endurance, strength, and muscle mass. Physicians in space medicine conduct tests to determine what types of exercise will most benefit astronauts who spend extended periods of time in space.

malady a disorder or disease of the body

a person is exposed to microgravity, there is less blood volume in the legs and more in the upper body. This change makes the brain sense that there is too much fluid in the body and triggers an adaptive response such as increased urine production. This is similar to the sensation experienced by many people upon entering a swimming pool. Even the chemical composition of blood and urine is altered, which perhaps reflects that other body tissue and organ changes are taking place in response to the loss of gravity. Given all of the effects of spaceflight upon the human body, several career opportunities exist to study and treat future space travelers.

Medical Challenges

Several questions remain about the scope of space medicine because scientists do not understand all of the changes that take place in the human body either on Earth or in space. Can all of the problems be treated? Is a treatment really needed? Is the prevention of adaptive changes that occur when humans go to space better than treatment after a change has already taken place? How can medical problems in space be prevented? Will the body's cells, tissues, and organs return to normal at different rates upon landing back on Earth or on another planet with similar gravity?

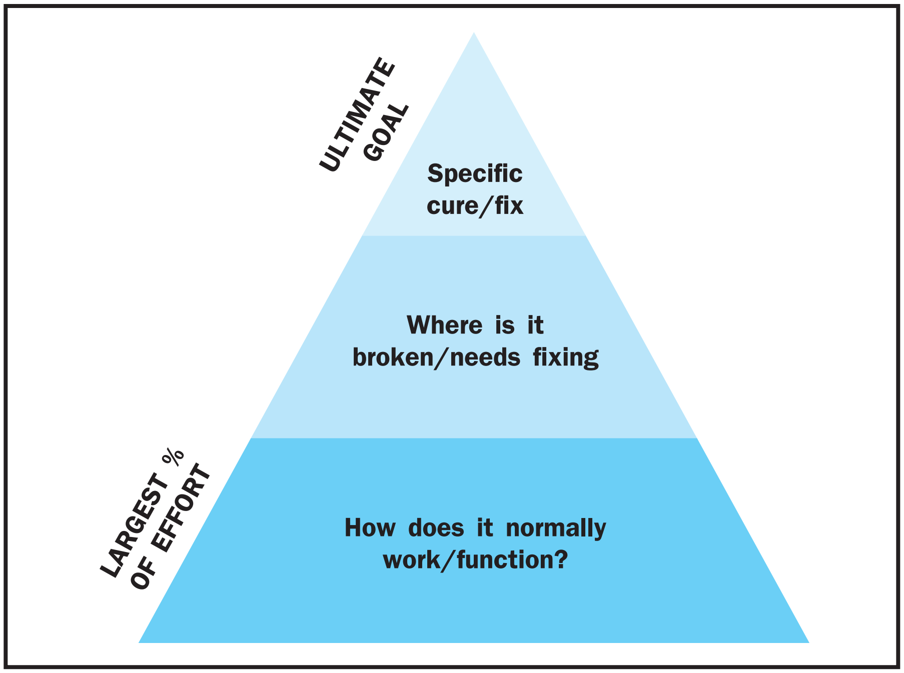
Because scientists understand so little about how the human body works in normal gravity on Earth, few specific cures have been found for medical conditions. Doctors often can only treat symptoms and not the causes of diseases. For instance, allergy medication eliminates the symptoms of the **malady**, but when a patient stops taking the medicine, the symptoms may return. A heart may no longer be able to beat properly, but a device such as a pacemaker can assist in doing the job. In neither of these cases has the underlying disease been either treated or cured. If the main objective is to find a cure for a problem, how can this be done if what needs to be fixed is unknown? And how does one know what to fix if it is not known how the body normally works?

Scientists must therefore conduct experiments on Earth and in space to: (1) understand how the body normally functions in these two environments, (2) determine how diseases and other medical conditions develop, and (3) either find a specific cure or prevent the disease (see accompanying figure). Perhaps scientists will also discover that, in some instances, the adaptations the human body makes in space are not all necessarily bad or in need of medical attention.

Lessons from Experience

During the late 1950s to early 1960s, in the early years of spaceflight exploration, it was impossible to anticipate every change in bodily function that would occur to those venturing into space. It was unclear if even simple tasks such as swallowing would become a health hazard for the astronauts (i.e., is gravity needed to "pull down" food and water into the stomach?). The answers to this and other questions were found by successfully sending animals and then Russian cosmonauts and U.S. astronauts into short spaceflights.

By the early twenty-first century, scientists had gained a better understanding about how day-to-day, bodily activities are affected by micrograv-



The distribution of current efforts by researchers to solve medical problems on Earth and in space.

ity. Though some negative side effects are indeed experienced (e.g., difficulty with eyesight focus, loss of balance, nausea), astronauts have by and large returned to live healthy lives on Earth.

Longer flights and numerous experiments later, scientists have a better idea of what may pose as a medical threat during long-term exposure to microgravity. These issues must be resolved to enable extended stays on the International Space Station (ISS) and flights to land humans on other planets such as Mars. The problems include a loss and reorganization of bone mass as well as loss of muscle strength and mass. If muscles are heavily used on Earth (such as with weight lifters), they become stronger and larger. Under the weightless conditions of space, the muscles no longer work as hard and become smaller (a condition known as atrophy). In space, the blood itself becomes weightless, and the heart will eventually atrophy because it has to work less to pump blood through the body. After a long trip in space, a sudden return to Earth might make an astronaut appear to have heart failure. Similarly, if bone does not sense the need to support the body against the effects of gravity, then spaceflight-induced bone loss might lead to osteoporosis-like problems upon a return to Earth.

Future Trends

To prevent microgravity-associated health problems and to ensure a safe return to normal bodily function, more studies are needed. Among the key areas for current and future research are diet, exercise, genetics, and whether or not hormones can produce their normal effects, both during and after spaceflight. Scientists and physicians trained to deal with these issues are needed both on the ground (e.g., in preparation for spaceflight) and as part of the flight team. Furthermore, understanding how the body changes in space will aid in the development of cures here on Earth, in addition to helping maintain the medical health of space travelers. For example, once it is known how bone is altered in space, would the discovery of a treatment also be useful to prevent or reverse osteoporosis?

The collective efforts of many biomedical-related fields are needed to fully understand and develop ways of coping with the effects of microgravity on the human body. The body is an integrated system in which different cells, tissues, and organs affect or interact with one another. When one system is altered, there are usually consequences to another system. Simply getting out of bed in the morning leads to many integrated changes—blood flows and pools in the legs, the blood vessels counteract this by contracting to "push" the blood upward, heart rate increases, and various hormones are released to prepare for the day's activities. Because of the integrative nature of human bodily functions, there are many career opportunities for basic research in such disciplines as pharmacology, biochemistry, biology, chemistry, physiology, and genetics. Physicians and other health-care professionals can then apply newly discovered biomedical information to ensure the continued improvement of human health on Earth and in space. SEE ALSO AGING STUDIES (VOLUME 1); AIDS RESEARCH (VOLUME 1); CANCER RESEARCH (VOLUME 1); MEDICINE (VOLUME 3).

Michael Babich

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Careers in Writing, Photography, and Filmmaking

The ability to communicate with others is necessary in all avenues of life, but in space science and technology it is critical to the successful furtherance of spaceflight objectives because of the lesser importance that most individuals assign to the endeavor. Indeed, a central feature of communication efforts throughout the space age has been the coupling of the reality of spaceflight with the American imagination for exploring the region beyond Earth. Without it, humans might never have slipped the bonds of Earth, ventured to the Moon, and sent robots to the planets. In the process, the dreams of science fiction afficionados have been combined with developments in technology to create the reality of a spacefaring people.

An especially significant spaceflight "imagination" came to the fore after World War II (1939–1945) and urged the implementation of an aggressive spaceflight program. It was seen in science fiction books and film, but more important, serious scientists, engineers, and public intellectuals fostered it. The popular culture became imbued with the romance of spaceflight, and the practical developments in technology reinforced these perceptions that for the first time in human history space travel might actually be possible.

Gene Roddenberry wrote scripts for television series such as *Dragnet* before creating *Star Trek.* His series would lead to movies featuring the Borg and its queen, shown here with the starship Enterprise's captain, Jean-Luc Picard.

There are many ways in which the American public may have become aware that flight into space was both real and should be developed. The communication of space exploration possibilities through the written, photographic, and electronic media began very early in the history of the space age. Since the 1940s science writers such as Arthur C. Clarke and Willy Ley had been seeking to bring the possibilities of spaceflight to a larger audience. They had some success, but it was not until the early 1950s that spaceflight really burst into the public consciousness.

Wernher von Braun's Role in Promoting Spaceflight

In the early 1950s the German émigré scientist Wernher von Braun, working for the army at Huntsville, Alabama, was a superbly effective promoter of spaceflight to the public. Through articles in a major weekly magazine, *Collier's*, von Braun urged support for an aggressive space program. The *Collier's* series, written in 1952, catapulted von Braun into the public spotlight as none of his previous activities had done. The magazine was one of the four highest-circulation periodicals in the United States during the early 1950s, with over 3 million copies produced each week. If the readership extended to four or five people per copy, as the magazine claimed, something on the order of 15 million people were exposed to these spaceflight ideas.

Von Braun next appeared on a variety of television programs, including a set of three highly rated Disney television specials between 1955 and 1957. These reached an estimated audience of 42 million each and immeasurably added to the public awareness of spaceflight as a possibility. As a result, von Braun became *the* public intellectual advocating space exploration, an individual recognized by all as an expert in the field and called upon to explain the significance of the effort to the general population.

The coming together of public perceptions of spaceflight as a near-term reality with rapidly developing technologies resulted in an environment more conducive to the establishment of an aggressive space program. Convincing the American public that spaceflight was possible was one of the most critical components of the space policy debate of the 1950s and 1960s. For realizable public policy to emerge in a democracy, people must both recognize the issue in real terms and develop confidence in the attainability of the goal. Without this, the creation of the National Aeronautics and Space Administration (NASA) and the aggressive piloted programs of the 1960s could never have taken place.

2001: A Space Odyssey

The powerful spaceflight concepts championed by von Braun found visual expression in a wide-screen Technicolor feature film released in 1968, *2001: A Space Odyssey.* Director Stanley Kubrick brought to millions a stunning science fiction story by Arthur C. Clarke about an artificially made monolith found on the Moon and a strange set of happenings at Jupiter. With exceptional attention to science fact, this film drew the contours of a future in which spaceflight was assisted by a wheel-like space station in orbit, a winged launch vehicle that traveled between Earth and the station, a Moon base, and aggressive exploration to the other planets. All of this was predicted to be accomplished by 2001, and the director and the technical advisors were concerned that their vision might be outdated within a few years by the reality of space exploration. It was not, and their vision still is far from becoming reality.

The Impact of Photography

The photographic record of spaceflight has also served to sustain interest in the endeavor. For example, the photographs taken of Earth from space sparked a powerful reaction among those who viewed them for the first time. Project Apollo forced the people of the world to view planet Earth in a new way. In December 1968 Apollo 8 became critical to this sea change, for the image taken by the crew, "Earthrise," showed a tiny, lovely, and fragile "blue marble" hanging in the blackness of space with the gray and desolate lunar surface in the foreground as a stark contrast to a world teeming with life.✶ Poet Archibald MacLeish summed up the feelings of many people when he wrote, "To see the Earth as it truly is, small and blue and beautiful in that eternal silence where it floats, is to see ourselves as riders on the Earth together, brothers on that bright loveliness in the eternal cold—brothers who know now that they are truly brothers." (MacLeish, December 25, 1968) The modern environmental movement was galvanized in part by this new perception of the planet and the need to protect it and the life that it supports.

✶The Apollo image "Earthrise" can be seen in the Volume 4 article "Earth—Why Leave?".

Carl Sagan as Public Intellectual

Astronomer Carl Sagan emerged as a public intellectual on behalf of space exploration in the 1970s in much the same way that von Braun had in the 1950s. An academic on the faculty at Cornell University, Sagan eschewed the scholarly trappings of the "ivory tower" to engage the broadest possible audience directly through writing, speaking, and television appearances. His brilliant thirteen-part *Cosmos* series on public television in 1980, like the *Collier's* series of von Braun, captured the imagination of a generation of Americans about the wonders of the universe and energized the public debate concerning space exploration in the 1980s. In part, the increases in federal budgets for space activities could be related to the excitement generated by Sagan's compelling arguments.

Sagan went on to fill von Braun's shoes as a public intellectual with verve until his death in 1996. He wrote best-selling nonfiction, such as *Cosmos* (1980) and *Pale Blue Dot: A Vision of the Human Future in Space* (1994), and a novel, *Contact* (1985). Always he drew a tight relationship among technical capabilities, philosophical questions, and human excitement and destiny. He rarely wrote for academic audiences, as was normal for other scholars, and published more articles in *Parade* magazine, reaching millions of readers, than in professional journals. He also took on the proponents of **pseudoscience**, especially efforts to convince individuals of extraterrestrial visitations to Earth, publishing a major work on the subject, *The Demon-Haunted World* (1995), near the end of his life. Sagan appeared on popular talk shows such as "The Tonight Show" with Johnny Carson and Jay Leno to espouse his vision of a hopeful future in space. His belief in a universe filled with life, and humanity's place in that universe, came to the big screen in 1997 with the making of *Contact* into a feature film starring Academy Award winner Jodie Foster.

pseudoscience a system of theories that assumes the form of science but fails to give reproducible results under conditions of controlled experiments

Opportunities in the Field

Opportunities to expound a compelling vision of a future in space exist in all arenas available for communication. Using written, photographic, and multimedia forms of communication, future writers and visual artists have the opportunity to become public intellectuals whose ideas expressed in these forms will shape the future of spacefaring in the United States. Indeed, it is largely up to such individuals to frame the debate on the future of spaceflight. Will the astronauts and their voyages to the Moon be remembered as being akin to Italian explorer Christopher Columbus and his voyages to the Americas—as vanguards of sustained human exploration and settlement? Or will their endeavors prove to be more like Leif Eriksson's voyages from Scandinavia several hundred years earlier, stillborn in the European process of exploration to new lands? No one knows yet, but the public intellectuals of the future using all of the tools of communication available to them will be the ones to prompt both the policymakers and the public to make decisions about sustained exploration. SEE ALSO CLARKE, ARTHUR C. (VOLUME 1); ENTERTAINMENT (VOLUME 1); LITERATURE (VOLUME 1); LUCAS, GEORGE (VOLUME 1); MOVIES (VOLUME 4); RODDENBERRY, GENE (VOLUME 1); SAGAN, CARL (VOLUME 2); SCIENCE FICTION (VOLUME 4); *STAR TREK* (VOLUME 4); *STAR WARS* (VOLUME 4); VON BRAUN, WERNHER (VOLUME 3).

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Clarke, Arthur C.

British Science Fiction Writer
1917–

Born at Minehead, Somerset, United Kingdom, on December 17, 1917, Arthur C. Clarke was fascinated by science fiction and astronomy at an early age. In the 1930s he joined the British Interplanetary Society. After enlisting in the Royal Air Force in 1941, he became a **radar** instructor and participated in the development of ground-controlled landings of aircraft under zero-visibility conditions.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

equatorial orbit an Earth orbit parallel to Earth's geographic equator

angular velocity the rotational speed of an object, usually measured in radians per second

In 1945 the technical journal *Wireless World* published Clarke's article "Extra-Terrestrial Relays," which proposed the use of three broadcast satellites in **equatorial orbit** to provide worldwide communication. Clarke chose an orbital altitude of 35,786 kilometers (22,300 miles) because at that distance the **angular velocity** of Earth's rotation would match that of the satellite. As a result, the satellite would remained fixed in the sky. Twenty years later, Early Bird was launched, the first of the commercial satellites that provide global communications networks for telephone, television, and high-speed digital communication, including the Internet.

After World War II, Clarke obtained a bachelor of science degree in physics and mathematics at King's College, London. In 1954 he became enchanted by underwater scuba diving, which simulated weightlessness in spaceflight. In 1969 Clarke moved to Sri Lanka.

Clarke has written eighty books on science and technology, along with their sociological consequences.✶ He collaborated with the director Stanley Kubrick on the film *2001: A Space Odyssey* (1968), which was based on his short story "The Sentinel." Clarke has received many honors and awards, including knighthood, the Franklin Institute Gold Medal, the UNESCO-Kalinga Prize, honorary fellow memberships and awards from major scientific and astronautical organizations, and a nomination for the Nobel Peace Prize in 1994.

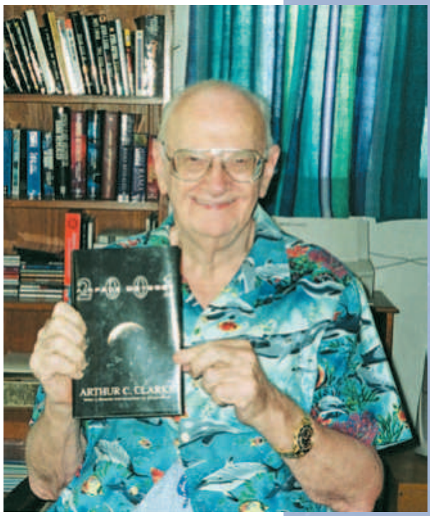
✶Clarke once said that his chief aim was an old science fiction cliché: "The search for wonder."

Among Clarke's works are the following books:

Nonfiction

- *Ascent to Orbit, a Scientific Autobiography: The Technical Writings of Arthur C. Clarke.* New York: John Wiley & Sons, 1984.
- *Astounding Days: A Science Fictional Autobiography.* New York: Bantam, 1989.
- *The Exploration of Space.* New York: Harper, 1951.

- *Greetings, Carbon-Based Bipeds!: Collected Essays, 1934–1998.* New York: St. Martin's Press, 1999.
- *How the World Was One: Beyond the Global Village.* New York: Bantam, 1992.
- *The Making of a Moon: The Story of the Earth Satellite Program.* New York: Harper, 1957.
- *Profiles of the Future: An Inquiry into the Limits of the Possible.* New York: Harper, 1962.
- *The Promise of Space.* New York: Harper, 1968.
- *Voices from the Sky: Previews of the Coming Space Age.* New York: Harper, 1965.



Arthur Clarke's published article "Extra-Terrestrial Relays" formed the basis for current global communications systems.

Fiction

- *Childhood's End.* New York: Ballantine, 1953.
- *The Fountains of Paradise.* New York: Harcourt, 1979.
- *The Hammer of God.* New York: Bantam, 1993.
- *Islands in the Sky.* Philadelphia: Winston, 1952.
- *Rendezvous with Rama.* New York: Harcourt, 1973.
- *The Sands of Mars.* London: Sidgwick & Jackson, 1951.
- *2001: A Space Odyssey.* New York: New American Library, 1968.
- *2010: Odyssey Two.* New York: Ballantine, 1982.
- *2061: Odyssey Three.* New York: Ballantine, 1988.
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SEE ALSO CAREERS IN WRITING, PHOTOGRAPHY, AND FILMMAKING (VOLUME 1); COMMUNICATIONS SATELLITE INDUSTRY (VOLUME 1); ENTERTAINMENT (VOLUME 1); SCIENCE FICTION (VOLUME 4).

Frederick C. Durant III

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Commercialization

"Space commercialization" is a general term that distinguishes private activities from those of the government in enabling the use of space from either an Earth-based operation or from space itself. Private-sector use of space involves activities that are expected to return a profit to investors, such as building, launching, and operating communications satellites or taking pictures of Earth from space to monitor crops.

In contrast to the private sector, government activities are performed to carry out specific missions for the public good. Examples range from national defense activities to scientific missions studying the planets, and also include satellites that monitor Earth's environment.

Because space research, development, and exploration are very expensive and risky, governments have funded most activities. During the 1990s, private companies began to expand beyond the already profitable communications satellite services, and develop the use of the space environment for the introduction of new products. The U.S. government requires a license for a U.S. firm to launch spacecraft and do business in space. Often when there is an overlap between a government mission and a private activity, will the government partner with a private company.

"Commercialization of space" is frequently confused with "privatization of space." Sometimes commercialization of space is used by the government to mean that a function previously performed by the government has been shifted to a private company, often with the government as a paying customer. "Privatization of space" involves the government reallocating authority, responsibility, and the risk of operations using government-owned assets and ultimately transferring asset ownership itself to the private sector. Because privatization is a process, there are many intermediate steps possible between total government management, control, and asset ownership and full privatization. And, because this process involves firms that are providing services for a profit, privatization and commercialization sometimes are used as synonyms even when they are not precisely the same.

Examples of Space Commercialization

The largest commercial use of space is by satellite communications and associated services. Long-distance communications are dependent on two major transmission modes: satellites and **fiber-optic cables**. Satellites are the cheapest and best providers of point to multipoint communications while fiber-optic cables provide efficient high-capacity point-to-point services. In 2000, estimated revenues from satellite communications operations, including direct-broadcast TV services, were greater than $25 billion annually. Commercial revenues are expected to grow very fast as new broadband satellites are developed that will be able to transmit Internet and other services. Global Positioning System (GPS) satellites that broadcast detailed location coordinates to handheld units, as well as to airplanes, ships, and automobiles, have provided many terrestrial commercial opportunities and this area is likely to grow very rapidly. (The GPS satellite system itself is government-owned and operated.)

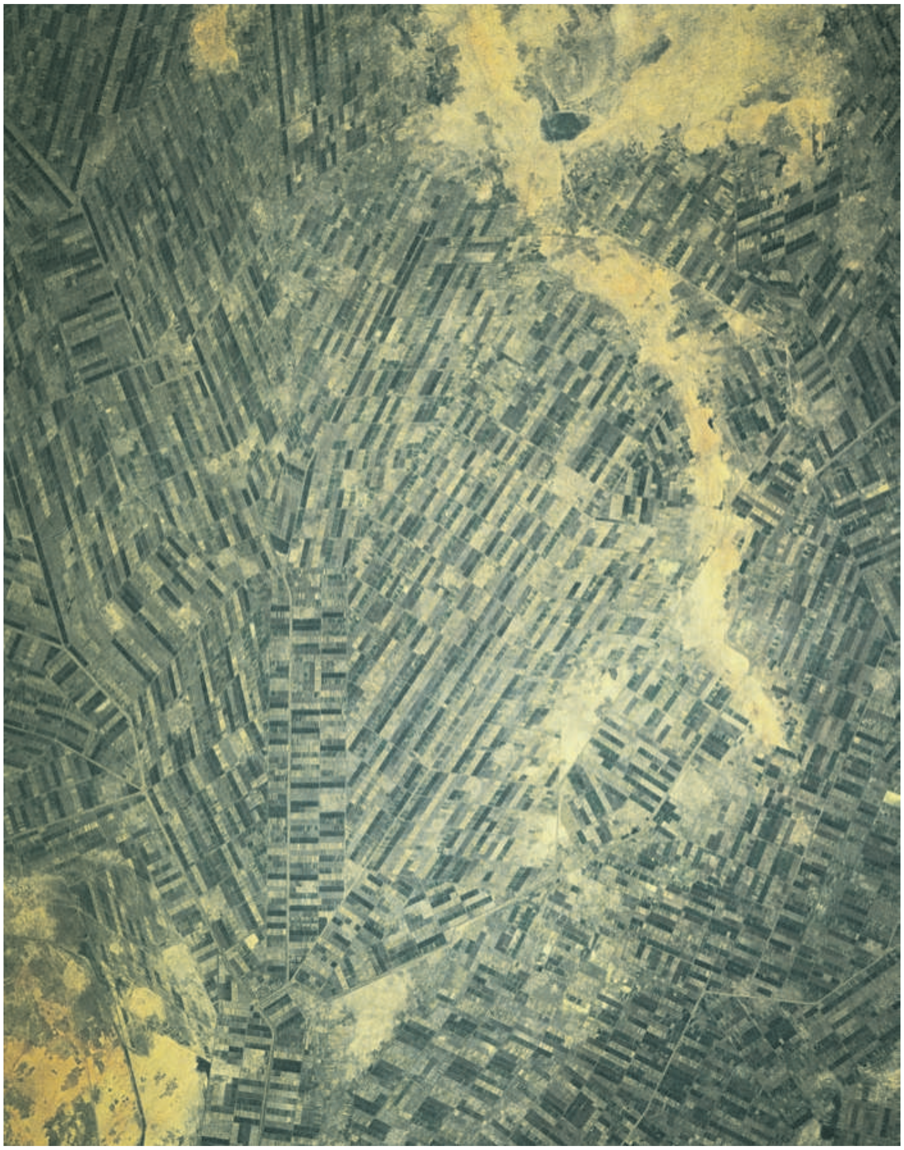
fiber-optic cable a thin strand of ultrapure glass that carries information in the form of light, with the light turned on and off rapidly to represent the information sent

Other uses of space for commercial purposes generate relatively small revenues but hold growth potential. Remote sensing (taking digital pictures of Earth from satellites) is used to monitor Earth and for mapping and discovering new sources of natural resources.

Launch vehicles that boost **payloads** into space also provide business opportunities for firms. Since the late 1980s, **expendable launch vehicles** (ELVs) have been privately manufactured and operated in the United States. Of course, the need for launch vehicles is determined by the need to put payloads in space. Worldwide, commercial ELV companies earned more than $10 billion in revenues in 2001. Several firms are designing and developing commercial reusable launch vehicles (RLVs); eventually some will even be capable of launching people into space. However, commercial versions of a human-rated RLV are many years in the future.

payloads the cargo carried into orbit by a space vehicle, usually a scientific experiment, satellite, or space station module

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused



One area of growth potential in space commercialization is remote sensing—taking digital pictures of Earth from satellites. This orbital image is of Gezira Scheme in Sudan, Africa, one of the world's largest irrigation systems.

Finally, the International Space Station (ISS) is being built and assembled in space. The ISS is the result of an international partnership between governments, which is promoting a wide variety of commercial opportunities. Companies are being encouraged to perform research and development onboard the ISS. There are proposals to have private firms provide power and other "utilities" for the ISS. One company is building a module that would attach to the ISS. This module could be a broadcast facility, feeding news, entertainment, and educational markets with pictures and happenings from space. There will also be a market for boosting cargo and human beings to and from the ISS, perhaps creating modest business opportunities.

The Value of Technology Spinoffs from Space

When technologies developed for the space program are used for other purposes, they are termed "spinoffs." Since the beginning of the space program, the cutting-edge research and development required for the unique environment of space has generated inventions and innovations. Many of the

The Covie, a compact electric concept vehicle, comes with a Global Positioning Satellite receiver linked to electronic machines at home, allowing the driver to remotely control and monitor home appliances.

technologies have their largest applications within the aerospace industry, but many also find their way into industrial applications and retail stores.

Examples of space spinoffs fall into several categories. First are the new products and services that consumers can purchase. Beyond satellite-based voice, television, and paging communication services, there are many other spinoff products. Materials such as lightweight **carbon-fiber composites** used in tennis racquets, boats, and other products were developed for the doors of the space shuttle. Insulating fabrics and thermal protection equipment used in space suits and onboard space equipment are now available for household uses as well as for firefighters and industrial safety equipment.

carbon-fiber composites combinations of carbon fibers with other materials such as resins or ceramics; carbon fiber composites are strong and lightweight

Second, the need for precision instruments to remotely monitor astronauts' health and to conduct other space activities has generated a vast new array of scientific and medical applications that permit better research and more accurate and less invasive medical procedures.

Many less obvious procedures and equipment developed for space have resulted in manufacturing improvements. For example, advanced clean room procedures needed for assembling satellites have been used to manufacture high-technology electronics. Research into new lubrication techniques has made industrial equipment last longer. Cheaper and more efficient water purification devices aid people in remote areas.

It is difficult to precisely measure the economic impact of space spinoffs. However, various studies clearly illustrate that the income and jobs created from these space technologies have contributed greatly to the long-run productivity of the economy and to improving the quality of everyday life. SEE ALSO International Space Station (volumes 1 and 3); Made with Space Technology (volume 1); Space Shuttle, Private Operations (volume 1).

Henry R. Hertzfeld

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Communications Satellite Industry

The beginning of the satellite communications era began with the publication of a paper written by Arthur C. Clarke in 1945. The paper described human-tended space stations designed to facilitate communications links for points on Earth. The key to this concept was the placement of space stations in **geosynchronous Earth orbit** (GEO), a location 35,786 kilometers (22,300 miles) above Earth. Objects in this orbit will revolve about Earth along its equatorial plane at the same rate as the planet rotates. Thus, a satellite or space station in GEO will seem fixed in the sky and will be directly above an observer at the equator. A communications satellite in GEO can "see" about one-third of Earth's surface, so to make global communications possible, three satellites need to be placed in this unique orbit.

geosynchronous Earth orbit orbit of a satellite that revolves around the Earth without changing its position in the sky relative to the planet

Clarke envisioned a space station, rather than a satellite, as a communications outpost because he felt that astronauts would be needed to change vacuum tubes for the receivers and transmitters. However, the concept became extraordinarily complex and expensive when life support, food, and living quarters were factored in. For this reason, and because telephone and television services were perceived as adequate, Clarke's idea was not given much attention. In 1948 the vacuum tube was replaced by longer-lived solid-state transistors, marking the dawn of microelectronics. Humans, it seemed, might not be required to tend space-based communications systems after all. Nonetheless, questions remained: Would there be a demand for communications satellites, and, if so, how would they be placed in orbit?

During the mid-twentieth century, people were generally satisfied with telephone and television service, both of which were transmitted by way of cable and radio towers. However, telephone service overseas was exceptionally bad, and live television could not be received or transmitted over great distances. Properly positioned satellites could provide unobstructed communications for nearly all points on Earth as long as there was a method to put them in orbit.

Shortly after World War II, the United States acquired the expertise of German rocket engineers through a secret mission called Operation Paperclip. The German rocket program, which produced the world's first true

A Juno I rocket is launched from Cape Canaveral, Florida, carrying Explorer I, the first American artificial satellite, into orbit in 1958.

✶ In 1944 and 1945, the Nazis launched V-2 ballistic missiles toward England, but the assault came too late to turn the war in Germany's favor.

rocket, the V-2,✶ was highly valuable to the United States. These engineers were sent to New Mexico to work for the army using hundreds of acquired V-2 missiles. Within a decade, the German engineers produced powerful missiles called Jupiter, Juno, and Redstone. At the same time, the U.S Air Force was interested in fielding intercontinental ballistic missiles (ICBMs) and was separately developing the Atlas, Thor, and Titan rockets to meet this mission. The navy also had a rocket program and was working on a medium-range missile called Vanguard.

On October 4, 1957, the Soviet Union launched Sputnik I, a satellite whose purpose was to demonstrate Soviet technology. Americans were alarmed and demanded that the government establish a space program to regain prestige. President Dwight Eisenhower, they felt, did not do enough to prevent the United States from lagging behind the Soviets technologically. In truth, Eisenhower had directed the navy to launch a satellite on Vanguard, but the rocket was encountering setbacks. The mission to launch the first American satellite fell to the army, whose Juno instrument was doing remarkably well. The satellite Explorer 1 finally went up on January 31, 1958. Launching satellites was possible, and communications satellite concepts were now seriously being considered.

The First Communications Satellites

On December 18, 1958, the military's Satellite Communications Repeater (SCORE) was launched into **low Earth orbit** (LEO) by a U.S. Air Force Atlas. SCORE was designed to receive a transmission, record it on tape, and then relay the transmission to another point on Earth within hours. President Eisenhower used the opportunity to demonstrate American technology by transmitting a recorded Christmas greeting to the world, the first time in history a satellite was used for communications.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Recognizing the potential of satellite communications, John Pierce, director of AT&T's Bell Telephone Laboratories, developed projects designed to test various communications satellite concepts. The National Aeronautics and Space Administration (NASA), only two years old, planned to send an inflatable sphere into space for scientific research. Pierce wanted to use the opportunity to reflect signals off the balloon's metallic surface. On August 12, 1960, the sphere, called Echo 1, was successfully launched, and Pierce was encouraged by the reflective signal tests. Because Echo 1 had no electronic hardware, the satellite was described as passive. For communications to be effective, Pierce felt that active satellites were required.

Meanwhile, the military was continuing with the tape-recorded communications concept, developing new satellites called Courier. The first one was destroyed when the rocket exploded. Courier 2 was successfully launched on October 4, 1960, but failed after seventeen days of operation. During this time, significant military resources were being allocated to Atlas, Titan, and intelligence satellites, which took priority.

Two years after the Echo 1 experiments, Bell Laboratories created Telstar, an active communications satellite designed to operate in medium Earth orbit (MEO), about 5,000 kilometers (3,107 miles) above Earth's surface. During this time, NASA selected a satellite design from RCA called Relay to test MEO communications but agreed to launch Telstar as soon as it was ready. Telstar 1 was launched on July 10, 1962, and Relay 1 was sent up on December 13 of the same year. Both were successful, and despite Relay 1's greater sophistication, people remembered Telstar's live television broadcasts from the United States to locations in Europe.

Advantages and Disadvantages. Soon the advantages and disadvantages regarding LEO and MEO communications satellites were being studied. One problem with communications satellites in orbits lower than geosynchronous is the number of satellites required to sustain uninterrupted transmissions. Whereas a single GEO satellite can cover 34 percent of Earth's surface, individual LEO and MEO satellites cover only between 2 and 20 percent. This means that a fleet of satellites, called a "constellation," is required for a communications network.

The major advantage in using LEO and MEO communications satellites is a minimization of latency, or the time delay between a transmitted signal and a response, often called the "echo effect." Even though transmissions travel at the speed of light, a time delay of 0.24 seconds for a round-trip signal through a GEO satellite can make phone calls problematic. Despite this drawback, sending three communications satellites to GEO would save money, and people would not need to wait years for an LEO or MEO constellation to be complete.

Comsat

✶On April 12, 1961, Soviet cosmonaut Yuri Gagarin became the first human in space, making a one-orbit, ninety-minute flight around Earth.

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

Shortly after the Soviet Union launched the first human into space,✶ President John Kennedy wanted a national plan for space exploration and settled on a series of programs that included the famous **Apollo** missions to the Moon. Less familiar but perhaps more significant for the long term, Congress, with the support of President Kennedy, authorized the establishment of an organization designed to integrate the nation's space-based communications network.

Formed in February 1963 by the Communications Satellite Act of 1962, the Communications Satellite Corporation, or Comsat, was given the task of creating a national communications satellite system in the earliest possible time. Half of Comsat would be publicly traded, and the other half would be purchased by satellite manufacturers. Comsat's first major hurdle was deciding what kind of satellite system it would pursue: LEO, MEO, or GEO. Because Telstar and Relay were successful, these MEO systems seemed the default choice. For uninterrupted communications service, however, about twenty satellites such as Telstar or Relay were needed, costing an estimated $200 million. The president of Comsat, Joseph Charyk, a veteran of satellite engineering programs, was not sure that this was the right way to proceed.

Meanwhile, Hughes Aircraft Company was developing the Syncom series of satellites, each designed to test communications technologies in GEO. The first two satellites were not entirely successful, but Syncom 3, launched on August 19, 1964, achieved a stationary GEO. Charyk was aware of the Syncom project early on and followed its progress closely. Comsat was beginning to realize that a GEO communications satellite network was the

President Kennedy speaks at Rice University, Texas, on September 12, 1962 on the space effort: "We choose to go to the moon. We choose to go to the moon in this decade and do other things, not because they are easy, but because they are hard. . ."

most practical in terms of cost. Nevertheless, Comsat asked a variety of companies to study the feasibility of LEO communications constellations in the event that a GEO system was unsuccessful. AT&T and RCA researched the merits of a random system, in which satellites drifted freely without any particular relationship to one another. STL and ITT studied the phased approach, where strings of satellites orbiting at LEO were spaced in such a way to allow for continuous, uninterrupted communications. Comsat finally decided on a GEO system, and on April 6, 1965, it launched Early Bird. This satellite also became a test bed for the latency problem, and methods to suppress the echo effect were successfully employed.

Bandwidth Capacity

During this time, NASA continued to fund research in communications satellite technology, contributing to programs such as Applications Technology Satellites (ATS). Six ATS units were developed and launched, and each was designed to test various technologies related to bandwidth capacity and new components. Of particular importance was bandwidth capacity, the range of **frequencies** used in a satellite.

Satellite communications providers were particularly interested in boosting the capacity of transponders used for telephone conversations and television broadcasts. A telephone call, for example, uses about 5 kilohertz of bandwidth. A satellite with 50 kilohertz of bandwidth can handle ten calls simultaneously. Early satellites could only handle about thirty calls at one time and were easily overwhelmed. Research continued to improve the capacity problems, and digital technologies have significantly increased the number of simultaneous calls. Satellite engineers also designed antennas that did not interfere with systems orbiting nearby and recommended adequate separation between satellites to prevent signals from interfering.

Becoming Global

After the establishment of Comsat, efforts were under way to approach the international community about setting up a global communications satellite network. Comsat dispatched several key people, along with U.S. State Department officials, to a dozen nations interested in the communications satellite market. In 1964, Intelsat was formed, and it started operations using part of the new Early Bird satellite launched in 1965. Comprised originally of twelve members, Intelsat is an organization that owns and operates global communications networks providing voice, video, and data services. Intelsat collects investment capital from its members and makes a profit from the sale or lease of satellite services. In 2000, Intelsat had 143 member countries and signatories, with Comsat still representing the United States.

Other international communications satellite organizations have since formed, such as Eutelsat, a cooperative formed in 1977 providing regional communications services for Europe. France, England, and Germany established the European Space Research Organization (ESRO) and the European Launch Development Organization (ELDO) shortly after the launch of an experimental communications satellite called Symphonie in 1967. ESRO was responsible for research, development, construction, and operation of **payloads** and ELDO handled launch activities. Because of management and

WHAT IS BANDWIDTH?

Bandwidth capacity refers to the range of frequencies. All frequencies are classified according to the electromagnetic spectrum and are measured in hertz (Hz). At one end, where frequencies are low, the spectrum includes radio and microwaves. In the middle, the spectrum is characterized by infrared radiation (IR), visible light, and ultraviolet (UV) radiation. High-frequency energy, such as X rays, gamma rays, and cosmic rays, occupies the other end of the spectrum. Within the radio spectrum, which is divided into eight segments ranging from extremely high frequency (EHF) to very low frequency (VLF), lies the communications spectrum.

This spectrum, which is important to communications satellites, is divided into ten parts. These are—from the highest frequency to the lowest—millimeter (in the EHF range), W, V, Ka, K, Ku, X, C, S, and L (in the ultra-high-frequency, or UHF, range). A typical communications satellite in orbit today will have a series of bandwidth-specific transmitter-receiver units, called transponders, classified as C-band or Ku-band.

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

elliptical having an oval shape

system integration concerns, ESRO and ELDO merged to form the European Space Agency in 1974. Three years later, the Conference of European Posts and Telecommunications (CEPT) approved the formation of Eutelsat, which by 2000 had nearly fifty members.

Comsat was also asked to assist in the development of a regional communications satellite organization for southwestern Asia, northern Africa, and areas of southern Asia. Comsat agreed and was contracted to develop and build what later became known as Arabsat. Inmarsat, founded in 1982, is another international organization providing global communications services to seagoing vessels and oil platforms.

The Soviet Union, recognizing the benefits of a global communications satellite network, was not interested in a GEO system because of the country's northern location. A GEO system comprised of three satellites would miss parts of the Soviet Union. The Soviets developed an ingenious solution by launching communications satellites into highly **elliptical** orbits. The orbit consisted of a very close and fast approach over the Southern Hemisphere while tracing a slow and lengthy arc over the Soviet mainland. In 1965 the Soviet Union launched its first communications satellite as part of an ongoing system called Molniya, a name also assigned to the unusual orbit it occupies.

The Soviet Union, despite being approached by representatives of Comsat and the State Department to join Intelsat, declined membership and initiated a regional network in 1971 called Intersputnik. Intersputnik was successful during the following decades with its Gorizont, Express, and Gals satellites but experienced funding difficulties after the collapse of the Soviet Union in 1991. In the 1990s, however, Intersputnik was revitalized with a membership of twenty-three nations and the recent introduction of a new series of satellites, the Express-A.

Back to LEO?

In the early 1990s, LEO communications satellite constellations were revisited. Microelectronics was allowing for smaller satellites with greater capacities, and the launch industry was stronger than it was thirty years earlier. Two companies that pursued this concept were Iridium and Teledesic.

Iridium's plan was to loft about 100 satellites into several LEOs to provide uninterrupted cell phone and pager services anywhere on Earth. Iridium became the first company to provide these services on November 1, 1998. Sixty-six Iridium satellites, all built by Motorola, were launched in the late 1990s. Unfortunately, Iridium filed for bankruptcy in 1999. ✶

✶ In 2000 Iridium Satellite LLC purchased the Iridium satellite system and began selling satellite phone service at much lower prices than its predecessor, Iridium.

Despite the anticipated effect of Iridium's 1999 bankruptcy on the market, Teledesic, a company planning to provide computer networking, wireless Internet access, interactive media, and voice and video services, will use LEO satellites developed and built by Motorola. Founded by Craig McCaw and Microsoft founder Bill Gates with $9 billion in 1990, Teledesic also experienced financial troubles but by 2000 was prepared to tap into part of the market originally pursued by Iridium. With Lockheed Martin contracted to provide launch services for all 288 satellites plus spares, Teledesic plans to be operational in 2005.

By 1998 satellite communications services included telephone, television, radio, and data processing, and totaled about $65.9 billion in revenues, or almost 7 percent of the total telecommunications industry. During that year, about 215 communications satellites were in GEO and 187 in LEO. SEE ALSO CLARKE, ARTHUR C. (VOLUME 1); COMMUNICATIONS, FUTURE NEEDS IN (VOLUME 4); GROUND INFRASTRUCTURE (VOLUME 1); SATELLITE INDUSTRY (VOLUME 1).

Phil Smith

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A refugee from Kosovo uses an Iridium satellite phone to contact loved ones while in a refugee camp outside of Tetovo, Macedonia. The satellite communications company donated phones for the refugees' use.

Crippen, Robert

American Astronaut
1937–

Robert Crippen has been a major contributor to America's space exploration efforts. From making the first historic flight of the space shuttle, to directing the Kennedy Space Center, to exploring opportunities in the private sector, Crippen has provided experience and leadership for both piloted and unpiloted spaceflight.

Crippen was born in Beaumont, Texas, on September 11, 1937. He graduated from New Caney High School in Caney, Texas, and received a bachelor of science degree in aerospace engineering from the University of Texas in 1960.

Crippen received his commission through the U.S. Navy's Aviation Officer Program at Pensacola, Florida. He continued his flight training at Whiting Field, Florida, and went from there to Chase Field in Beeville, Texas, where he received his "wings," becoming a qualified pilot. From June 1962 to November 1964, he was assigned to Fleet Squadron VA-72, where he completed two and a half years of duty as an attack pilot aboard the aircraft carrier USS Independence. He later attended the U.S. Air Force (USAF) Aerospace Research Pilot School at Edwards Air Force Base, California, and remained there as an instructor after his graduation. In October 1966,

Robert Crippen on April 29, 1979, in a photo taken prior to his first spaceflight in 1981.

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

Crippen was among the second group of aerospace research pilots to be selected to the USAF Manned Orbiting Laboratory Program.

Crippen joined the National Aeronautics and Space Administration (NASA) as an astronaut in September 1969 following the cancellation of the Manned Orbiting Laboratory program. He was a crewmember of the Skylab Medical Experiments Altitude Test, a fifty-six-day simulation of the Skylab mission. He was also a member of the astronaut support crew for the Skylab 2, 3, and 4 missions and the Apollo-Soyuz Test Project mission. Crippen's first spaceflight was in 1981, as pilot of STS-1, the first space shuttle mission. In 1983 Crippen was spacecraft commander of STS-7. He completed two more space shuttle flights as commander in 1984.

In 1987 Crippen was stationed at NASA's John F. Kennedy Space Center (KSC) serving as the deputy director of shuttle operations for NASA Headquarters. He was responsible for final shuttle preparation, mission execution, and the return of the **orbiter** to KSC following landings at Edwards Air Force Base. From 1990 to 1992, he was responsible for the overall shuttle program at NASA Headquarters in Washington, D.C. From 1992 to 1995, during his tenure as director of KSC, Crippen presided over the launch and recovery of twenty-two space shuttle missions, establishing and developing new quality management techniques while ensuring the highest safety standards in an extremely hazardous environment.

Crippen left NASA in 1995 and joined the Lockheed Martin Information Systems Company as their vice president of automation systems. The following year he became their vice president of simulation and training systems. In October of that year he was named to the newly created position of president of the Thiokol Aerospace Group.

Crippen's accomplishments have earned him many awards. Among them are the NASA Exceptional Service Medal, the Department of Defense Distinguished Service Award, the American Astronautical Society of Flight Achievement Award, and four NASA Space Flight Medals. SEE ALSO History of Humans in Space (volume 3); Skylab (volume 3); Space Shuttle (volume 3).

Vickie Elaine Caffey

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"Robert Hutchings Goddard." *National Inventors Hall of Fame.* <http://www.invent.org/book/book-text/46.html>.

D

Data Purchase

Congressional funding for space science has been steady at a few billion dollars per year, so there is a known, existing market. Until the early 1990s, each deep-space mission cost taxpayers about $2.5 billion. Since the National Aeronautics and Space Administration (NASA) introduced the concept of "faster, better, cheaper," the cost of deep-space missions has dropped to $250 million and less. The Near Earth Asteroid Rendezvous (NEAR) and the Lunar Prospector missions had full lifecycle costs of about $250 million and $100 million, respectively. Both had five science experiments, so the average taxpayer cost of the new knowledge per mission was about $50 million for each data set for NEAR and about $20 million each for Lunar Prospector.

Beginning in 1997, commercial space companies such as SpaceDev have offered to collect desired space science data at their own corporate risk and to sell it to NASA, which is the agency responsible for collecting scientific data in space. NASA's Lunar Prospector had instruments orbiting the Moon looking for evidence of water, and NEAR had five science experiments examining the properties of the visited asteroid. SpaceDev proposed to collect similar science data for sale to NASA at prices far below NASA's costs.

Even though commercial companies build most of the components and subsystems that make up a deep-space spacecraft, no commercial mission beyond Earth **orbit** has ever been performed. This is mainly because NASA allocates money to its own deep-space missions. NASA managers fear their budgets will be cut if missions fail, so managers are very conservative in their mission and spacecraft designs, and they try to control all mission decisions. This results in more expensive spacecraft and missions because the components are generally older, heavier, and more expensive and require more power. This equipment is specified because it has flown before, and therefore has "heritage," and managers believe they cannot be punished if they use this "proven" hardware.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Commercial companies have to make profits if they are to perform space missions. Companies wishing to fly commercial missions use modern business practices and smaller, less expensive hardware to reduce costs below NASA's. These practices cause government managers to fear increased risk from commercial missions. If companies insure their missions, however, the government should consider the taxpayer risk eliminated, and the cost savings could then be achieved. An additional problem in performing commercial deep-space missions is that some NASA employees are afraid the private sector will take over all such missions in the future, reducing the need for NASA employees.

If companies do not make a profit, they cannot raise money because investors expect to make a competitive return on their investment that is equal to or better than other investment opportunities at that time. If the two main sources of revenue are science and entertainment data, then a commercial space mission must focus on these areas. To get NASA to purchase space science data, a company must first know exactly what data are important to NASA, as determined by committees of scientists that advise NASA. Unfortunately, these committees do not publish a list of desired space science ranked by importance. This, however, is set to change with the establishment of science-driven exploration priorities starting in 2002.

NASA has no contracting mechanism set up through which it can purchase space science data, so commercial companies have to navigate a very time-consuming (i.e., years-long) process of submitting proposals when NASA is ready. NASA proposal reviewers do not approve data purchases unless they are completely convinced a mission will fly, even though there is no risk in such cases because the data do not have to be paid for until they are delivered. The Catch-22 problem with this reasoning is that it is impossible for a commercial company to raise tens of millions of dollars to fully fund a mission unless the investors are convinced the mission will sell its data at a profit. This has resulted in a stalemate, and no commercial deep-space missions have been flown, even though such endeavors could be a clear win-win situation for taxpayers, scientists, and the commercial companies. SEE ALSO NASA (VOLUME 3); PLANETARY EXPLORATION (VOLUME 1); PLANETARY EXPLORATION, FUTURE OF (VOLUME 2).

James W. Benson

Internet Resources

SpaceDev: The World's First Commercial Space Exploration and Development Company. <http://www.spacedev.com>.

E

Education

In the 1960s many young people in the United States were inspired to pursue aerospace-related careers because of the U.S. commitment to send humans to the Moon. Universities saw an influx of enthusiastic students ready to take on the challenges of the Apollo program. Six Apollo Moon landings brought twelve astronauts to explore the lunar surface. But Moonwalkers are prehistory to students in the twenty-first century. Consequently, universities today put forth the challenge of a human mission to Mars to attract students.

Rapid advances in technology and computers have influenced more students to pursue courses of study in the sciences and space-related engineering and technology programs. Many computer experts who lost their jobs in the crash of the "dot-com" industry subsequently explored the field of aerospace engineering. Even if students do not decide on a space-related career, an aerospace engineering degree provides them with a wide variety of employment choices.

What are these students looking for in a college or university? They not only want a good selection of courses in the fields of their interests, but students also want exposure to innovative research in the field. Colleges and universities are addressing these needs largely by building valuable relationships with space-related organizations, aerospace companies, government agencies like the National Aeronautics and Space Administration (NASA), and other colleges and universities. Internships are frequently beneficial experiences for students, and often lead to employment opportunities at the sponsoring facility.

How Universities Attract New Students to Space Sciences

The public affairs departments at some universities have realized the potential of promoting their students' and professors' accomplishments. A good example of this is the University of Arizona in Tucson, which sends out weekly press releases about discoveries made by faculty and student astronomers using their Kitt Peak Observatories and astronomical spacecraft.

A university whose graduates become astronauts or known in a field of space science or aerospace engineering is also a pull for students. This is

The Discovery Laboratory at NASA's Marshall Space Flight Center provides hands-on educational workshops for teachers and students.

not only true for the University of Arizona at Tucson, but also the Massachusetts Institute of Technology, the California Institute of Technology, and Purdue University, among others.

One of the opportunities Purdue University affords both its graduate and undergraduate students is the chance to be a part of a tight-knit academic community with top professors in the aerospace field. This personal attention makes their program a popular one with students. Purdue claims to have produced more astronauts than any other university.

A New Array of Space Courses

Many colleges and universities have expanded their degree programs and course offerings in the fields of space sciences, astronomy, and Earth sciences to attract more students, as well as professors and research grants. The future holds a vast array of space-related careers. For example, space tourism in the decades to come will require a wide range of careers, and students at Rochester Institute of Technology are getting ready. In the departments of hotel management, food management, and travel programs, students are enrolled in what is likely the world's first college course on space tourism.

Promoting Space in Universities

National Space Grant Consortium. One of the most effective programs for bringing more space research and related projects, as well as funding, to universities is NASA's National Space Grant College and Fellowship Program. This program funds space research, education, and public service projects through a network of consortia in each of the fifty states, Puerto Rico, and the District of Columbia.

Each state's space grant consortium provides the students with information about local aerospace research and financial assistance. They also develop space education projects in their states. Some space grant projects, such as the one at the University of Colorado in Boulder (CU Boulder), involve students in current space missions. Students at CU Boulder are monitoring a spacecraft from their own mission control room on campus. At the Colorado School of Mines, students can enroll in courses on space resources and work with former and current NASA experts.

Universities Space Research Association. The Universities Space Research Association (USRA) is a private nonprofit corporation formed under the auspices of the National Academy of Sciences. All member institutions have graduate programs in space sciences or aerospace engineering. Besides eighty-two member institutions in the United States, there are two member institutions in Canada, two in England, and two in Israel.

USRA provides a mechanism through which universities can cooperate effectively with one another, with the government, and with other organizations to further space science and technology and to promote education in these areas. A unique feature of USRA is its system of science councils, which are standing panels of scientific experts who provide program guidance in specific areas of research. Most of USRA's activities are funded by grants and contracts from NASA.

Universities Worldwide

The International Space University (ISU), through both its summer courses and its permanent campus in France, has made major contributions to establishing new curricula. It draws the top students worldwide, because their professors are leading figures from space-related industries, government and international organizations, and universities around the world. ISU students come to the university with their specialist backgrounds and broaden their perspectives through increased knowledge in other relevant fields. Another example of international efforts to attract students is found at Saint Louis University at its Madrid campus in Spain, whose aerospace program has drawn students from abroad to study in St. Louis, Missouri.

Student Space Competitions

Universities are also involved in efforts to reach out to younger students and expose them to space sciences. Space-related projects and competitions for kindergarten through twelfth-grade students sponsored by a university member of the National Space Grant—or in collaboration with other organizations such as the National Space Society, the Challenger Center for Space Science Education, the Space Foundation and the Planetary Society—can make an impression on students that will influence their career decisions much later.

The experience of being involved in science fair projects also provides students with a sense of ownership and interest that lasts throughout their careers. Many university scientists and engineers, as well as experts from aerospace companies, are involved in helping and judging science fairs.

Through space-related professional organizations like the American Institute of Aeronautics and Astronautics, the aerospace division of American Society of Civil Engineers, and the Institute of Electrical and Electronics Engineers, universities are providing opportunities for students to submit papers and projects to be judged by experts in the field. These competitions, which are held at the organizations' conferences, provide an avenue for building relationships with aerospace professionals, as well as other students. These relationships can form an essential network of colleagues as students launch into their careers.

NASA and other organizations sponsor an array of design projects for students of all ages. Projects can include flying their experiment on a KC-135 airplane that provides 25 seconds of **microgravity** at a time. Other competitions involve designing space settlements and Moon and Mars bases.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

NASA's Commercial Space Centers

NASA's commercial space centers are a consortia of academia, government, and industry who partner to develop new or improved products and services, usually through collaborative research conducted in space. The NASA Space Product Development office manages 11 of the 17 centers that perform research in the areas of biotechnology, agribusiness, structure-based drug design, and materials research. Topics of interest at the centers include space power, satellite communication networks, **remote sensing**, mapping, microgravity materials processing, medical and biological research and development, **crystallography**, space automation and robotics, engineering, space technology, and combustion in space. SEE ALSO Career Astronauts (volume 1); Careers in Astronomy (volume 2); Careers in Business and Program Management (volume 1); Careers in Rocketry (volume 1); Careers in Space (volume 4); Careers in Space Law (volume 1); Careers in Space Medicine (volume 1); Careers in Space Science (volume 2); Careers in Spaceflight (volume 3); Careers in Writing, Photography, and Filmmaking (volume 1); International Space University (volume 1).

remote sensing the act of observing from orbit what may be seen or sensed below Earth

crystallography the study of the internal structure of crystals

Barbara Sprungman

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Universities Space Research Association. <http://www.usra.edu>

ELV *See Launch Vehicles, Expendable (Volume 1).*

Energy from Space

base load the minimum amount of energy needed for a power grid

Forecasts indicate that worldwide demand for new **base-load** electrical power generation capacity will continue to grow throughout the twenty-first century. However, evidence is mounting to show that the use of fossil fuels—coal, oil, and natural gas—and the resulting increase in greenhouse gas emissions may be leading to measurable global climate change. New energy technologies are needed to offset the future growth in fossil fuel use.

One concept that would provide power on a significant scale for global markets is energy from space. Earth is about 150 million kilometers (93 million miles) from the Sun. Sunlight constantly delivers 1,358 watts of energy per square meter of area to the part of Earth facing the Sun. However, by the time the sunlight reaches the surface of Earth, atmospheric filtering has removed about 30 percent of the initial energy even on a clear day. Moreover, the effects of the seasons and the day-night cycle further reduce the average energy received by an additional 90 percent. Often, the remaining 100 to 200 watts per square meter can be blocked completely by weather for days at a time.

A solar power satellite, by contrast, could collect sunlight in space and convert the energy into electrical current to drive a wireless power transmission system, which would in turn beam the power down to receiving antennas on Earth. Earth-bound receiving antennas could capture the transmitted energy—almost twenty-four hours a day, seven days a week—and deliver it to local electrical grids as base-load power. This approach could eliminate the need for extremely large **solar arrays** on the ground and dramatically expensive energy storage systems, but would require a number of new technological advances.

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

multi-bandgap photovoltaic cells photovoltaic cells designed to respond to several different wavelengths of electromagnetic radiation

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

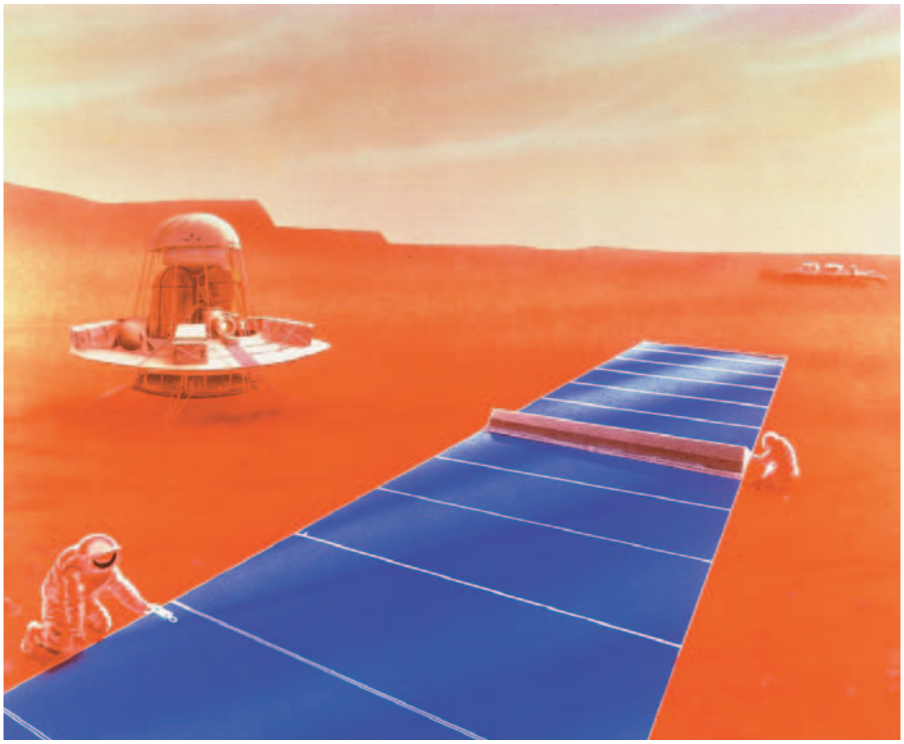
high-power klystron tube a type of electron tube used to generate high frequency electromagnetic waves

phased array a radar antenna design that allows rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

Details of the Concept of Energy from Space

Power Generation in Space. Typically, photovoltaic arrays are used to generate power in space. These are solid-state devices that exploit the characteristic of semiconductors such as silicon to allow incoming photons to readily dislodge electrons, a process that creates voltage. Key measures of the effectiveness of these technologies are the specific power (e.g., watts produced per kilogram of solar array mass) and the efficiency (e.g., watts produced per square meter of solar array area). By the early twenty-first century, space solar power technology research programs were using concentrating lenses and **multi-bandgap photovoltaic cells** to achieve specific power levels approaching 200 watts per kilogram and efficiencies of almost 30 percent. These figures represent advances of more than a factor of three over the state-of-the-art technology of the late 1990s.

Wireless Power Transmission. Power can be transmitted using either radio **frequencies** or visible light. In the case of radio frequencies, a wide range of devices could be used to generate the power beam, including **high-power klystron tubes**, low-power solid-state devices, and magnetrons, which are a type of vacuum tube providing in-between levels of power (and are also used in household microwave ovens). In all of these cases, a number of the devices would be arranged and operated in a lockstep **phased array** to create a coherent, collimated (parallel) beam of energy that would be transmitted from space to the ground. The efficiency of the transmitter



Energy collection in space from other planets or satellites could revolutionize the method of power delivery on Earth.

can be as high as 80 percent or more. On the ground, a radio frequency power beam would be converted back to voltage by a rectifying antenna (also known as a "rectenna") operating at about 80 percent efficiency. Taking into account losses of the collimated beam at the edges of the rectenna and small levels of interference from the atmosphere, a power beam might generate about 100 watts per square meter on the ground on average.

The Challenge of Large Systems in Space. A central challenge of space solar power is that of launching and building these exceptionally large systems in space. As of the early twenty-first century, the cost of space transportation ranged from $5,000 to $22,000 per kilogram of **payload**, launched to Earth orbit. In order to be economically viable, space solar power systems must be launched at costs of no more than $400 per kilogram. Such a dramatic improvement requires the development of a range of new technologies and new types of space transportation systems.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Base-load Solar Power Systems: Ground and Space. The projected costs of base-load solar power using ground-based solar arrays are clearly dominated by the cost of the energy storage system needed to allow energy received during a clear day to be delivered to customers at night—or during several consecutive days of cloudy weather. These costs can be greater than $15,000 per kilowatt-hour of energy stored. In other words, to power a house using 2 kilowatts of power over five days of cloudy weather would require about $4 million to build the energy storage system alone. Conversely, the installation cost for a space-based solar power system (providing power for hundreds of thousands of homes) might be expected to range between $100,000 and $300,000 per home, for a comparable power-using home. This is still much greater than the cost of installing new fossil-fuel power-generating capacity, but the cost of a space-based solar power system could be as little as 1 percent of the cost of a comparable ground-based system.

History and Future Directions

In the 1970s the U.S. Department of Energy and the National Aeronautics and Space Administration (NASA) extensively examined large solar power satellite systems that might provide base-load power into terrestrial markets. From 1995 to 1997 and in 1998, NASA reexamined space solar power (SSP), with both encouraging technical results and cautionary findings concerning the economics of introducing the technology during the first two decades of the twenty-first century. As a result, from 1999 to 2000, NASA conducted the SSP Exploratory Research and Technology program, which refined and modeled SSP systems concepts, conducted research and development to yield "proof-of-concept" validation of key technological concepts, and laid the foundation for the creation of partnerships, both national and international. A number of innovative concepts and technology advances have resulted from these efforts, including a new solar power satellite concept, the Integrated Symmetrical Concentrator, and new technologies such as lightweight, high-efficiency photovoltaic arrays, inflatable heat radiators, and new robots for space assembly. Future technology efforts will focus on providing the basis for better-informed decisions regarding solar energy in space and related research and development. SEE ALSO Power, Methods of Generating (volume 4); Solar Power Systems (volume 4).

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Entertainment

Outer space is big business for the entertainment world. The earliest record of a work of science fiction, written to fuel the imagination and entertain the public, was the Greek satirist Lucian's *Vera historia* (True history), penned around C.E. 170. In Lucian's tale, a sailing vessel is caught up by a whirlwind and after a journey of eight days arrives at the Moon. Lucian's description of this imaginary lunar voyage set the scene for many stories, films, and even computer games that have followed.

Science fiction novels sell in phenomenal numbers, appealing to the reader's wish to escape the everyday and stimulating the imagination with the possibilities of tomorrow. Many novelists such as Ben Bova and Neil Ruzic have made careers in science fiction writing. Others, such as James Michener (author of *Space*), Isaac Asimov, and Arthur C. Clarke have been lured by the theme of space, as one compass of a much broader writing career. Science fiction conventions celebrate this genre and allow fans an op-

Hollywood's depictions of alien life forms have ranged from the gentle extraterrestrial E.T. to the terrifying alien of *Aliens* (pictured).

portunity to meet with famous authors, hear how they develop their themes related to the future of space exploration, and dissect the plots. These conventions are also major business enterprises.

In modern times the most notable entertainment of the first half of the twentieth century was Orson Welles's broadcast of *The War of the Worlds.* English novelist and historian H. G. Wells wrote this tale of a Martian invasion as a magazine serial in 1897, but Welles's eerie radio rendition of the tale in 1938 sent shock waves through the United States as listeners tuned in to what they thought was a serious report of alien invasion.

Television: From *Star Trek* to *Nova*

Some of the most successful and longest-running series on television have had themes of space exploration. *Star Trek*, the brainchild of the legendary Gene Roddenberry, through its various generational formats has made the careers of several actors and actresses and met with so much enthusiasm that it has spawned Star Trek conventions. The British invention, *Dr. Who*, also met with universal, long-term success and was assimilated as one of the "cult" shows of the twentieth century. *Babylon Five* also developed a very significant following, and the Jim Henson–backed series *Farscape*, featuring a lost astronaut thrown into the distant regions of space, is the Sci-fi channel's longest running original series.

Space themes are not confined to futuristic fictional series on television, although these are by far the best known and the greatest revenue generators. Aliens are a common theme both as a dramatic effect in a storyline and as the subject matter of serious newsmagazine programs about scientific exploration and **pseudoscience**. Educational programs about space exploration have great popular appeal and, by extension, attract significant advertising dollars to television stations. One of the great television successes of the 1990s was Tom Hanks's HBO series *From the Earth to the Moon*, the story of the Apollo missions that landed twelve humans on the Moon.

pseudoscience a system of theories that assumes the form of science but fails to give reproducible results under conditions of controlled experiments

In 2000 the Discovery Channel's in-depth study of the International Space Station represented a significant programming investment. Finally, news magazine programs such as *Nova* frequently return to stories of space exploration because the human fascination with the unknown and the "great beyond" of the universe draws a large audience.

Films: Special Effects and Special Stories

microgravity the condition experienced in free fall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Outer space can be daunting, fascinating, and mysterious—a gift to moviemakers. Facing the challenges of working in **microgravity** calls for fearless heroes and feats of courage. And re-creating outer space for the motion picture audience offers numerous possibilities for the special effects department.

People may snicker at the title of the 1956 film *Invasion of the Body Snatchers*, but this movie is an influential classic and still very scary. It tells the story of residents of a small town who are replaced by inert duplicates, which are hatched from alien "pods."

2001: A Space Odyssey, Stanley Kubrick's influential 1968 masterpiece (with the screenplay written by Arthur C. Clarke), opened the imagination to the possibility of other intelligent entities developing in time frames different from the evolution of humans on Earth, while also featuring alien encounters and a computer with an attitude called HAL. In *2001*, possibly the most influential space movie to date, Kubrick enticed the audience with the vastness and timelessness of space in comparison to the current human condition.

From the days of the earliest space-themed movies, directors have been awed by the subject matter and have worked studiously to be as authentic as possible in the representation of spaceflight and off-world locations. This is how space historian Fred Ordway and space artist Robert McCall (who painted the lunar mural in the National Air and Space Museum in Washington, D.C.) found themselves in London, consulting on the making of *2001*, and how countless astronauts have been called upon to advise actors on how to realistically simulate behavior in microgravity.

The 1977 blockbuster *Star Wars*, and the two subsequent episodes in the trilogy, *The Empire Strikes Back* (1980) and *Return of the Jedi* (1983), opened a new era in opening the imagination of moviegoers to space. In this series, and *Episode I: The Phantom Menace* (1999), legendary producer George Lucas introduced audiences to tales of life and conflict in a vast universe populated by creatures of mind-boggling diversity and cunning.✶

✶**In May 2002, *Episode 2: Attack of the Clones* was released.**

The 1977 film *Close Encounters of the Third Kind*, directed by Steven Spielberg, describes a first contact with alien beings. Impressive cinematography won an Oscar for Vilmos Zsigmond. Spielberg's *E.T. The Extra-Terrestrial*, released in 1982, cemented Spielberg's reputation as a director and won John Williams an Academy Award for his score, with additional Oscars going to the sound and visual effects teams. *E.T.* is a classic of the sympathetic alien genre of movies, which developed along with the growing understanding of the unique nature of human life in the solar system and with the increasing knowledge about the origins of life. Its enduring influence is demonstrated by its rerelease to the big screens in 2002.

The blockbuster of the 1990s was *Apollo 13*, based on the book *Lost Moon* by Apollo 13 commander Jim Lovell and Jeffrey Kluger. This exhilarating story of the ill-fated Apollo 13 Moon mission was directed by Ron Howard and starred Tom Hanks, Bill Paxton, Kevin Bacon, Gary Sinise, and Kathleen Quinlan. Sticking painstakingly close to the true story of Apollo 13, this 1995 movie told the tale of the human ingenuity, fast thinking, and enormous courage that brought the crew of Apollo 13 back from the Moon safely after a catastrophic explosion deprived them of the majority of their air supply. The film provided a marked contrast with the media headlines of failure (because the crew failed to land on the Moon) that had formed public opinion about the mission twenty-five years earlier.

In the late 1990s, as scientific understanding of asteroids grew as a result of better telescopes and the detailed images from robotic missions such as Galileo and the Near Earth Asteroid Rendezvous mission, a crop of movies about the threat of asteroid or comet collisions with Earth were released. Both *Deep Impact* and *Armageddon* did well at the box office and served to broaden the public debate on the threat of asteroid impacts.

Space Cowboys, released in 2000, reflected growing concern with the amount of space debris circling the planet and, on occasion, falling uncontrolled to Earth. And movies telling of the human exploration of Mars—one of the great space challenges for the human race in the twenty-first century—were on the rise.

It is impossible to discuss films about space without mentioning the large-scale IMAX films on a range of space topics that are screened at numerous science museums around the world. These films trace the history of the human exploration of space with awe-inspiring visual effects provided by Mother Nature.

Exhibits and Theme Parks

The best-known visitor attractions with space themes include the most visited museum in the world, the National Air and Space Museum in Washington, D.C.; the Epcot Center at Disney World in Orlando, Florida; and Tomorrowland in California. Space theme parks, which allow visitors to sample the technologies of the future or simulate a spaceship ride or a walk on the surface of the Moon or Mars, have been developed by visionaries who foresee hundreds of thousands of people routinely traveling in space in the future.

Video and Computer Games

Computers play a major role in simulating complex rendezvous, docking, and landing maneuvers for space missions. They also provide exciting games that test a player's skill in retrieving a satellite, docking or maneuvering a spacecraft in zero gravity, and much more. If the majority of people cannot experience space travel themselves, some of the computer games available are the next best thing. SEE ALSO Apollo (Volume 3); Careers in Writing, Photography, and Filmmaking (Volume 1); Clarke, Arthur C. (Volume 1); Impacts (Volume 4); *Star Trek* (Volume 4); *Star Wars* (Volume 4).

Pat Dasch

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F

Financial Markets, Impacts on

The space industry is in the midst of a rapid evolution whose growth is being driven by mainstream commercial forces, with some Wall Street analysts projecting the market to grow to more than $150 billion in the next ten years.

If these analysts are correct, the fuel that will propel the commercial space industry to such heights is the venture capital—the "lifeblood" of every emerging industry—that individuals and institutions are willing to invest in a variety of endeavors. The financing of space projects, once thought by many observers as too risky, has been substantial. More than $100 billion is expected to flow into the space industry between 1995 and 2010.

Until the mid-1990s, most investment organizations were relatively unsophisticated about space projects. In the early twenty-first century, most investment organizations are willing to review business plans on the basis of business prospects and revenue forecasts. As space attracts greater amounts of venture capital, the field will act as a **catalyst** for economic expansion worldwide in a variety of ways.

catalyst a chemical compound that accelerates a chemical reaction without itself being used up; any process that acts to accelerate change in a system

For starters, commercial space is spawning a plethora of innovative start-up companies that think of space less as a scientific frontier than as a place to make money. Most of these fledgling businesses are not traded on any stock exchange. However, many plan to "go public," meaning that they intend to sell common shares to the public. That is how Microsoft, Biogen, and many other industry leaders began in the 1980s, when the biotechnology and information technology industries were still in their infancy. Like those industries, space will serve as an engine for job growth and wealth creation.

Satellites: A Driving Force

Of all the activities associated with commercial space, satellites are likely to drive the space industry's growth for the foreseeable future. Satellites have the advantage of speed, mobility, and costs, independent of their Earth orbit. A single satellite system can reach every potential user across an entire continent. For many applications, satellite technology provides the most cost-effective way of providing service over a wide area. As a result, satellites will be instrumental in helping to raise the standard of living in many underdeveloped countries where there is little or no **communications infrastructure**. In that role, the economic impact of commercial space may be incalculable.

communications infrastructure the physical structures that support a network of telephone, Internet, mobile phones, and other communicaton systems

Satellites provide a broad menu of services. These range from mobile telephony to direct-to-home broadcast of television, cable, and video pro-

Satellites are likely the force that will drive the space industry, as they have advantages that are independent of their Earth orbit, such as speed and mobility.

gramming. The wave of the future is broadband, which refers to a frequency on the **electromagnetic spectrum** that will allow satellites to provide high-speed Internet access, interactive video, and video on demand.

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

In 1998 a combination of failed attempts to launch satellites, in-orbit satellite failures, and business plans gone awry sent investors scrambling as they pulled their support from ventures. This could happen again. On the other hand, commercial space is still in an early stage of development, and if recent history is any guide, investors' understanding of this unique business will continue to increase, and sufficient venture capital will remain available. SEE ALSO COMMERCIALIZATION (VOLUME 1); COMMUNICATIONS SATELLITE INDUSTRY (VOLUME 1); MARKET SHARE (VOLUME 1).

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Getting to Space Cheaply

G

It costs a lot to get to space—in 2001 it cost as much to put something in **low Earth orbit** ($22,000 per kilogram [$10,000 per pound]) as it did in 1957. Anyone who wants to do things in space (e.g., such as experimenters and scientists) has a cost hurdle to overcome that is not encountered in any other area of human endeavor.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Low Earth orbit (LEO) is a few hundreds miles up. To get to LEO, it takes 30,000 feet per second of velocity change; the total energy needed to get to the Moon is about 45,000 feet per second. LEO is therefore two-thirds of the way to the Moon.

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

aerodynamic heating heating of the exterior skin of a spacecraft, aircraft, or other object moving at high speed through the atmosphere

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Two factors make the step from Earth to LEO hard. First is Earth's atmosphere, which causes **drag** and **aerodynamic heating**. Second is the gravity gradient, or the change in the force of gravity as one moves away from Earth. The force of gravity declines inversely as the square of the distance from Earth, meaning that the farther away one gets from Earth, the easier it is to overcome the force of gravity. As a result, it is harder to get from Earth to LEO than from LEO to almost anywhere else in the solar system.

Expendable Launch Vehicles and Single-Stage-to-Orbit Reusable Rockets

Throughout the twentieth century, getting to space was accomplished almost exclusively with expendable launch vehicles (ELVs)—rockets that are used once and then discarded in the process of putting their **payloads** into orbit. ELVs are inherently incapable of providing cheap access to space for the same rationale that throwing away an automobile after each use is also not economical. Nevertheless, ELVs are here for the foreseeable future (i.e., the early twenty-first century).

As of February 2002, every rocket used to place payloads into orbit has used multiple parts, or stages. Each stage is itself a working rocket. One or more stages are discarded and dropped off as the vehicle ascends, with each discard eliminating mass, enabling what is left over to make orbit.

However, a single-stage-to-orbit (SSTO) reusable rocket would probably be the best technical solution to inexpensively get to LEO. Even when all parts of a multistage rocket are reused, the rocket still needs to be put back together again. An SSTO rocket would not have to be reassembled, reducing the number of people required for operations.

Unfortunately, it is hard to get to LEO without staging. To get to LEO with a single stage, a rocket has to be 90 percent fuel, leaving only 10 percent for everything else. Such a rocket has proven difficult in practice to build, leading to the continued use of multistage rockets.

In 1994 the National Aeronautics and Space Administration (NASA) decided to develop technologies to lead to a reusable launch vehicle (RLV) with a single-stage rocket. Its major step toward this goal was the $1.4 billion X-33 program, which aimed to fly a vehicle to demonstrate some of these technologies. Like many X-vehicle programs before it, the X-33 encountered severe technical difficulties as well as budget overruns and schedule delays. As a result, NASA terminated the X-33 program in early 2001.

NASA is also planning to investigate technical paths to SSTO other than conventional rockets. All involve air-assisted propulsion, such as ramjets, supersonic combustion ramjets ("scramjets"), or liquid air cycle rockets, and all lie in the future.

The Marketplace

There is only one commercial space market: geostationary communications satellites, a market that has had dependable growth for decades. There are several possible new markets, such as remote sensing and space tourism. Remote sensing is the act of observing from orbit what may be seen or sensed below on Earth. But remote sensing requires only a few additional launches a year. Another possible new market, LEO communications satellite con-

The X-33, an unpiloted vehicle, was designed to launch vertically like a rocket and land horizontally like an airplane.

stellations, was halted by the business failure of Iridium, the first such system.✶ Without new markets there are no business needs for anything but ELVs and no incentives to develop new launch systems to get payloads to space cheaply.

✶**For more on Iridium, see the Volume 1 article "Business Failures."**

ELVs available at the beginning of the twenty-first century include the two EELV ("Evolved ELV") families paid for by the U.S. Air Force: the Atlas V and Delta IV. Still available for purchase are the Delta II and III, as well as the Atlas II and III ELVs, and the Boeing SeaLaunch ELV, a converted Zenit rocket launched from a ship at sea. There is also the market leader, the French Ariane 4 and 5 ELV family. The Russian Proton and Rokot ELVs are also available, as are the Chinese Long March families of throwaway boosters.

New Beginnings

Kistler Aerospace is designing and building a two-stage-to-orbit RLV. The company will need investments of $200 million to $400 million above the $500 million already spent to achieve a first flight in 2002 or 2003. There

The X-34 Technology Testbed Demonstrator is delivered here to NASA on April 16, 1999. Results gleaned from this technology will contribute to the development of lower-cost reusable launch vehicles.

suborbital trajectory the trajectory of a rocket or ballistic missile that has insufficient energy to reach orbit

are also small company start-ups such as Kelly Space and Technology and Pioneer Rocketplane, which are involved in developing technologies to get to space cheaply. Kelly wants to develop the Astroliner, a winged rocket towed into the air by a 747 jet and released at altitude to soar on a **suborbital trajectory** under its own power. At the high point of its trajectory, an upper stage is released and injected into LEO. The Astroliner descends and then lands using onboard jet engines.

Pioneer Rocketplane also has an airplane-like RLV it wants to develop, the Pathfinder, which would take off using jet engines. Once at altitude the Pathfinder meets a tanker carrying liquid oxygen, which air-to-air refuels the Pathfinder's liquid oxygen tanks, which are empty at takeoff. After the Pathfinder and the tanker disconnect, the Pathfinder's rocket engines fire, putting it in a suborbital trajectory. At its high point, an upper stage is released and injected into LEO. The Pathfinder descends and then lands using its jet engines.

Space Access LLP will need $5 billion to get to first flight. The company's SA-1 winged vehicle is designed to take off using an ejector ramjet—a ramjet that can also convert to function as a "pure" rocket engine. Once at higher altitude and speed, the vehicle would switch to rocket propulsion and exit the atmosphere where, at the high point of its trajectory, an upper stage would be released and be injected into LEO. This particular upper stage would descend and land for reuse using rocket propulsion to de-orbit, space shuttle–style heat shield tiles, and a parachute. In the meantime, the main SA-1 vehicle would descend and land using its onboard ramjets.

Both the Astroliner and the Pathfinder will need about $300 million to get to first flight. But all of the small RLV companies have had incomes of only a few million dollars a year, and while most of them manage to stay in business, none have yet been able to obtain sufficient funding to begin full development. (A few have small NASA study contracts.) Several other RLV start-ups, such as Rotary Rocket, have failed to obtain sufficient funding and have been forced out of business. The problem is that as of the early twenty-first century, all of the RLV start-up firms have been able to obtain funding only from "angels"—investors who are personally interested in the project. It is only the large established aerospace companies (e.g., Boeing, Lockheed Martin, Orbital Sciences) that manage to secure significant amounts of funding. SEE ALSO LAUNCH INDUSTRY (VOLUME 1); LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); LAUNCH VEHICLES, REUSABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4); SPACEPORTS (VOLUME 1).

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Global Industry

From the earliest forays into commercial space, competition has been fierce. The United States has an established lead in the design, construction, and marketing of satellites. At the end of the twentieth century, U.S. satellites were being launched routinely for a significant number of nations by launch vehicles provided by eight different nations from launch sites all around the world. The transfer of export license processing from the U.S. Department of Commerce to the U.S. Department of State in 1999 resulted in a conspicuous slowdown in satellite exports, but even this impediment did not compromise U.S. leadership in this world market. The decision to change licensing authority arrangements in the United States was a response to instances of transfer of technological information to China by U.S. companies that the American government deemed inappropriate. This article will explain how space business enterprises had become internationally interwoven to a deep degree by the opening of the twenty-first century.

Changes Following the Challenger Disaster

Space business underwent some major changes between the mid-1980s and the end of the twentieth century. Following the explosion of the space shuttle Challenger because of a technical malfunction in 1986, the United States decided to no longer use the space shuttle to carry commercial **payloads** into orbit. It quickly became clear that the United States had put too much reliance on one launch vehicle, the shuttle. Lack of a good alternative launch system sent aerospace companies scurrying to develop suitable rockets to fill the gap. More importantly, it meant that the United States had lost its dominant position in the launch business to the growing competition from other nations.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Initially the main competition came from the European Ariane launchers. Over time, more and more nations became involved in the commercial launch business, most notably Russia (after the end of the Cold War), Japan, and China. By 2000, eight nations boasted satellite-launching capabilities and several multinational commercial launch services had been established.

Odyssey, a self-propelled, commercial, floating launch pad, combines the resources of the world's leading aerospace companies.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Much of the expertise in rocketry developed in the period between World War II (1939–1945) and the glory days of the Saturn V rocket and the Apollo missions to the Moon was lost in subsequent years as the United States limited its civilian space activities to **low Earth orbit** (LEO). The development of new launch vehicles was marred by expensive failures, raising questions about U.S. reliability in the launch business and forcing insurance rates higher. Loss of domination of the world space launch business coupled with a cutback in U.S. government space contracts resulted in a slew of mergers and acquisitions as aerospace companies streamlined to remain competitive.

Mergers and Acquisitions

In the largest American mergers of the 1990s, Lockheed Corporation merged with Martin Marietta Corporation to become Lockheed Martin Corporation, and the Boeing Company absorbed McDonnell Douglas Corporation as well as elements of Rockwell International Corporation (the corporation that had built the space shuttles) and Hughes Electronics Corporation. This climate of mergers and acquisitions started in response to events in the United States but continues as the industry reacts to events worldwide that impact this global market. For example, two significant companies merged in 2000 when Honeywell Inc. acquired AlliedSignal Inc. in an all-stock deal valued at $14 billion.

The focus on LEO communications networks and on the design of launch vehicles limited in capability to delivery to near-Earth space was another shaping factor in the development of the global industry. Companies such as the unsuccessful Iridium planned to provide worldwide communications capability primarily for an international business clientele. This market initiative stalled because of a combination of technological developments in fiber-optic networks (greatly undercutting the cost of space-based communication systems), and a poor assessment of the market niche. The push toward LEO networks, however, increased emphasis on the global marketplace.

Globalization—the worldwide expansion of corporate business activity—also became a factor in the space industry towards the turn of the century. The creation of companies such as International Launch Services, which combined American business savvy with access to customers and merchandizing from Lockheed Martin and with the technical reliability of Russian rocketry, was typical of the trend towards international leveraging of assets for market success. Another company, Sea Launch, brought even more partners together, teaming another Russian rocket, U.S. corporate business leadership, operations and management from Boeing, a Norwegian-built oceangoing launch platform, and initially, a Cayman Islands registry. The trend of mergers and acquisitions was not confined to the United States. In 1999 Aérospatiale Matra, DaimlerChrysler AG, and Construcciones Aeronauticas S.A. merged their space capabilities to create the transnational firm EADS, the European Aeronautic Defence and Space Company. In 2000, Matra, BAE Systems, and DaimlerChrysler formed Astrium, covering the whole spectrum of space business. Further refinements of European consolidations have responded to changing trends in the aerospace industry related to economic slowdowns in both Japan and the United States, and the terrorist attacks of September 11, 2001.

The Global Nature of the Commercial Space Business

Even before the trend for mergers and acquisitions and the development of corporations geared to worldwide operation in a global market, the commercial aerospace industry was intensely internationally interconnected. For example, while a launch vehicle might be built in the United States or Japan, some component parts would come from elsewhere and payloads—the satellites that were lofted into space by the launch vehicles—frequently brought together instruments and components from several additional nations. Furthermore, each launch and its payload has to be insured against catastrophic failure of the launch vehicle, failure of the launch vehicle to place the satellite in the correct orbit, and malfunction of the satellite itself. Whereas the United States develops the majority of the world's satellites and has regained a significant share of the launch market, the majority of launch insurance comes from Europe. Australian-based insurance companies have also been a significant provider of insurance and reinsurance for the space business. Insurers require detailed knowledge of the vehicle and payload to be insured, resulting in the necessary transfer of detailed information about a planned launch to individuals outside the originating nation. The insurance element provides one more illustration of the global nature of the space industry with its many component parts.

A Sea Launch Ukrainian/ Russian–built Zenit rocket carries a satellite into space. In 1999 a total of 128 spacecraft launched.

Growth Trends in the Global Space Industry

The first year in which commercial space revenues exceeded revenues from government space contracts was 1998. In subsequent years, the growth of commercial space business has widened the gap between commercial revenues and government revenues from space commerce. A total of 128 spacecraft were launched in 1999. Seventy-six of those launches were for commercial customers and fifty-two were government missions, highlighting that the industry driver has changed from the government sector to the commercial sector. Eight countries were responsible for the 128 launches, which had a success rate of 89.7 percent.

In 1999 direct broadcast satellite television was the fastest-growing consumer electronics product in history, and more then 35 million people worldwide received their TV via satellite. Digital audio radio was predicted to be the hot electronics product for the first decade of the twenty-first century, with an audience of more than 49 million subscribers expected by 2009. Worldwide, the space industry employed nearly 1.1 million people in 1999 and posted revenues of $87 billion. Worldwide space revenues for the years 2000 to 2005 were projected to total $619.4 billion. SEE ALSO AEROSPACE CORPORATIONS (VOLUME 1); BUSINESS FAILURES (VOLUME 1); INSURANCE (VOLUME 1).

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Global Positioning System

One hazard of human existence is being geographically lost, which can sometimes mean the difference between life and death. The ability to know one's position was considerably enhanced on February 22, 1978, when members of the U.S. Air Force (USAF) Space Division based in Los Angeles, California, launched the first NAVSTAR (Navigation Satellite with Timing and Ranging) satellite in the Global Positioning System (GPS). This satellite-based navigation system enables users anywhere on Earth to determine their location to a high degree of accuracy.

Components of the System

GPS is a satellite-based navigation system consisting of three segments: space, ground, and user. The space and ground segments are run by a military organization called the United States Space Command, which is located in Colorado Springs, Colorado. This command, composed of components of the USAF, the U.S. Army, and the U.S. Navy, launches the NAVSTAR satellites and is responsible for space and ground operations. The user segment includes any organization, ship, person, or airplane that uses GPS.

The space segment consists of a constellation of twenty-four satellites based in six different orbital planes at an altitude of 20,000 kilometers (12,400 miles). In this orbit, each satellite circles the planet twice in twenty-four hours and travels at the speed of 3.89 kilometers per second (8,640 miles per hour). Each satellite has an inclination of 55 degrees with respect to the equator, which means that it flies to a maximum of 55 degrees north latitude and 55 degrees south latitude during its orbits. The ground segment consists of the **radar** stations that monitor the satellites to determine the position and clock accuracy of each satellite. The locations of these ground stations are: Hawaii; Ascension Island, located in the southern Atlantic; Diego Garcia, an island in the Indian Ocean; Kwajalein, part of the Marshall Islands of the western Pacific; and Schriever Air Force Base, Colorado.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

The Global Positioning System enables users anywhere on Earth to determine their location via a receiver, such as this GPS wristwatch by Casio Computer.

The stations are staffed continuously to ensure that GPS broadcasts the most accurate data possible.

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

oscillations energy that varies between alternate extremes with a definable period

Each NAVSTAR satellite weighs about 1,000 kilograms (2,200 pounds) and is 5.25 meters (17 feet) long with its **solar arrays** extended. The spacecraft transmits its timing information to Earth with the power of 50 watts, obtained from the solar panels and augmented battery power. Using its 50 watts, the satellite transmits two signals called "Links," L_1 and L_2, shorthand for Link1 and Link2. L_1 and L_2 are "downlinks" because their signals go to Earth. Two cesium and two rubidium atomic clocks provide signal timing. Atomic clocks are not powered atomically; they measure the precise **oscillations** of cesium and rubidium atoms. These oscillation measurements are so accurate that an atomic clock, if left unadjusted, would gain or lose one second every 160,000 years. But how does accurate timing from a satellite at an altitude of 20,000 kilometers translate into a position within meters on Earth?

How Positions Are Determined

Distance to the satellite—the range—is the key for determining positions on Earth. Time is related to range by a very simple formula: Range = Velocity × Time. For GPS, the range is the distance from the receiver to the satellite; the velocity equals the speed of light (300,000 kilometers per second [186,300 miles per second]); and the time is the time it takes to synchronize the satellite signal with the receiver. Because the speed of light is so fast, the key to measuring range is the accurate timing provided by the atomic clocks.

What is meant by synchronizing the satellite signal with the receiver? First, imagine that a GPS satellite begins to play the song "Twinkle, Twinkle, Little Star." Simultaneously, a GPS receiver starts playing the same song. The satellite's signal has to travel 20,000 kilometers to the receiver, and by the time it does, the words are so late that when the receiver says

"Star" the satellite's signal starts its first "Twinkle." If two versions of the song were played simultaneously, they would interfere with one another. Consequently, the receiver determines the delay time when it receives the satellite's first "Twinkle" and then starts to play the receiver's tune with a delay time calculated, thereby synchronizing with the satellite's signal. The amount of delay time is the signal travel time. This signal travel time is multiplied by the speed of light to determine the range.

Obviously, the GPS does not use "Twinkle, Twinkle, Little Star," but rather it generates an electronic signal. This signal is similar to the interference heard on the radio when one cannot tune in the correct station or the "snow" one sees on one's television when the set is not on an operational channel. This electronic signal from the GPS satellite is called the Pseudo Random Code (PRC).

A PRC is a very complex electronic signal that repeats its pattern. The pattern of zeros and ones in the digital readouts ensures that the user segment receivers synchronize only on a NAVSTAR satellite downlink and not on some other electronic signal. Because each satellite has its own unique PRC, the twenty-four satellites do not jam each other's signals. This allows all the satellites to use the same GPS **frequencies**. Each satellite transmits two PRCs, over L_1 and L_2. The L_1 PRC is known as Coarse Acquisition (CA), and it allows civilian receivers to determine position within 100 meters (330 feet). The second PRC is called the precise code, or "P," and is transmitted on L_2. The P combines with the CA for orientation and then encrypts the signal to permit only personnel with the correct decoding mechanism, called a key, to use it. When L_2 is encrypted, it is called the Y code and has an accuracy of 10 meters (33 feet).

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

Besides clock accuracy and PRC reception, the receiver needs to know the satellite's location. A typical receiver anywhere on Earth will see about five satellites in its field of view at any given instant. The USAF uses the GPS Master Plan for satellites to ensure that a minimum number are always in view anywhere on Earth. Additionally, all GPS receivers produce an almanac that is used to locate each GPS satellite in its orbital slot. The USAF, under the control of U.S. Space Command, monitors each satellite to check its altitude, position, and **velocity** at least twice a day. A position message, a clock correction, and an ephemeris (the satellite's predicted position) are also updated and uplinked to the GPS satellite daily.

velocity speed and direction of a moving object; a vector quantity

A receiver needs ranges and satellite location information from three satellites to make a position determination. To obtain this, the receiver determines the range while synchronizing its internal clock on the first satellite's correct **Universal time**, which is based on the time in Greenwich, England. Once the clocks have been synchronized and the range to the first satellite has been determined, the receiver also determines the ranges to two other satellites. Each satellite's range can be assumed to be a sphere with the receiver at the center. The intersection of the three spheres yields two possible positions for the receiver. One of these positions must be invalid because it will place the user either in outer space or deep inside Earth, so the receiver has to be at the second position. Then the receiver compares the satellite's ephemeris and current almanac location to obtain the receiver's latitude and longitude. A fourth GPS satellite's range synchronizes the receiver's clock with all the atomic clocks aboard the spacecraft, narrows the

Universal time current time in Greenwich, England, which is recognized as the standard time on which Earth's time zones are based accuracy of the receiver's position to only one intersecting point, and determines the receiver's altitude.

Selective Availability and Differential GPS

There are several errors in timing, ephemeris, and the speed of light for which the system must correct. However, the crews of U.S. Space Command occasionally must induce errors to keep the accuracy of the GPS system from falling into the hands of a hostile force. This error inducement is called "selective availability." To accomplish this, the crew inserts either intentional clock or ephemeris errors. On May 1, 2000, President Bill Clinton ordered the removal of selective availability, greatly enhancing the public use of GPS. However, the probability that access to data would be blocked in times of hostilities has led to a proposal for an independent European GPS-style system called Galileo.

When selective availability was introduced, a number of people wanted more accurate GPS readings, leading to the invention of Differential GPS. This system uses a known surveyed position, such as an airport tower, upon which is placed a GPS receiver. The GPS receiver determines its position constantly and compares the GPS position to the surveyed position and develops a "correction" factor that can be applied to make the accuracy of the GPS in the range of inches. Applications of Differential GPS include precision landings with aircraft and precision farming, which allows a farmer to know exactly where to apply fertilizer or pesticide, or both, within a field. Differential GPS is so accurate that it also permits scientists to accurately measure the movement of Earth's tectonic plates, which move at the speed of fingernail growth.

GPS receivers are currently on ships, trains, planes, cars, elephant collars, and even whales. This system promises to change the way we live, and satellite-based navigation is predicted to become a multibillion-dollar industry in the early twenty-first century.

Commercial Enterprises Involved in GPS

There are a number of commercial companies involved in the GPS industry. The largest are the companies that make the satellite itself, Lockheed Martin, Hughes (recently taken over by Boeing), Rockwell (also recently taken over by Boeing), and Boeing Space. The survivor of the takeover business will probably build the next block of GPS satellites, the 2-F block that will be without selective availability.

Commercial possibilities in GPS are in the following areas: aviation, geosciences, marine applications, mapping, survey, outdoor recreation, vehicle tracking, automobile navigation, and wireless communications. Since there are a number of companies involved in GPS, only four of these will be reviewed. Companies that are selling their GPS services for other than space support include Garmin, which is headquartered in Olathe, Kansas, and has subsidiary offices in the United Kingdom and Taiwan. Garmin sells navigation receivers that are portable and have brought navigation to the masses for hiking, motor boat operation, and other recreational vehicle arenas.

Another large company that employs over 500 workers in the manufacture of receivers is Magellan Systems Corporation, located in San Dimas, California. Magellan brought into market the world's first handheld commercial receiver for ordinary uses. Since 1989, Magellan has shipped more than one million of these units and has produced annual sales that now top $100 million. In 1995, Magellan introduced the first hand-held GPS receiver under $200 which led to even greater market expansion. Trimble Navigation Limited, located in Sunnyvale, California, offers services very similar to those of Garmin and Magellan. Trimble also has a subsidiary in the United Kingdom. Trimble has a particularly accurate receiver called the Scoutmaster, which has been used since 1993 with great success. The receiver allows an individual to not only determine latitude and longitude, but also speed on Earth's surface and distances to input navigation points.

Motorola Corporation has been very cooperative in their affiliation with universities putting **payloads** on satellites and on balloons. Using Motorola GPS units such as the Viceroy and the Monarch, university students have tracked balloon payloads over 240 miles and have used the navigation information to determine the jet stream speed and balloon altitudes over the United States. As the GPS system continues, so too, will ideas from small companies about how to use this information commercially, thus developing industries that people can only dream about at this time in our history. SEE ALSO MILITARY CUSTOMERS (VOLUME 1); NAVIGATION FROM SPACE (VOLUME 1); RECONNAISSANCE (VOLUME 1); REMOTE SENSING SYSTEMS (VOLUME 1).

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

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American Inventor and Educator
1882–1945

Robert Hutchings Goddard was born in Worcester, Massachusetts, on October 5, 1882. After reading science fiction as a boy, Goddard became excited about exploring space. He pioneered modern rocketry in the United States and founded a field of science and engineering. Goddard received a Ph.D. from Worcester Technical University in 1911 and joined the faculty at Clark University.

As a physics graduate student, Goddard conducted static tests with small solid-fuel rockets, and in 1912 he developed the mathematical theory of rocket propulsion. In 1916 the Smithsonian Institution provided funds for

Robert Goddard, pictured here next to a liquid-propellant rocket, launched the first payload-carrying rocket.

his work on rockets and in 1919 published his research as "A Method of Reaching Extreme Altitudes." Goddard argued that rockets could be used to explore the upper atmosphere and suggested that with a **velocity** of 11.18 kilometers per second (6.95 miles/second), without air resistance, an object could escape Earth's gravity and head into infinity or to the Moon or other celestial bodies. This became known as Earth's escape velocity.

Goddard's ideas were ridiculed by some in the popular press, prompting him to become secretive about his work. However, he continued his research, and on March 16, 1926, Goddard launched his first liquid-fueled rocket, an event that heralded modern rocketry. On July 17, 1929, he flew the first instrumented **payload**, consisting of an aneroid barometer, a thermometer, and a camera. This was the first instrument-carrying rocket. After rising about 27 meters (90 feet), the rocket turned and struck the ground 52 meters (171 feet) away, causing a large fire.

Charles A. Lindbergh* visited Goddard and was sufficiently impressed to persuade philanthropist Daniel Guggenheim to award Goddard a grant

velocity speed and direction of a moving object; a vector quantity

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

***In 1927 Charles A. Lindbergh became the first pilot to make a nonstop solo flight from New York to Paris.**

of $50,000, with which Goddard set up an experiment station near Roswell, New Mexico. From 1930 to 1941 Goddard launched rockets of ever-greater complexity and capability. The culmination of this effort was the launch of a rocket to an altitude of 2,743 meters (9,000 feet) in 1941. Late in 1941 Goddard entered naval service and spent the duration of World War II developing a jet-assisted takeoff rocket to shorten the distance required for heavy aircraft launches. This work led to the development of the throttlable Curtiss-Wright XLR25-CW-1 rocket engine that later powered the Bell X-1 and helped overcome the **transonic barrier** in 1947. Goddard died in Baltimore on August 10, 1945. SEE ALSO Careers in Rocketry (volume 1); Rocket Engines (volume 1); Rockets (volume 3).

Roger D. Launius

transonic barrier the aerodynamic behavior of an aircraft moving near the speed of sound changes dramatically and, for early pioners of transonic flight, dangerously, leading some to hypothesize there was a "sound barrier" where drag became infinite

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Ground Infrastructure

The ground-based infrastructure for a satellite is responsible for a number of support functions, such as commanding the spacecraft, monitoring its health, tracking the spacecraft to determine its present and future positions, collecting the satellite's mission data, and distributing these data to users. A key component of the infrastructure is the ground station, which is an Earth-based point of contact with a satellite and a distributor of user data.

Spacecraft and **payload** support consists of maintaining a communications link with the satellite to provide satellite and payload control. The ground station collects satellite telemetry (transmitted signals) to evaluate its health, processes state of health information, determines satellite **orbit** and attitude, and issues satellite commands when required.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Mission data receipt and relay is a vital function of the ground station. This includes receiving mission data and payload telemetry. The ground station computers process these data into a usable format and distribute them to the users by way of electronic communication lines such as satellite or ground-line data link or even the Internet.

A generic ground station consists of an antenna to receive satellite signals; radio frequency receiving equipment to process incoming raw electronic signals; and mission data recovery equipment, computers, and data interface equipment to send data to users. Additionally, telemetry, tracking, and control equipment monitors the spacecraft's health status, and radio frequency transmitting equipment sends commands to the satellite via the station antenna.

Station Personnel

A large satellite control station has several types of centers staffed by a diverse range of qualified personnel. The Control Center (CC) accomplishes

This complex in Madrid, Spain, is one of three complexes that comprise the NASA Deep Space Network, which spans the world and tracks spacecraft throughout the solar system.

overall control of the ground station, and all other station centers are responsible to the CC. A senior individual who has several years' experience working with the satellite systems and the station leads this center. The Satellite Operations Control Center (SOCC) is responsible for satellite health. A senior engineer leads this team, which tracks the satellite and its telemetry. The Payload Operations Control Center (POCC) is responsible for the payload's status and health. A senior engineer also leads this team, which monitors the spacecraft's payload and the quality of data it is collecting. The SOCC and POCC must also determine causes for spacecraft malfunctions and corrections that might be required. The Mission Control Center is responsible for reviewing mission data to ensure their quality for the users. Because it is the last link before the users obtain their data, this center is led by an expert such as a scientist. The Station Control Center is responsible for the ground station upkeep, such as distributing power, providing cooling for the computers, and taking care of general maintenance on all other station equipment. This team is usually led by a civil engineer with a number of years of maintenance experience.

For a smaller satellite operation many of these jobs are combined. One computer might run the CC and the Mission Control Center functions while another accomplishes the SOCC and POCC jobs. If the operation is small, three people and two computers can run the entire ground station.

Commercial Satellite Ground Stations

Depending upon the size, commercial satellite ground stations are available from several corporations with different price structures. This section examines two large processing facility manufacturers: Raytheon and Honeywell; one transportable ground station company, Datron; and one foreign company, RDC ScanEx.

Raytheon Corporation of Denver, Colorado, offers large ground stations including antennas, satellite command and control, mission planning, management, front-end processing, and terminal equipment. One example of their extensive capability for satellite ground station operations is their software, which uses over three million lines of code in operations activities. With their 1800 Denver-based employees, Raytheon has built and supplied more than 40 international ground stations. The large ground stations are prohibitively expensive for any organizations other than governments or very large universities.

Another example of commercial ground stations is Honeywell's Data Lynx series of ground stations. Honeywell offers antennas, tracking, data acquisition, commanding, satellite management, and data processing. The U.S. Navy has taken advantage of Honeywell's expertise by employing their ground stations for the Naval Earth Map Observer satellite system that employs **hyperspectral** sensors. Lockheed Martin has also used Honeywell's ground stations in the Poker Flats Satellite Tracking facility located near Fairbanks, Alaska. Similar to the Raytheon system, the Data Lynx is very expensive to operate and maintain.

hyperspectral imaging technique in remote sensing that uses at least sixteen contiguous bands of high spectral resolution over a region of the electromagnetic spectrum; used in NASA spacecraft Lewis' payload

There are several examples of companies that build small satellite tracking ground stations that require few people. Datron from Simi Valley, California, has built a transportable satellite station that can be used for military tactical intelligence gathering, disaster area assessment, and remote area coverage. The Datron portable ground station is compatible with the Landsat, SPOT, RADARSAT, IKONOS, and Quickbird satellites. Although not as expensive as the Raytheon and Honeywell ground stations, Datron requires a substantial sum for its transportable ground station.

An example of a foreign commercial company that uses minimum equipment to create a ground station is the Russian private company known as RDC ScanEx. This company focuses on personal computers to acquire, track, and download data from several different weather satellites such as the National Oceanic & Atmospheric Administration polar satellites and the Russian Earth remote sensing satellites. The Liana system uses a small, omnidirectional antenna to acquire satellite signals that are sent direct to a personal computer (PC) for processing and distribution. This system requires one person with no special training to run the system as all components are within a small PC area. This company has sold more than 80 of these systems, at very competitive prices of less than $5,000 per station. SEE ALSO Communications for Human Spaceflight (volume 3); Communications

SATELLITE INDUSTRY (VOLUME 1); SATELLITE INDUSTRY (VOLUME 1); TRACKING OF SPACECRAFT (VOLUME 3); TRACKING STATIONS (VOLUME 3).

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Human Spaceflight Program

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The first human to go into space, Soviet cosmonaut Yuri Gagarin, made a one-orbit, ninety-minute flight around Earth on April 12, 1961. Up to mid-2001, only 407 additional humans (370 men and 37 women) have gone into orbit, some of them making multiple journeys into space. Most of these individuals were a mixture of career astronauts, trained either to pilot space vehicles or to carry out a changing variety of tasks in orbit, and **payload** specialists, who also went through extensive training in order to accompany their experiments into space. In addition, there were a few people who got the opportunity to go into space because of their jobs on Earth (e.g., U.S. politicians). Other individuals flew into space because their country or company had paid for access to space, thereby getting the right to name someone to participate in the spaceflight in exchange for that funding. For example, a prince from Saudi Arabia went into space aboard a space shuttle and helped launch a Saudi communications satellite. A Japanese jour-

Human spaceflight is becoming increasingly diverse, with an emphasis on international cooperation. Clockwise from right are Curtis L. Brown Jr., commander; Steven W. Lindsey, pilot; Stephen K. Robinson, mission specialist; Pedro Duque, mission specialist representing the European Space Agency; Chiaki Mukai, payload specialist representing Japan's National Space Development Agency; Scott F. Parazynski, mission specialist; and U.S. Senator John H. Glenn Jr. (D-Ohio), payload specialist.

nalist, representing his television network, went aboard the Soviet space station Mir.

Citizens in Space

The United States began a "citizen in space" program in the 1980s. The goal of the program was to identify ordinary individuals who could communicate the experience of spaceflight to the general public. The first person selected was a teacher, Christa McAuliffe. Unfortunately, she and six other astronauts were killed when the space shuttle Challenger exploded seventy-three seconds after liftoff on January 28, 1986. After the disaster, the United States abandoned the idea of taking ordinary people into space, and limited trips aboard the space shuttle to highly trained specialists. The restriction was relaxed in 2002, when Barbara Morgan, another teacher, was assigned to flight status.

The Challenger disaster was a vivid reminder that taking humans into space is a difficult and risky undertaking. It is also very expensive; the launch of a space shuttle, for example, costs several hundred million dollars. Only two countries, the United States and Russia (from 1922 to 1991 known as the Soviet Union), have developed the expensive capabilities required for human spaceflight. In 1999 China tested, without people on board, a spacecraft that could support humans in orbit.

Low Earth Orbit

Human spaceflight since 1961 has been limited to **low Earth orbit** (LEO) with the exception of the period from December 1968 to December 1972, when twenty-seven U.S. astronauts (three per mission) traveled to the vicinity of the Moon during Project Apollo. Of these astronauts, twelve actually landed on the Moon's surface and carried out humanity's first exploration of another celestial body.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Project Apollo was the result of a 1961 Cold War political decision by U.S. President John F. Kennedy to compete with the Soviet Union in space. Since the end of Apollo, advocates have argued for new exploratory missions to the Moon and especially to Mars, which is considered the most interesting accessible destination in the solar system. However, the lack of a compelling rationale for such difficult and expensive missions has meant that no nation, or group of nations, has been willing to provide the resources required to begin such an enterprise. A major human spaceflight issue is: Under what circumstances, if any, will people once again journey beyond Earth orbit?

The Soviet Program

During the 1960s the Soviet Union attempted to develop the capability to send people to the Moon, but abandoned its efforts after three test failures with no crew aboard. Beginning in the early 1970s the Soviet Union launched a series of Salyut space stations, which were capable of supporting several people in space for many days. Then in March 1986 the Soviet Union launched the larger Mir space station. Mir was continuously occupied for most of the subsequent fifteen years until it reached the end of its lifetime; it was de-orbited into the Pacific Ocean in March 2001. Soviet cosmonaut Valery Polyakov spent 438 days aboard Mir, the longest spaceflight

Canadian mission specialist Chris A. Hadfield stands on space shuttle Endeavour's remote manipular system, attached to the portable foot restraint.

by any person. After the United States and Russia began cooperating in their human spaceflight activities in 1992, U.S. astronaut Shannon Lucid visited Mir, and spent 188 days in orbit, the longest spaceflight by an American.

Human Spaceflight at the Turn of the Century

Human spaceflight at the turn of the twenty-first century thus remained a government monopoly. The possibility of privately operated, profit-oriented human spaceflight activities remained an elusive objective, though it was advocated by a variety of groups and individuals. However, a significant step in the direction of private spaceflight occurred in April 2001 when American millionaire Dennis Tito paid Russia to send him for a six-day visit to the International Space Station.

In the United States, the National Aeronautics and Space Administration (NASA) in 1996 began to turn over much of the responsibility for operating the space shuttle to a private company, United Space Alliance, which was jointly owned by Boeing and Lockheed Martin, the two largest U.S. aerospace firms. But NASA limited United Space Alliance's freedom to market space shuttle launch services to nongovernment customers, and NASA retained control over which people could fly aboard the shuttle. However, after Tito's flight, this policy was re-evaluated, and NASA decided to accept applications from paying customers for such flights. A privately funded corporation called MirCorp worked with Russia to try to keep the Mir station in operation, perhaps by selling trips to the space station for tens of millions of dollars to wealthy individuals or by other forms of private-sector use of the facility. Tito was Mircorp's first customer, but he could not be launched in time to travel to Mir before it was de-orbited.

The International Space Station and Beyond

The International Space Station, developed and funded by a sixteen-nation partnership, will offer opportunities for privately financed experiments in its various laboratories. It may be possible for those carrying out such experiments to pay NASA to send their employees to the space station to carry out such experiments. If research or other activities aboard the International Space Station prove to have economic benefits greater than the cost of operating the facility, it is conceivable that it could be turned over to some form of commercial operator in the future. If the International Space Station were fully or partially commercialized, and the various ways of transporting experiments, supplies, and people to and from the station were operated in whole or part by the private sector, the future could see the overall commercialization of most activities in LEO. If this were to happen, governments would act as customers for the transportation and on-orbit services provided by the private sector on a profit-making basis.

The most exciting vision for the future is widespread public space travel, sometimes called space tourism.✶ If this vision were to become reality, many individuals, not just millionaires or those with corporate sponsorship, could afford to travel into space, perhaps to visit orbiting hotels or other destinations. Much has to happen, however, before this would be possible. Most fundamentally, different forms of space transportation, much less expensive and much less risky to operate, need to be developed. Although there have been many proposals for such transportation systems, none of these proposals has yet come close to becoming reality. The technological challenges to developing such a system are formidable and are likely to require a government-industry partnership, given the high costs associated with overcoming those challenges. Until these challenges are met, human spaceflight is likely to remain restricted to a fortunate few. SEE ALSO ASTRONAUTS, TYPES OF (VOLUME 3); CAREER ASTRONAUTS (VOLUME 1); COSMONAUTS (VOLUME 3); HISTORY OF HUMANS IN SPACE (VOLUME 3); INTERNATIONAL SPACE STATION (VOLUMES 1 AND 3); TOURISM (VOLUME 1).

✶On April 25, 2002, South African Mark Shuttleworth followed in Dennis Tito's footsteps, traveling into space to become the world's second space tourist.

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Insurance

Every ten days, on average, another rocket carrying a telecommunications satellite thunders heavenward. This satellite might be destined to become part of the international telephone network, or to provide direct-to-home television, or be designed to provide a new type of cellular phone service or Internet backbone links. Regardless of its eventual purpose, a wide range of people around the world will be focused on its progress as its fiery plume streaks upward. Flight controllers monitor its position while the manufacturers of the satellite check critical systems. The satellite owners wait anxiously

It can cost hundreds of millions of dollars to build and launch a satellite. Because there is a 10 percent rocket failure rate, insurance is a critical element of space business.

to see if their critical investment will successfully reach its orbital destination. But there is another group of people, often overlooked, who also intensely monitor the fate of the rocket and satellite—the space insurance community.

The commercial space industry would not exist today without the space insurance industry. For example, in the case of a satellite slated for launching, unless the owners of and investors in the satellite are able to obtain insurance, the satellite will never be launched. A typical telecommunications satellite costs around $200 million. Another $80 million to $100 million is needed to launch this satellite into its proper orbit. Given the historic 10 percent failure rate of rockets, very few private investors or financial institutions will place this amount of money at risk without insurance to cover potential failures. Insurance is an essential part of the financing for any commercial space venture.

The Growth and Development of the Space Insurance Industry

The growth of the commercial space industry and the growth of the space insurance industry go hand in hand. National governments did not require insurance at the beginning of the space age, so it was not until the early 1970s, when companies decided to build the first commercial satellites for the long-distance phone network, that space insurance was born. In these early years the few space insurance policies were usually underwritten as special business by the aviation insurance industry.

The explosion of the space shuttle Challenger in 1986 marked a dramatic new phase in space insurance. The National Aeronautics and Space Administration (NASA) decided that the shuttle would no longer be used to launch commercial satellites. This forced commercial satellites onto **expendable launch vehicles**, which had a higher risk of failure than the relatively safe shuttle. Owners and investors actively sought insurance to protect their satellite assets, and this growing demand established space insurance as a class of insurance of its own.

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

The success of commercial satellites led to strong growth in the space insurance industry, which exceeded $2 billion revenue annually worldwide by 2001. Similarly, the ability to obtain insurance against failures enabled investors to achieve commercial financing for space projects. In turn, this stimulated the growth of the commercial space industry such that commercial spending on space projects equaled government spending in 1998. The role of space insurance in securing commercial financing is so well-established that government agencies, such as NASA and the European Space Agency, now also insure selected projects. This trend will continue and space insurance will play a central role in unlocking financing for new commercial ventures on the International Space Station and beyond.

Insurance—A Global Industry

Space insurance, like other forms of insurance, is a global industry. The largest concentration of companies is in London, where space insurance and insurance in general originated. Major companies exist all over the world, however, including in the United States, Germany, France, Italy, Australia, Japan, and Scandinavia. Virtually every country that has commercial satellites participates in the space insurance industry, either through direct underwriters or reinsurers. Reinsurers insure the insurance companies, agreeing to accept some of the risk for a fee. This spreading of risk is crucial, as it is difficult for one company or country to absorb a loss in the hundreds of millions of dollars from a single event. The global spreading of risk takes advantage of worldwide financial resources and is a fundamental aspect of the insurance industry.

Insurance premiums can vary from 4 percent to 25 percent of the project's cost depending on the type of rocket and satellite, previous history, and new technology being used and policy term. Accurate and up-to-date information is essential in setting rates and a major issue is government restrictions on the flow of technical information. Market forces and recent losses also affect rates. Rates were increasing in the early twenty-first century as companies adjusted to the very high insurance losses incurred from 1998 to 2000.

Brokers and Underwriters

The space insurance industry is essentially made up of two types of companies: the brokers and the underwriters. The broker's task is to put together an appropriate insurance program for the satellite owner, while the underwriter puts up security in the form of insurance or reinsurance. The broker identifies the client's insurance needs over the various phases of a satellite's life: manufacture, transport to the launch site, assembly onto the rocket, launch, in-orbit commissioning, and in-orbit operations. The broker then approaches the underwriting companies and asks how much coverage they will provide and what premium rate they will charge. Most underwriting companies will not take more than $50 million of any one risk. Hence the broker must often contact several underwriters to place the client's total risk at consistent rates. Once the package is agreed to, legal contracts complete the arrangements.

Jobs in Space Insurance

The space insurance industry can offer fascinating work for those interested in space. There are two main roles: the broker, who has a business development role—finding clients and negotiating insurance programs; and the underwriter, who leads the complex task of establishing the insurance rates. Experience in the space insurance industry is essential for both of these roles, and often a business, legal, financial, or technical background is required. Companies also have technical experts who understand satellites and rockets, a legal department for writing contracts, a finance department handling the accounts and money transfers, and a claims department for assessing losses and processing claims. Actuaries, who generally have a mathematics background, model the expected losses and help the underwriter and the technical experts set the rates.

As permanent habitation of space through the International Space Station leads to the discovery of new commercial opportunities, space insurance will evolve to cover these new commercial realities. Insurance remains an essential ingredient for commercial space business and will continue to play a vital role in humanity's growing commercial exploration of space. SEE ALSO Communications Satellite Industry (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Satellite Industry (volume 1); Search and Rescue (volume 1).

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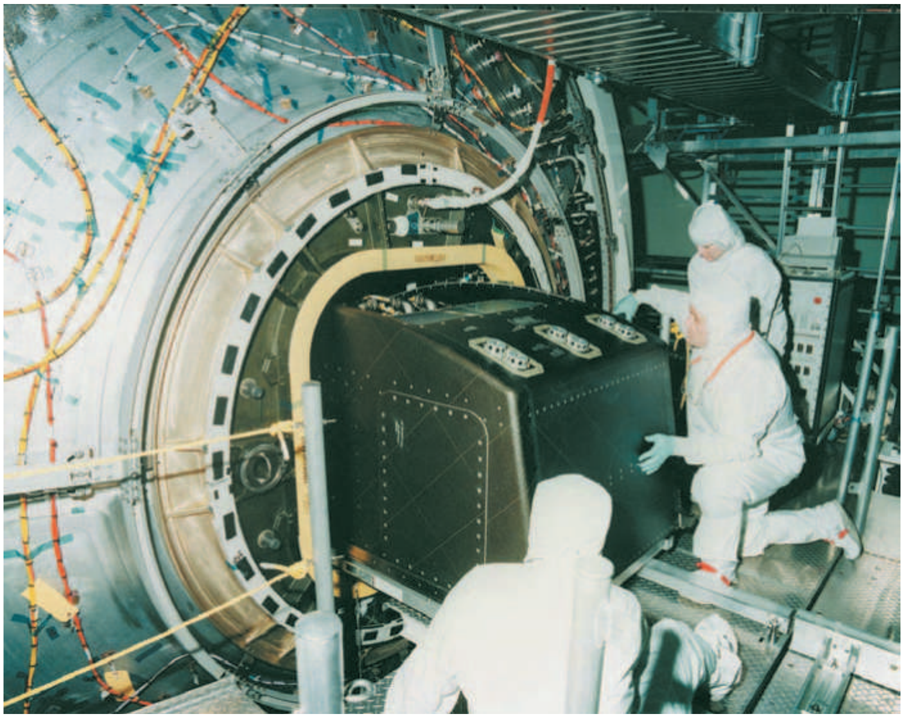
International Space Station

The International Space Station (ISS) is a scientific and technological wonder. It is a dream being realized by a multinational partnership. The ISS provides a permanent human presence in space and a symbol of advancement for humankind.✶ There is great promise and discovery awaiting those who will use the space station.

✶**The ISS has a wingspan that is over a football field long.**

Just as the global explorers of the fifteenth century circled the globe in their square-sailed schooners in search of riches—gold, spices, fountains of youth, and other precious resources—so too is the space station a wind-



Boeing technicians slide a systems rack into the U.S. Laboratory module intended for the International Space Station. The laboratory will contain 13 racks with experiments and 11 racks with support systems, with each rack weighing nearly 1,200 pounds.

jammer plowing the waves of space, exploration the riches it holds. The space station brings together the adventure of fifteenth-century explorers with twenty-first-century technology and industry. The space station is, at its essence, an infrastructure that will facilitate and transmit new knowledge, much like that provided through the virtual world of the Internet. In regard to the space station, the question is: From where will the value of this virtual world come? Or, put in terms of the fifteenth-century explorers, "What is the spice of the twenty-first century in the new frontier of space?"

At this stage, no one can guess what the most valuable and profound findings from space station research will be. Space research done to date, however, does point the way to potential areas of promise that will be further explored on the ISS. The space environment has been used to observe Earth and its ecosphere, explore the universe and the mystery of its origin, and study the effects of space on humans and other biological systems, on fluid flow, and on materials and pharmaceutical production.

The space station creates a state-of-the-art laboratory to explore ourselves and the world. The discoveries we have made to date in space, while significant, are only the foundation for what is to come. Research in **microgravity** is in its infancy. Throughout the thousands of years that physical phenomena have been observed, including the relatively recent 400 years of documented observations, it has been only in the period since the 1960s that experiments in microgravity of more than a few seconds have been observed; only since the late 1990s has there been a coordinated set of microgravity experiments in space. The most telling indicator is that by the end of 2001 more than half of all microgravity experiments had been conducted since 1998.

microgravity the condition experienced in free fall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

History is rife with failed predictions. Nevertheless, perhaps the best way to try to predict the future is to look at the evolution of the past, using

The view from space shuttle Atlantis following undocking from the International Space Station, after sucessfully outfitting the station for its first resident crew.

history and the current situation as a jumping-off point, while recognizing the challenge in predicting the future. The following represents an attempt to peer into the future, to see what promise lies ahead for the space station by looking at the past and the present.

Previous Advances from Space Activities

In the twentieth century, space exploration had a profound impact on the way we viewed ourselves and the world in which we live. Viewing our planet from space for the first time gave us a unique perspective of Earth as a single, integrated whole. Observations of Earth's atmosphere, land, and oceans have allowed us to better understand our planet as a system and, in doing so, our role in that integrated whole. Many aspects of our lives that are now taken for granted were enabled, at least in part, by investments in space. Whether making a transpacific telephone call, designing with a computer-aided design tool, using a mobile phone, wearing a pacemaker, or going for an MRI, we are using technology that space exploration either developed or improved.

In the early twenty-first century, commercial interests offer a myriad of products and services that either use the environment of space or the results of research performed in microgravity. Just a few examples include:

- *Satellite communications:* Private companies have operated communications satellites for decades. Today, private interests build, launch, and operate a rapidly expanding **telecommunications infrastructure** in space. The initial investment in space of the United States helped fuel the information revolution that spurs much of the nation's economy today.
- *Earth observation/remote sensing:* A growing market for Earth imagery is opening up new commercial opportunities in space. Private interests now sell and buy pictures taken from Earth orbit. Land-use planners, farmers, and environmental preservationists can use the commercially offered imagery to assess urban growth, evaluate soil health, and track deforestation.
- *Recombinant human insulin:* The Hauptman-Woodward Medical Research Institute, in collaboration with Eli Lilly and Company, has used structural information obtained from crystals grown in space to better understand the nuances of binding between insulin and various drugs. Researchers there are working on designing new drugs that will bind to insulin, improving their use as treatments for diabetic patients.

What all these discoveries have in common is that they use space as a resource for the improvement of human conditions. Efforts aboard the ISS will continue this human spirit of self-improvement and introspection. And the twenty-first century holds even greater promise with the advent of a permanent human presence in space, allowing that same spirit to be a vital link in the exploration process. The space station will maximize its particular assets: prolonged exposure to microgravity and the presence of human experimenters in the research process.

THINGS ARE CLEARER WITH HINDSIGHT

The commissioner of the U.S. Office of Patents said, "Everything that can be invented has been invented"—in the year 1899. In 1962 the Decca Recording Co. rejected the Beatles stating: "We don't like their sound, and guitar music is on the way out." More recently, in 1981 Microsoft Chairman Bill Gates said in reference to the computer, "64K ought to be enough for anybody."

telecommunications infrastructure the physical structures that support a network of telephone, Internet, mobile phones, and other communicaton systems

Potential Space Station–Based Research

The ISS will provide a laboratory that can have profound implications on human health issues on Earth. Many of the physiological changes that astronauts experience during long-term flight resemble changes in the human body normally associated with aging on Earth. Bone mass is lost and muscles **atrophy**, and neither appear to heal normally in space. By studying the changes in astronauts' bodies, scientists might begin to understand more about the aging process. Scientists sponsored by the National Aeronautics and Space Administration are collaborating with the National Institutes of Health in an effort to explore the use of spaceflight as a model for the process of aging. This knowledge may be translated into medical wonders, such as speeding the healing of bones and thereby reducing losses in productivity. By beginning to understand the process by which bones degenerate, scientists might be able to reverse the process and expedite the generation of bone mass.

atrophy condition that involves withering, shrinking, or wasting away

The microgravity environment offers the opportunity to remove a fundamental physical property—gravity—in the study of fluid flow, material growth, and other phenomena. The impacts on combustion, chemistry, biotechnology, and material development are promising and exciting. The combustion process, a complex reaction involving chemical, physical, and thermal properties, is at the core of modern civilization, providing over 85 percent of the world's energy needs. By studying this process on the ISS, commercial enterprises could realize significant savings by introducing new-found efficiencies.

Researchers have found that microgravity provides them with new tools to address two fundamental aspects of biotechnology: the growth of high-quality crystals for the study of proteins and the growth of three-dimensional tissue samples in laboratory cultures. On Earth, gravity distorts the shape of crystalline structures, while tissue cultures fail to take on their full three-dimensional structure.

The microgravity environment aboard the ISS will therefore provide a unique location for biotechnology research, especially in the fields of protein crystal growth and cell/tissue culturing. Protein crystals produced in space for drug research are superior to crystals that can be grown on Earth. Previous research performed on space-grown crystals has already increased knowledge about such diseases as AIDS, emphysema, influenza, and diabetes. With help from space-based research, pharmaceutical companies are testing new drugs for future markets.

In addition to these scientific findings, the ISS serves as a real-world test of the value of continuous human presence in space. There are already companies focused on space tourism and the desire to capitalize on the human presence in space. A myriad of future scenarios are possible, and the imagination of entrepreneurs will play a key role.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Inevitably, private interests will move to develop orbital infrastructure and resources in response to a growing demand for space research and development. The permanent expansion of private commerce into **low Earth orbit** will be aided as the partners of the ISS commercialize infrastructure and support operations such as power supply and data handling. This trend is already under way with several commercial payloads having flown on the space shuttle and on the ISS.

The ISS is an unparalleled, international collaborative venture. In view of the global nature of the ISS, the international partners (sixteen countries) recognize the value of consulting on and coordinating approaches to commercial development. Each international partner retains the autonomy to operate its own commercial program aboard the ISS within the framework of existing international agreements, and mechanisms of cooperation are possible where desired. SEE ALSO Aging Studies (volume 1); Crystal Growth (volume 3); History of Humans in Space (volume 3); International Space Station (volume 3); Made with Space Technology (volume 1); Microgravity (volume 2); Mir (volume 3); Skylab (volume 3).

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International Space University

As space programs become increasingly international and commercial in nature, the education of the space-sector workforce needs to continually adapt to maintain this pace. The International Space University (ISU) is dedicated to meeting this challenge by training the world's next generation of professionals who will lead the way into space.

The ISU provides postgraduate training for students of all nations who are interested in space. Each year, the ISU conducts a two-month summer program in various locations around the world. Examples of past ISU Summer Session locations include Thailand, Chile, Sweden, and the United States. In addition, the ISU provides a master of space studies program at its central campus in Strasbourg, France.

Because specialist knowledge alone is no longer sufficient to meet the challenges of complex space programs implemented by governments and companies from around the world, the ISU presents an interdisciplinary, international, and intercultural approach. The university provides participants with a thorough appreciation of how space programs and space business work. This is accomplished through extensive coursework in science, engineering, law and policy, business and management, and other space-related fields. In addition, all ISU students participate in a student design project that allows them to integrate their classroom learning in a complex, hands-on, practical exercise. Because this design project is conducted with classmates from all over the world, it allows ISU students to master the challenges of working with international teammates in an intercultural environment.

Since the first summer session in 1988, more than 1,500 students from more than 75 countries have reaped the benefits of an ISU education. Most of these students have gone on to work in successful careers in space and related fields. Universally, ISU alumni credit their professional success to the broad intellectual perspectives gained at the university as well as to their extensive international network of contacts in the space community. The university's interactive, international environment provides its students with continuous opportunities to forge professional relationships with colleagues and with its faculty, who also come from many different countries.

At an International Space University summer session, students learn about space suit design.

The Origins of the International Space University

The ISU was the brainchild of three young men✶ in their early twenties who, as college students, became interested in space exploration. Passionate about space, they proposed a university dedicated to a broad range of space-related subjects for graduate students from all parts of the world. With their enthusiasm, they succeeded in winning over important players in the space field, including science fiction author Arthur C. Clarke, who became chancellor of ISU. The founders' vision for the university was that it would be an institution dedicated to a peaceful, prosperous, and boundless future through the study, exploration, and development of space for the benefit of all humanity.

✶Peter H. Diamandis, Todd B. Hawley, and Robert D. Richards founded the International Space University.

The ISU began to materialize in the summer of 1988 as participants in the first ISU summer session gathered at the Massachusetts Institute of Technology in Cambridge. Four years after this initial session, Strasbourg, France, was selected as the site for the ISU central campus. The first master of space studies program was initiated in September 1995 following the move of the campus to Europe. SEE ALSO CAREERS IN SPACE SCIENCE (VOLUME 2); EDUCATION (VOLUME 1).

Margaret G. Finarelli

Internet Resources

International Space University. <http://www.isunet.edu>.

Launch Industry

The process by which satellites, space probes, and other craft are launched from the surface of Earth into space requires equipment, machinery, hardware, and a means, usually a rocket vehicle of some sort, by which these materials are lifted into space. The businesses that exist to service these launching needs form an international space transportation industry. That launch industry, also referred to as space launch service providers, has been estimated to generate $8 billion in total annual sales, with the United States earning about half of that amount. By comparison, the total U.S. sales of all aerospace equipment, including aircraft, missiles, and other space equipment amounted to $151 billion in 1999.

The space launch services industry is currently dominated by three firms: Arianespace in Europe, Boeing Launch Services in California, and International Launch Services of Reston, Virginia, which is owned by Lockheed Martin Corporation of Littleton, Colorado. While the three firms account for more than 80 percent of the world's commercial space launches, they are by no means the only firms in the business today. While the types of satellites being launched remain mainly civil, military, and large commercial communications craft, the evolution of the use of space may change that makeup in the decades ahead. Should that mix of cargo change, so too may the dominant launch service providers. There is a saying in the launch industry—"You are only as good as your last launch"—that may apply to this shifting outlook.

Launching this rocket requires equipment, machinery, and hardware, all of which are provided by businesses within the launch industry.

Complicating the degree to which specific businesses have specialized in the launching of different types of spacecraft is the nature of the competition itself. Experts and analysts in space transportation suggest as the twenty-first century begins that there are too many launch firms seeking too few satellites that need launching. Should such a trend continue, several of the smaller firms, and possibly elements of the larger ones, may go out of business in the years ahead.

The Origins of the Industry

The commercial launch industry has its roots in the Cold War missiles that formed the launching rockets of the early space age. Following the launching of the world's first artificial satellite of Earth, Sputnik 1, by the Soviet Union on October 4, 1957, the governments of the USSR and the United

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

States were the only entities that possessed space launch vehicles. The fleets of intercontinental **ballistic** missiles developed by the two nations served as the basis for the only rockets big and powerful enough to **orbit** satellites into space. The launching rockets were mainly used to place government spacecraft into Earth orbit or towards the Moon or other planets. During the period of the late 1950s to early 1960s there were no commercial satellites in existence for which commercial launchers were needed. All spacecraft were owned by the civil or military part of the governments of the Soviet Union and the United States.

When foreign nations that were aligned with either country needed a satellite launch in the mid-1960s, the satellite was shipped to the launching site of the United States or USSR and launched. But eventually the technology of satellites matured to the point where other nations sought to have their own space programs. In Europe, the United Kingdom, France, and Germany each developed varying types of spacecraft that were launched by the United States from its existing sites at either Cape Canaveral in Florida or Vandenberg Air Force Base in southern California. Japan, Brazil, and China also developed satellite technology. Nations aligned with the USSR included Mongolia, China, and other Southeast Asian nations. France and China were among the first nations other than the United States and USSR to develop their own independent space-launching rockets. Japan developed a version of the U.S. Delta space booster under a licensing agreement with McDonnell Douglas Corporation, although the technology of the launching rocket was carefully protected by the United States.

The Development of Arianespace

Eventually, by the mid-1970s, Europe sought to develop a commercial means of launching European-made military, civil, and commercial satellites. The United States had begun the development of the partially reusable space shuttle during this period, and France was left out of the shuttle's development. In partial response, France and several European countries came together to establish the European Space Agency and an entity called the European Launch Development Organization. Among their first objectives was the development of a commercial space-launching rocket that would be entirely made within the nations that were part of the space organization. The company that emerged from that effort was named Arianespace, and its family of throwaway expendable rockets was called Ariane.

Ariane was unlike the Soviet R-7 and Proton rockets and U.S. Delta and Atlas rockets because it was not based on an existing ballistic missile design but was instead created from the start as a commercial launching vehicle. The company was established in March 1980 and conducted its first launch on May 24, 1984.

Arianespace has evolved to capture about half of the existing market for space launch services, conducting more than 130 commercial launches of different types of Ariane rockets by 2000. The company, based in France with a staff of 350 employees, launched forty-four satellites during a three-year period from 1995 to 1997, a world's record. In the first years of the twenty-first century, Arianespace was in the process of phasing out a smaller rocket called Ariane 4 and phasing in a larger replacement rocket called Ariane 5. At the end of 2001, Arianespace reported that it had contracts for

Arianespace of Europe is one of three firms that currently dominate the global launch services industry. The Ariane 4 rocket, seen here, is being replaced by the larger Ariane 5.

the launch of 216 satellites and nine automated flights of cargoes to the International Space Station. Its launching base is in Kourou, French Guiana, on Earth's equator.

The Rise of Delta and Atlas

In the United States, government-controlled launches of expendable rockets were to end in the early 1980s as the space shuttles became operational. By a national decision made by the National Aeronautics and Space Administration (NASA) in 1972, the shuttles were to become the sole means by which U.S. satellites of any type could be launched into orbit. The throw-away expendable rockets, all based on earlier generations of ballistic missiles, were to be completely replaced by the shuttles. But the development of the shuttle took longer and was both more expensive and less reliable than was promised. By the mid-1980s the U.S. Department of Defense, a major customer for space shuttle launches, elected to continue production of the Delta and Titan launching rockets as alternates to the shuttles for launches of military spacecraft. In 1985 President Ronald Reagan announced a shift in U.S. space policy that would allow both civil and government satellites to be launched on these expendable rockets as well as the shuttles.

Following the explosion of the space shuttle Challenger in January 1986, a further shift in policy diverted satellite launches away from shuttles entirely. The shuttles would launch only those satellites that could not be flown aboard any other vehicle. This policy shift in the mid-1980s would serve to reinvigorate the U.S. space launch industry, which had lost most of its share of space-launching services during the period when the shuttles were taking over the launching of all U.S. satellites.

Commercial versions of the Delta and Atlas rockets, partially funded by the Defense Department and NASA, soon entered service to compete against the Arianespace vehicles. McDonnell Douglas began offering a commercial Delta II rocket as a launching vehicle. General Dynamics Corporation and Convair Astronautics began selling larger Atlas rockets. A third commercial rocket based on the huge military Titan III booster was also sold commercially but only for a brief period. Its builder, Martin Marietta Corporation, could find only two customers before it was phased out. Titans were relegated to missions for the U.S. military.

Following the end of the Cold War in the early 1990s, the U.S. aerospace industry contracted through a series of mergers and acquisitions. Martin Marietta acquired the line of Atlas rockets, adding them to its stable of military Titan boosters. The Boeing Company acquired McDonnell Douglas and its Delta boosters. Eventually, Martin Marietta was itself acquired by Lockheed Corporation, forming Lockheed Martin Corporation. By the mid-1990s the U.S. launch industry was comprised of Boeing, Lockheed Martin, and a smaller firm called Orbital Sciences, which sold two smaller rockets, the winged Pegasus and the Taurus.

Russian Launchers

The changes wrought by the end of the Cold War affected the Soviet Union's space-launching programs as well. Commercial sales of the Proton rocket were conducted initially by a government-industry partnership called Glavcosmos in the early 1980s. But after the Cold War ended, Protons were made commercially available as part of the rocket catalog being assembled by Lockheed Martin. A separate firm called International Launch Services (ILS) was established in June 1995 to sell both Atlas and Proton rockets on the world's commercial market. ILS, jointly owned by the U.S. firm Lockheed Martin and the Russian rocket design companies Khrunichev, and Energyia, reported a backlog of $3 billion worth of rocket contracts in 2000 and conducted six Proton and eight Atlas launches during that year.

But the Proton rockets were not the only commercial launching vehicles available from Russian space factories. A modified version of the Russian Zenit rocket was being sold by a consortium comprised of Boeing, Ukrainian rocket firms, and a Norwegian company that builds drilling ships. The resulting company, called Sea Launch, launches the Zenit rockets from a floating launching pad towed to the mid-Pacific Ocean. Starting in 1999, Sea Launch began conducting annual launches with only one failure through 2001.

Yet a third commercial rocket is being marketed from Russia, and this one has an historic pedigree. The R-7 space booster, which launched the Sputnik 1 in 1957 and the world's first human in space, Yuri Gagarin, in 1961, is also for sale today. Starsem, a company partly owned by Arianespace, is selling the R-7 in various designs and launching them for customers from the same launching pads used in 1957 and 1961. Starsem officials say their business plan requires only one launch per year to be viable. Through 2001 the Starsem R-7 rockets, called Soyuz, have been commercially launched without any failures. Other versions of the Russian Soyuz rockets used by the Russian government carry cosmonauts to the International Space Station—and also carried space tourist Dennis Tito to the space station in April 2001.

Japan in Space Launch

Following the use of a licensed version of the Delta rocket, the Japanese government developed its own series of space launchers. In 1977 Japan began a series of studies aimed at creating a wholly Japanese-made commercial rocket. The first of the resulting rockets, called H-I, was flown in 1986, and eventually nine of the boosters were flown until 1992. A much larger rocket, called H-II, was developed for the Japanese government. While chiefly intended for Japan's own government satellites and other **payloads**, a commercial version was planned. Development of the H-II, however, was slowed by launch failures, and the program was terminated in 1999. It was replaced by the more advanced—and cheaper—H-IIA. The H-IIA made its first test flight in 2001 with commercial sales planned by 2003. This rocket would compete against the larger series of Delta, Atlas, and Ariane launchers.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

China Tries to Compete

China also has sought to develop commercial launching vehicles, with all of them based on the nation's early missile design programs. The Long March series of rockets, available in different sizes, each capable of lifting different types of satellites, became available in July 1990 following the first test flight of the Long March 2E. A second commercial vehicle, the 3B, was also offered for commercial flights. American satellites using the Long March as launching vehicles require special export licenses. Geopolitical issues have also occasionally made sales of the rocket difficult or impossible for Western customers. Several spectacular failures of the vehicles have also hampered sales. By 2001, however, advanced systems had restored the Long March to flight without failure, and a larger version began launching test versions of a future Chinese piloted space capsule. Chinese government officials have indicated that systems from the space capsule versions will be used on commercially available craft, further strengthening China's position as a provider of space launch services.

India Enters the Fray

polar orbits orbits that carry a satellite over the poles of a planet

The Indian government has also been developing a family of space launch vehicles that will also be offered for commercial sales. The PSLV and GSLV expendable rockets have been tested for launching satellites into **polar orbits** as well as launching larger commercial communications craft. A successful flight of the GSLV occurred in 2001. India has created a commercial company to market the GSLV, but a flight rate of only one or two a year is expected by around 2005.

Other Competitors in the Industry

Brazil planned to also develop and market a smaller commercial rocket called the VLS. A launch failure, however, placed the project's future in doubt. Israel also has developed a commercial rocket, adapted in part from its ballistic missile program. Thus far, launches of the rocket, called the Shavit, have been limited to Israeli satellites. Efforts to base the Shavit at launch sites other than in Israel have not been successful. Pakistan and Indonesia have expressed interest in developing space-launching rockets, but neither has yet developed a final configuration for commercial sales. The Indonesian government made an announcement in 2000 that development of a commercial space booster was a major priority, but no reports have been seen as to the project's fate. North Korea claimed a test flight of a satellite launcher in 1998. Many Western observers believe, however, that the rocket is a ballistic missile and is not yet in a launch vehicle design configuration.

Russia has several new designs of expendable rockets on the drawing boards, including a rocket called Angara that may replace the Proton for commercial sales late in the new century's first decade. In 2001 the United States began fielding a new family of rockets called the evolved expendable launch vehicle (EELV). Both Boeing and Lockheed Martin were selling EELV versions, called the Delta IV and Atlas V, respectively.

Since the failed attempt at selling commercial launching services aboard the space shuttles, no nation has yet offered launches aboard a reusable launch vehicle. Many companies are hard at work in the United States and Canada, trying to be among the first to offer commercial launching services for space tourists or others aboard a reusable craft. With changes continuing to affect the space industries of the world, and new technologies in development, no one can predict the future direction of the space launch industry. The people and equipment seeking rides to space are as varied—and unpredictable—as the evolution of the rocket itself. SEE ALSO Augustine, Norman (volume 1); Global Industry (volume 1); Launch Facilities (volume 4); Launch Sites (volume 3); Launch Vehicles, Expendable (volume 1); Satellites, Types of (volume 1); Spaceports (volume 1).

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Launch Services

Commercial launch services are used to place satellites in their respective orbits. Launch services represent, by far, the most lucrative aspect of the launch-for-hire business. The European Space Agency (ESA), United States, Russia, People's Republic of China, India, and some international organizations supply or plan to supply launch vehicles for the purpose of placing satellites in orbit. Although the majority of launch vehicles are used for

A Delta rocket lifts off at Cape Kennedy carrying the world's first commercial communications satellite, Early Bird. The satellite, launched in 1965, was intended to operate as a switchboard relaying radio, television, teletype, and telephone messages between North America and Europe.

broadcast satellites, satellites are also launched for wireless telephony. For example, the mobile communications systems Globalstar and Iridium Satellite LLC are cell phone satellite networks for global use.

Europe

By 2000 the ESA's Arianespace Consortium had 125 launchings of orbit communications satellites (comsats). The basic first stage of a launch vehicle has four liquid propellant engines, but the Ariane launch vehicle has great versatility because of the number of engines that can be attached to its first stage. Two solid or two liquid propellant or two solid and two liquid propellant or four liquid propellant engines can be added to the first stage. This permits a wide variety of payloads to be placed in orbit. Arianespace also operates a heavy-lift rocket, the Ariane 5, which is intended mostly for commercial use but can be used for other purposes: the launching of scientific and military spacecraft, for example.

United States

In the United States two companies dominate the launching business, Lockheed Martin (LM) and Boeing. LM supplies the various configurations of the Atlas/Centaur launch vehicle, and Boeing offers the Delta class of launch vehicles, including Delta II, Delta III, and Delta IV. The mass of payload that each Delta can lift into **orbit** distinguishes them from other launch vehicles. The Delta vehicles can have various additional solid propellant engines attached to their first stage, allowing still further variations in payload-lifting capability. For example, three or six or nine solids may be attached to the first stage of the Delta II.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

LM's Atlas/Centaur can have variations in the type of first stage engines used or the size of first stage propellant tanks. LM has a business arrangement with the Khrunichev and Energia companies of Russia for the manufacture and use of a rocket engine developed by Russia that will be used in the first stage of the Atlas. It will be a replacement for the less powerful engines that have been used in the past.

In conjunction with Russian companies, LM uses the Russian four-stage Proton launch vehicle to launch payloads mostly to **geosynchronous orbit**. Proton has also been used to launch Iridium satellites, seven at a time, into a 800-kilometer (480-mile) orbit.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Russia

The Russians use their Proton launch vehicle for their own launches as well. In addition, a French-Russian company called Starsem uses the Russian Soyuz to launch commercial payloads. Soyuz is a modification, largely in its upper (third) stage, of the launch vehicle used to send cosmonauts to the Mir space station.

Eurokot, a German-Russian organization, uses modified Russian intercontinental ballistic missiles, known in the Western world (i.e., the North Atlantic Treaty Organization [NATO]) as the SS-19, Stiletto, to place payloads in **low Earth orbit**. All stages of these are made of solid propellants. They are launched from silos buried deep in the ground (like the U.S.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

The European Infra-Red Space Observatory (ISO) was launched by the Ariane 44P from Kourou space center in French Guiana in 1995. The launch was the rocket's eightieth.

Minuteman missiles). They have seen very limited use for payloads of about two tons, which means they are restricted to launching wireless telephony satellites and other small payloads.

Russia is developing a new series of rockets called Angara, which are intended to replace many of Russia's present stable of launch vehicles both for commercial and private use. The payload capability can range across the entire spectrum of currently available Russian rocketry and extend beyond to larger payloads.

China

The People's Republic of China has developed a series of rockets, all called Long March. The rockets range from a two-stage Long March 2C used to launch a pair of Iridium satellites to the three-stage Long March 3B used for launching comsats to geosynchronous orbit. China's ability to launch comsats, most of which are manufactured in the United States, has been hampered by political differences between the two countries. During the period 1998 to early 2000 very few U.S.-built satellites were exported to China for launching because of changes in U.S. export controls for space hardware.

Other International Organizations

A number of other launch vehicles are available which have seen limited use in very specific areas. The Pegasus and Taurus, built by the Orbital Sciences Corporation of the United States, have launched small payloads of 400 kilograms (880 pounds), among which have been clusters of seven small comsats used for the transmittal of data for business.

The country of Ukraine together with a division of Boeing, the Russian Energia Company, and the Norwegian company Kvaerner Maritime (a ship and oil rig builder) have formed Sea Launch. Sea Launch consists of a command ship, a former oil rig converted to a seagoing launching platform, a two-stage rocket called Zenit, and a third stage for the Zenit. The platform and the ship are based at Long Beach, California, and travel to longitude 154 degrees west on the equator for launching. This procedure takes advantage of Earth's rotation speed, thus adding 1,524 feet/second at the equator for the Zenit 3SL, either reducing the amount of propellant needed or permitting an increase in payload weight. Sea Launch has successfully flown a simulated payload and has launched five commercial communications satellites.

Reusable Launch Vehicles

The only reusable rocket to date is the U.S. space shuttle. The system that launches it is only partially reusable because the large tank holding liquid propellant is discarded after each launching and the solid rockets that are recovered from the ocean need extensive refurbishment at considerable expense before their reuse. Reusability is a much desired but not a realized concept. There have been paper studies, but nothing has been fully tested, leaving the commercial worth of reusable launch vehicles still in question.
SEE ALSO Launch Facilities (volume 4); Launch Industry (volume 1); Launch Sites (volume 3); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Rockets (volume 3); Spaceports (volume 1).

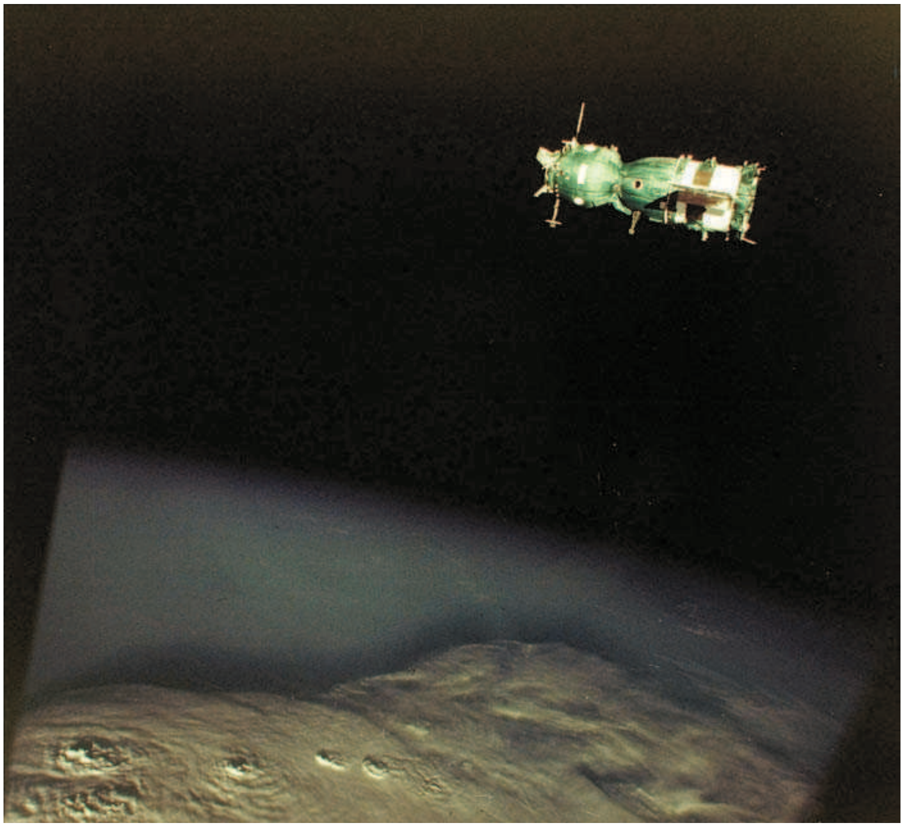
Saunders B. Kramer

Internet Resources

Arianespace. <http://www.arianespace.com>.
Boeing. <http://www.boeing.com>.
Lockheed Martin. <http://www.lockheedmartin.com>.

Launch Vehicles, Expendable

Expendable launch vehicles (ELVs) are rockets that carry satellites, people, and space probes but are not recovered or reused. These rockets are ex-



The Soviet Soyuz spacecraft as photographed from the American Apollo spacecraft in Earth orbit in July 1975. The three major components of the Soyuz craft are easily visible: the Orbital Module (sphere-shaped), the Descent Vehicle (bell-shaped), and the Instrument Assembly Module (cylinder-shaped).

pendable, meaning that they are thrown away after their flights are completed. Expendable rockets can take many forms, but the most commonly used ones are powered by either liquid fuel or solid fuel and use multiple stages to propel their cargoes of spaceships, probes, or satellites into outer space.

Each of the rocket's stages consists of a self-contained rocket engine or motor and the fuel such as hydrogen, kerosene, or a solid fuel that looks a lot like the eraser on a pencil. Along with the engine and fuel are tanks to hold the materials, lines and pumps, and electrical systems to move the engine while in flight. Once the fuel in the stage has been used up, the stage is usually dropped away and the next stage ignited. These rockets continue to burn stage by stage until the right altitude or speed for its designated space mission has been reached.

Evolution from Military Missiles

Expendable rockets are used today by the United States, France, China, Brazil, Russia, India, and Israel to place satellites into Earth **orbit** and toward the Moon and planets. Most of the rockets now in use as launching vehicles evolved from missiles developed during military conflicts such as World War II (1939–1945). Beginning with a German missile called the V-2, these weapons were created to carry large high-energy explosives to hit cities or troop encampments. Later, after World War II ended, larger

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object and more powerful missiles were created to carry nuclear weapons to targets on the other side of Earth.

Two nations, the United States and the Soviet Union, were the first to develop these large bomb-carrying missiles. After World War II ended, the German scientists who designed the V-2 missile fled Germany. Some of them surrendered to the United States, while others escaped to the Soviets. Each group of German scientists, engineers, and technicians sought to continue the development of rocketry and missiles in their new countries. In the Soviet Union, missile development was made a top priority by the Communist government. Part of the reason for the emphasis on missiles was the Soviet Union's lack of jet-powered bombers that could carry atomic bombs from Russia to targets in the United States. If large missiles could be built successfully, they could carry the bombs to their targets.

In America, Wernher von Braun headed the group of German rocket and missile experts. Von Braun was the head of the German missile program and was considered to be the most advanced expert on rocketry designs during and after the war. In the Soviet Union, his counterpart was Sergei Korolev, who was designated by the Soviet government as the "Chief Designer" of human-carrying and large expendable rockets.

Korolev became the head of a large central design bureau, and his "customers" were the specific missions assigned to his bureau. These included the design, manufacture, and test of the first Soviet intercontinental **ballistic** missile, the R-7; the first- and second-generation human-carrying space capsules, called Vostok and Soyuz; and a series of larger and more advanced liquid-powered expendable rockets, called Proton and N-1. These latter rockets were to be used in the Soviet lunar-landing program. The original purpose for the Proton, however, was as a very large missile that could fly from Russian bases and attack targets in the United States. The missile version of Proton was never developed, and instead it became a launching rocket for heavy **payloads** and space probes to the planets. Proton was also designated as the carrier rocket for the Soviet piloted lunar space capsule, called Zond.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

In America, von Braun developed a series of liquid-fueled rockets called Juno and a large army missile called Redstone. These rockets were adapted for scientific space missions by von Braun's team working at the Redstone Arsenal in Huntsville, Alabama. By emplacing a small basket of solid rockets on the nose of the Juno II, von Braun was able to insert a small U.S. satellite into Earth orbit on January 31, 1958, marking the first U.S. artificial Earth satellite. Korolev did the same with the R-7, launching the Sputnik satellite three months earlier, on October 4, 1957.

Improvements to U.S. and Soviet Rockets

Increasingly, both the United States and the Soviet Union made improvements to their missiles that made them capable satellite and space capsule launchers. The U.S. equivalent to the Soviet R-7 was an intercontinental ballistic missile named Atlas. Developed initially for the U.S. Air Force to carry atomic warheads to targets in the Soviet Union, the air force and the newly created National Aeronautics and Space Administration (NASA) modified the missile's design to replace its bomb-carrying nosecone. In the nosecone's place, with reinforced nose sections, the Atlas could carry an ad-

Expendable rockets similar to this Ariane 4 rocket are critical to civil, military, and commercial satellite launches.

ditional liquid-fueled rocket stage that could send payloads—satellites, capsules, or space probes—into orbit or to the Moon or Mars.

In 1959 the Atlas missiles were modified to carry Project Mercury one-person space capsules, just as Korolev had done with the R-7 and its Vostok and Soyuz capsules. Eventually the Atlas and R-7 each received more powerful engines and larger upper stages. While the Mercury and Vostok projects have long since ended, both the Atlas and R-7 rockets are still in service, using advanced subsystems and powerful upper stages. Both are being sold today on the commercial space launch market, competing with each other for commercial sales.

The Atlas and R-7 were not the only throwaway rockets to evolve during the Cold War. The United States took a smaller and more limited intermediate range rocket called the Thor and adapted it for launching scientific space probes, beginning in 1960. Eventually the Thor grew to become, under the name Delta, one of the most reliable space launchers in history. In its Delta II, III, and IV variants it is still in government, military, and commercial use today.

Von Braun also developed the only U.S. throwaway rocket that was created from scratch and not evolved from missiles. From October 1961 until May 1973 three versions of a rocket called Saturn were used by NASA to support the man-on-the-Moon program called Project Apollo. The larger of these rockets, the Saturn V, sent Apollo astronauts to the surface of the Moon from 1969 to 1972 and lifted America's first space station, Skylab, in May 1973. Skylab itself was developed from the upper stage of the Saturn V rocket.

Briefly, the Soviet Union developed an expendable rocket called Energyia that was not developed from a missile. It flew in 1988 and 1989, in one flight carrying the unpiloted Buran space shuttle. The collapsing economic situation in Russia forced the abandonment of the Energyia program after those two flights.

The Evolution of Other Nations' Expendable Rockets

The launch vehicles used by China also evolved from ballistic missile designs. But the expendable rockets developed and flown by Japan, Brazil, and India are all new designs that had no direct missile ancestor, although all were strongly influenced by missile systems in use at the time. Israel's expendable rocket, a small booster named Shavit, is believed to have evolved from that nation's Jericho missile program.

France's fleet of commercial Ariane rockets were also created entirely apart from any missile project. Since 1979, Ariane rockets have been launching commercial satellites for customers worldwide, French military and government payloads, and payloads for the European Space Agency and the French Space Agency, CNES.

Today, expendable rockets are the mainstay of civil, military, and commercial satellite launches. The R-7 is still flying as the booster that lifts the Soyuz piloted space capsules. A commercial version is also for sale, flying from the same launching pad where the first satellite, Sputnik 1, and the first human, aboard Vostok 1, were launched in 1957 and 1961, respectively. The U.S. Atlas and Delta rockets are expected to be flying well into the twenty-first century, as are the Chinese missile-derived space boosters. The era of the expendable rocket may prove to be a long one in the evolving history of the space age. SEE ALSO Launch Facilities (volume 4); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Rockets (volume 3); Spaceports (volume 1); von Braun, Wernher (volume 3).

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Launch Vehicles, Reusable

A reusable launch vehicle (RLV) is a craft designed to place **payloads** or crews into Earth orbit, and then return to Earth for subsequent launches. RLVs are designed to reduce launch costs by reusing the most expensive components of the vehicle rather than discarding them and building new

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The aim of the X-34 program was the development of low-cost space access through reusable launch vehicles.

ones for each mission (as is the case with expendable launch vehicles, known as ELVs). The definition of RLVs does not include reusable craft launched from expendable launch vehicles. As of 2001, the only operational RLV was the U.S. space shuttle. A number of concepts were being developed or studied. Some were partially reusable. Most employed rockets, while others used jet engines, aircraft, or high-speed rail systems.

RLVs may be categorized by whether the vehicle takes off horizontally or vertically and whether it lands horizontally or vertically. An RLV may also be described as single-stage-to-orbit (SSTO) or two-stage-to-orbit (TSTO). Vehicles such as the space shuttle, which takes off vertically using a two-stage system and lands horizontally, have the easiest design because horizontal takeoff involves more demanding flight loads, vertical landing requires the craft to carry enough propellants to land, and SSTO requires a higher ratio of propellant to vehicle weight. Nevertheless, the economics of preparing a single stage, rather than two stages, have kept space engineers interested in SSTO designs. Future RLVs also are expected to employ more advanced, reliable systems, making them safer than expendable launch vehicles, and thus allow launches from inland sites (i.e., no stages to splash down into the ocean), perhaps even airports, where weather is less of a concern than at coastal spaceports.

Early Concepts

Because it was easier to adapt existing military missiles, which are designed for a single flight, most launchers have been expendable. Nevertheless, space visionaries have often focused on RLVs. One of the most significant early concepts was a three-stage vehicle designed by German-born American engineer Wernher von Braun in 1952 and popularized in his book *Across the Space Frontier*. The first two stages would parachute into the ocean for recovery while the winged third stage, carrying crew and cargo, landed like an airplane. The 1951 movie *When Worlds Collide* depicted a rocket-powered sled that gives a vehicle its initial boost.

Several RLV concepts were advanced in the 1960s. Notable among these was a reusable design by a man named Philip Bono, then with Douglas Aircraft Company. His design comprised a core vehicle holding a payload bay, liquid oxygen tank, and a ring of small rocket engines around the base. Liquid hydrogen was carried in external tanks that could be hinged outward to enhance atmospheric control during entry. This unique engine arrangement followed the aerospike concept developed by Rocketdyne. In this approach, the pressure from the shock wave produced by the vehicle's high-speed ascent becomes the outer wall of the engine nozzle from which the exhaust streams. The resulting exhaust appears to be a spike of hot gas, thus leading to the nickname "aerospike."

In the late 1960s the U.S. aerospace industry offered a number of reusable designs as the National Aeronautics and Space Administration (NASA) sought ways to reduce the cost of space launches. Maxwell Hunter, then with Lockheed Missiles & Space Co., proposed a wedge-shaped reusable vehicle with main engines in its tail, and a large external tank that was shaped like an inverted V and was wrapped around the nose of the vehicle. The tank would be discarded after its propellants had been consumed, leaving the main body to return to Earth.

Space Shuttle

Following the Apollo 11 Moon landing in 1969, NASA proposed a space program that would provide the basic building blocks in support of a wide range of human space missions: a space shuttle, a space station, a space tug, and a nuclear interplanetary stage. In this plan, the space shuttle was a fully reusable vehicle. The booster would fly back to the launch site after launch, and the orbiter at the end of the mission; both would be quickly prepared for the next mission. NASA soon realized that such a massive craft would cost more than it could afford. A series of redesign efforts traded the high development cost and low per-flight cost of the original design for a lower development cost and a higher per-flight cost. Literally dozens of variations were studied before arriving at the final design. One interesting variation employed two piloted flyback boosters and a piloted orbiter outwardly identical to the boosters. The concept was to reduce costs by designing one airframe for two purposes. This design meant, however, that three vehicles had to be prepared for each launch. The Soviet Union largely copied the final space shuttle design for its Buran shuttle, which flew only once.

Advanced RLVs

Even before the shuttle started flying, designers continued to look at advanced reusable concepts, such as North American Rockwell's immense winged StarRaker, which was envisioned as taking off and landing like a jetliner. The SSX (Space Ship eXperimental) proposed by Hunter in 1984 was based on an earlier design of a passenger vehicle. Hunter's efforts helped lead to a U.S. Department of Defense (DoD) project that opened the current reusable era. The DoD's purpose was to design a single-stage vehicle that could orbit military replacement satellites during a national emergency.

NASA and several private ventures have initiated the development of reusable launch vehicles, such as this artist's concept of an express rocket, for the promotion of space tourism.

McDonnell Douglas Corporation was contracted to build and test fly the DC-X, a one-third-scale suborbital model of the Delta Clipper, a larger version that would launch satellites on short notice. While not capable of spaceflight, the DC-X incorporated many of the technologies needed for an SSTO vehicle, including highly automated systems enabling a quick turnaround (just twenty-six hours) between launches. It made eight successful test flights between August 18, 1993, and July 7, 1995, and then was taken over by NASA and flown four times as the DC-XA between May 18 and July 31, 1996. It was destroyed on its last flight when one landing strut failed to deploy and the vehicle tipped over at landing.

The DC-X led NASA to a broader launch vehicle technology program to reduce the cost of putting a payload in space from $22,000 per kilogram ($10,000 per pound) to $2,200 per kilogram ($1,000 per pound) or less. The principal programs as of the early twenty-first century were the X-33 and X-34. The X-33 was a one-third-scale test model of the Lockheed Martin concept for VentureStar, an automated vehicle capable of launching up to 18,650 kilograms (50,000 pounds). In operation, VentureStar would launch, orbit, and land much as the shuttle does, but without discarding boosters or tanks. Other major differences include systems that can be readied for reflight with less maintenance (or no maintenance) than the shuttle requires. Significant structural and other problems raised the cost of the X-33 project and in 2001 NASA canceled the project. Also canceled was the X-34, a demonstration vehicle built largely from commercially available parts. It would have been launched from a jumbo jet, flown to an altitude of 76,200 meters (250,000 feet) and then glided to Earth for landing. It, too, encountered severe technical problems.

In place of the X-33 and X-34 programs, NASA initiated the Space Launch Initiative (SLI) program to study more conventional two- or three-stage-to-orbit second-generation RLV, possibly using the aerospike engine concept, which looked promising in the X-33 project. The important underlying features would be new electronics and materials that would allow automated preparation and checkout of vehicles and more rapid launches, and highly automated manufacturing processes. Goals include reducing the risk of crew loss to once per 10,000 missions, and the cost of launches to less than $1,000 per pound of payload in orbit. Beyond the second-generation RLV, NASA is looking at advanced space transportation concepts that could realize the earlier dreams of combining jet rocket combustion cycles in a single power plant, use electromagnetic railways as an Earthbound booster stage, or even laser- and microwave-powered craft.

In addition to NASA's efforts, several private ventures have initiated activities to develop RLVs for business, including space tourism. Most have stalled or failed for lack of financial backing. The Roton, conceived by Rotary Rocket, would employ high-speed helicopter blades to provide controlled flight following reentry (a concept studied by NASA in the 1960s). The vehicle would have a two-person crew, would launch vertically, and could place a 2,600-kilogram (7,000-pound) payload into orbit.

In 1996 the X PRIZE was announced. Like the Orteig prize, which stimulated aerial flight across the Atlantic Ocean (and was won by Charles Lindbergh with the first nonstop New York–Paris flight in 1927), the X PRIZE is intended to stimulate nongovernmental space travel, including tourism. It will award $10 million to the first entrant that achieves a nongovernmental, suborbital flight reaching 100 kilometers (62 miles) in altitude with pilot and payload equivalent to three people total, and makes a repeat flight within two weeks. Burt Rutan, creator of the Voyager round-the-world aircraft, is designing the Proteus vehicle, which will air-launch one of the competing spacecraft. SEE ALSO Launch Services (volume 1); Launch Vehicles, Expendable (volume 1); Reusable Launch Vehicles (volume 4); Rockets (volume 3); Spaceports (volume 1); von Braun, Wernher (volume 3); X PRIZE (volume 1).

Dave Dooling

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Law of Space

The law of space is the field of the law that relates to outer space or outer space-related activities conducted by governments, international organizations, and private individuals. International space law governs the activities of states and international organizations, whereas domestic, or national, space law governs the activities of individual countries and their citizens. Both areas of space law govern the activities of private persons and businesses.

International Space Law

Soon after the launch of the Soviet satellite Sputnik in 1957, the United Nations became active in the creation, development, and implementation of a system for studying the legal problems that may result from the exploration and use of outer space. Since the establishment of the United Nations Committee on the Peaceful Uses of Outer Space in 1958, five major multilateral treaties and conventions have been adopted or ratified by many countries to establish the framework to address concerns about outer space matters:

1. The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (1967), commonly known as the Outer Space Treaty, established basic principles regarding outer space and its exploration and use, including the conduct of activities pursuant to international law;
2. The Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (1968), commonly known as the Rescue Agreement, safeguarded the prompt return of astronauts to the host country;
3. The Convention on International Liability for Damage Caused by Space Objects (1972), commonly known as the Liability Convention, established an international legal regime to assess liability and compensation for damage, injury, or death resulting from space activities and objects;
4. The Convention on Registration of Objects Launched into Outer Space (1976), commonly known as the Registration Convention, provides for a centralized registry of space objects maintained by the Secretary General of the United Nations; and
5. The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (1979), commonly known as the Moon Agreement, declares the Moon to be the "common heritage of all mankind." It has not been ratified by states that have or are likely to develop the ability to **orbit** around or land on the Moon.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

These treaties provide the framework for international space law. Their principles and provisions relate to the exploration and use of outer space and are binding upon the countries that have ratified them. Together, these principles and provisions guide countries that have not ratified the international treaties. Space law includes international arms control treaties that

The United Nations has developed international treaties that act as space law for most countries.

prohibit or restrict the deployment or use of certain rocket and missile weapon systems. Space law also includes agreements, treaties, conventions, rules and regulations of nations and international organizations, executive and administrative orders, and judicial decisions.

The International Telecommunications Union (ITU), an agency of the United Nations, is the world's regulatory body for the coordination and regulation of the radio frequency spectrum and the space-based and land-based facilities that provide global telecommunications services. Nearly every country in the world is a member of the ITU. The launching of commercial satellites, particularly those that provide telecommunications services, is the most common space activity. The ITU's management of the orbital positions of these satellites and prevention of harmful interference caused by radio frequency transmissions are accomplished by the adherence of the member countries to the provisions of the International Telecommunication Convention (1973).

In the United States the Federal Communications Commission is the regulatory authority for private, commercial, and state and local government use of the radio frequency spectrum. The commission controls the licensing of space satellites and ground Earth stations and regulates their use of radio **frequencies** to ensure that telecommunications services are free from interference by other transmissions.

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

Domestic Space Law

Launches of commercial satellites for telecommunications, **remote sensing**, and **global positioning systems** are governed by the regulatory regimes of the countries that conduct those launches. As the launching state, a country that has launched a rocket or missile is liable under the international treaties for any damage caused by the launch activity to third parties. Each launching state's domestic regulations also address the responsibilities and liabilities of the launching entity.

remote sensing the act of observing from orbit what may be seen or sensed below Earth

global positioning system a system of satellites and receivers that provide direct determination of the geographical location of the receiver

The conduct of space launches from U.S. territory or by U.S. citizens or businesses from anywhere outside the national territory is governed by the Commercial Space Launch Act of 1984. This act supplies the legal framework for the relationship between the government and the commercial space launch industry. The act directs the secretary of transportation to regulate space transportation and streamline the licensing process for commercial space activities pursuant to international treaty obligations and national policy. This statute is implemented by the Office of the Associate Administrator for Commercial Space Transportation of the Federal Aviation Administration. Commercial launch providers are required by the act to obtain insurance for death, injury, or property damage suffered by third parties. If an accident occurred during the launch activity, the U.S. government would pay any international claims in excess of the insurance level.

Other laws of the United States apply to the operation of private remote sensing satellites (the Land Remote Sensing Commercialization Act of 1984); the encouragement of commercial activity on the space station and government purchases of commercially produced scientific data (the Commercial Space Act of 1998); the protection of intellectual property and the patenting of inventions made, used, sold, or practiced in space (Public Law 101-580 on Inventions in Outer Space, 1990); and attempts to minimize the amount of orbital debris (the National Aeronautics and Space Administration Authorization Act, 1994 and 1995).

As the space industry has expanded from a niche market benefiting a limited high-tech scientific and military base to a global concern affecting geographically dispersed industries and consumers, the scope of space law has grown. From the initial steps of establishing the principles for the exploration and use of outer space by nations and governments, space law in the twenty-first century encompasses rational and reasonable approaches to representing the demands of persons in virtually every part of the world for enhanced communications, education, entertainment, environmental, and transportation services. As space commerce grows, space law will continue to address the unique problems posed by commercial activities in space. SEE ALSO CAREERS IN SPACE LAW (VOLUME 1); LAW (VOLUME 4); LEGISLATIVE ENVIRONMENT (VOLUME 1); REGULATION (VOLUME 1); SPACEPORTS (VOLUME 1).

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Legislative Environment

When Congress created the National Aeronautics and Space Administration (NASA) in 1958, it did not consider the need to commercialize space. At the time, the United States was fighting the Cold War against the Soviet Union. The purpose of the new space agency was to bring together America's many space programs to compete with the Soviet Union, which had launched the first satellite into orbit.

NASA's missions, as defined by Congress, were to expand human knowledge of Earth and space, to preserve America's role as a leader in "aeronautical and space science and technology," and to cooperate with other nations in the pursuit of these goals. Not until 1984 did Congress add the requirement for NASA to "seek and encourage to the maximum extent possible the fullest commercial use of space."

The Legal Framework to Support Commercial Space Activities

The legal framework to support commercial space enterprises gradually evolved in response to the development of space technologies and the maturing of space industries. The U.S. Defense Department set the first major space business into motion by launching the Satellite Communications Repeater (SCORE) in 1958. The orbiting vehicle could receive and record audio signals from ground stations, then rebroadcast them to other locations around Earth, creating a rudimentary global communications delivery system.

Arthur C. Clarke was the first to suggest using space to facilitate communications. In 1945, in a paper titled "Extraterrestrial Relays," Clarke proposed a three-satellite constellation, placed in **geosynchronous orbit** 35,786 kilometers (22,300 miles) above Earth, in which the satellites could send and receive audio signals. Although SCORE operated only two weeks before its batteries died, it validated the concept of space communications and opened the way for private industry to build a network in space.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Private industry subsequently developed two communication satellites, Telstar and Relay, which NASA launched in 1962. The satellites were powered by solar cells and relayed telephone, television, and data signals between ground stations on Earth. The success of the new technology led Congress to pass the Communications Satellite Act—the first commercial space legislation. The act established the Communications Satellite Corporation (Comsat), a partnership between government and private industry that in turn brought 12 other countries into a consortium to fund and operate a nonprofit global communication satellite network dubbed Intersat.

The creation of additional satellite communication networks followed, including Eurosat, Arabsat, and Inmarsat. Government was involved in all these systems. Not until 1974 did private industry place into **orbit** a purely commercial satellite—Westar—which was financed by Western Union. The

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

The U.S. Congress, forty-three years after creating the National Aeronautics and Space Administration in 1958, seeks to commercialize space.

satellite offered video, audio, and data services. Soon after, RCA launched Satcom, designed with solid-state transmitters.

At the beginning of the twenty-first century there were some 500 satellites orbiting Earth. In addition to communications, satellites are used for remote sensing, navigation, and military purposes. The Federal Communications Commission licenses communication satellites.

Facilitating Commercial Payloads

Space launch vehicles, like satellites, were originally developed in partnership with the federal government. Until 1984 U.S. private industry relied on NASA to boost commercial **payloads** to space. With the passage of the Commercial Space Act, NASA was removed from the launch business—except for the space shuttle—and the industry was allowed to operate as a commercial enterprise. Thereafter, satellite producers could contract directly with launcher providers to deliver payloads to space. To ensure public safety, the government requires all launches to be licensed. Originally, this was the responsibility of the Department of Transportation, but it was later transferred to the Office of Commercial Space Transportation at the Federal Aviation Administration.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Commercial space enterprises have grown to include remote sensing. From space, satellites can collect spectral data that has commercial applications in such fields as natural resource management, urban planning, and precision agriculture. The licensing of remote sensing satellites is the responsibility of the National Oceanic & Atmospheric Administration.

The Commercial Space Act of 1998

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

In 1998 Congress passed a series of amendments to the Commercial Space Act to further promote the commercial development of space. One provision authorized the licensing of space vehicles that re-enter the atmosphere—a response to the development of **reusable launch vehicles**. The legislation encouraged the commercial purchase of remote sensing data for science applications, instead of reliance on government employees to build and gather such data. It also required NASA to establish a market-based price structure for commercial enterprises aboard the International Space Station (ISS).

NASA and the Department of Defense

Congress annually enacts legislation to fund NASA and space programs in the Department of Defense (DoD). These bills often contain policy directives. For instance, legislation in 1999 to fund NASA included a provision to allow the space agency to retain funds generated from commercial activities on the ISS.

Jurisdiction over NASA and DoD space programs is spread among several congressional committees. The Armed Services Committees in the House and the Senate consider policy issues involving defense space programs. Oversight of NASA is the responsibility of the Science Committee in the House and the Commerce Committee in the Senate. The Appropriations Committees in both the House and Senate provide funding for space programs.

Finally, the president issues legal directives that affect the development of space commerce. Presidential order has increasingly opened to the public the Global Positioning System (GPS), a constellation of navigational satellites built for military purposes. For instance, on May 1, 2000, President Bill Clinton directed the military to stop scrambling GPS signals, thereby improving the accuracy and marketability of commercial GPS devices.

The president and Congress annually determine how much the federal government will spend on space research and development. The presidential administration submits to Congress comprehensive budget plans for NASA and the DoD space programs that contain proposed funding for individual research and development projects. Congress reviews and often changes the amounts requested. In seven of its eight years, the Clinton administration cut NASA's budget. Congress, during the Clinton years, generally supported additions to the budget, but not enough to reverse the general downward trend.

In 1998 revenue generated from space commerce eclipsed, for the first time, the investment in space from government. This trend is expected to continue, with government increasingly moving to the sidelines and private industry leading the way in the development of space. New regulations and legislation will be needed to provide a clear legal framework for the expansion of space commerce. SEE ALSO Clarke, Arthur C. (Volume 1); Law (Volume 4); Law of Space (Volume 1); Regulation (Volume 1); Spaceports (Volume 1).

Bill Livingstone

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Licensing

All commercial launches (or re-entries or landings) conducted by a U.S. company are regulated by the Commercial Space Launch Act (CSLA) of 1984 and its 1988 and 1998 amendments. Under the CSLA, each launch (or re-entry) must have a license. This is true even when launching offshore, as is the case with Kistler Aerospace, which is headquartered in Seattle but launches in Australia, or Sea Launch, a venture composed of Boeing, a Russian company, and a Norwegian company that launches from a ship. These regulations are an outcome of the United Nations's 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, which places responsibility for any liabilities that might result from a space launch and/or reentry (for instance, if a person or building is hit by a spent rocket stage) on the launching state.

To assure "the public health and safety, safety of property, and the national security and foreign policy interests of the United States," Congress enacted the CSLA and established FAA/AST. The Office of the Associate Administrator Commercial Space Transportation (AST), is part of the Federal Aviation Administration (FAA). Its web site, ast.faa.gov, lists all relevant rules, laws, regulations, and documents necessary to obtain a launch license.

FAA/AST is organized as the Office of the Associate Administrator (the headquarters office of AST); the Space Systems Development Division (SSDD); and the Licensing and Safety Division (LASD). SSDD develops regulations and policy and provides engineering support and forecasting; LASD is the organization that actually evaluates applications and issues licenses. Helping advise FAA/AST is an industry group, the Commercial Space Transportation Advisory Committee (COMSTAC), which FAA/AST established and sponsors. COMSTAC meets quarterly. FAA/AST also licenses spaceport operators (and their spaceports), such as at Cape Canaveral, Florida, and at Vandenberg Air Force Base, California.

FAA/AST officials encourage those seeking a launch license to meet with the organization in "pre-licensing consultations" before submitting an actual license application. FAA/AST conducts a policy review, a **payload** review, a safety evaluation, an environmental review, and a financial responsibility determination based on the data in the license application. It contacts the applicant if it needs more data or if it requires the applicant to change something to qualify for the license.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Once the official application arrives, FAA/AST has 180 days to issue a license. Since 1984 officials have issued the license in almost every case. There have been only two or three exceptions, and in these cases FAA/AST initially rejected the application because of technical lapses. Once applicants made corrections, the FAA/AST granted the license and the rocket flew. After FAA/AST issues a license, it monitors the licensee through launch to assure compliance with regulations and requirements. SEE ALSO Law (volume 4); Law of Space (volume 1); Legislative Environment (volume 1); Regulation (volume 1).

Timothy B. Kyger

Internet Resources

Federal Aviation Administration. <http://ast.faa.gov>.

Literature

Long before Sputnik 1 became humankind's first orbiting spacecraft in 1957 and before the first astronauts landed on the Moon in 1969, science fiction and science fact writers provided the theories, formulas, and ideas that gave birth to space travel. Some of these thinkers and storytellers wrote fancifully. Others expressed their ideas in precise mathematical equations with intricate scientific diagrams. All of them succeeded in helping to make space travel a reality by the mid-twentieth century.

Early Works of Science Fiction

Early works of science fiction relied more on whimsical solutions to spaceflight. During the seventeenth century, Francis Godwin's *The Man in the Moon* employed a flock of swans to transport a voyager to the lunar surface. Frenchman Cyrano de Bergerac (1619–1655) wrote space travel novels that described bottles of morning dew lifting people into the sky.

Far more serious scientific thought went into the works of two nineteenth-century space fiction writers. In 1869 American Edward Everett Hale wrote a novel called *The Brick Moon.* This book was the first that detailed the features and functions of the modern Earth-orbiting artificial satellite. French science fiction writer Jules Verne penned two space travel works, *From the Earth to the Moon*, in 1865, and, five years later, *Round the Moon.* In both books, Verne chronicled the adventures of explorers from post–Civil War America who take a trip to the Moon. Although the form of propulsion was unrealistic (the explorers were shot into space by a gigantic cannon), many other aspects of the stories anticipated the actual lunar missions undertaken by the National Aeronautics and Space Administration (NASA) in the 1960s and 1970s. Verne correctly predicted everything from the phenomenon and effects of weightlessness in space to the shape of the capsule used by the Apollo astronauts. He even proved uncannily accurate in anticipating the Florida launch site, Pacific Ocean splashdown, and recovery by U.S. naval forces of the Apollo missions.

Twentieth-Century Rocket Pioneers

Verne's novels had a strong impact on the three most important rocket pioneers of the twentieth century. One of them was American Robert H. Goddard. As a boy, Goddard was so inspired by the Frenchman's tales of lunar trips that he dedicated his life to achieving spaceflight. As a young physics professor in Massachusetts, Goddard designed and constructed solid-propellant-like rockets. In 1917 the Smithsonian Institution agreed to provide funding for his high-altitude rocket tests. Two years later, Goddard wrote a paper for the Smithsonian titled "A Method of Reaching Extreme Altitudes." This pamphlet discussed the mass required to propel objects beyond Earth's atmosphere—even to the Moon. He also theorized that liquid propellant made for a far more powerful and efficient fuel for rockets than solid propellant. Goddard launched the world's first liquid-fueled rocket in 1926. Ten years later, he published the results of this historic event in his second Smithsonian paper, "Liquid-Propellant Rocket Development."

The second father of modern rocketry was Russia's Konstantin Tsiolkovsky. His works focused on liquid-propellant rockets, kerosene as a fuel, and space station design. Tsiolkovsky's *Investigation of Universal Space by Means of Reactive Devices*, published in 1891, proposed the use of multistage rockets for space travel. Through his science fiction and mathematical study, he laid the foundation for the Soviet Union's successes in spaceflight, which began in the 1950s.

The third great pioneer of rocket theory was the Romanian-born Hermann Oberth. Like Goddard and Tsiolkovsky, Oberth espoused the virtues of liquid-fueled rockets for space voyages. In 1923, he wrote a book called *The Rocket into Planetary Space*. Besides advertising the use of liquid oxygen and alcohol for rocket fuel, he also stressed the importance of using strong yet lightweight alloys for constructing launch vehicles and spacecraft. His *Ways to Spaceflight*, written in 1929, discussed the possibility of building large orbiting space mirrors that could transmit energy to Earth and illuminate cities at night.

There were several other key spaceflight writers and theoreticians of the early twentieth century. In 1929 Hermann Noordung of Croatia wrote *The Problem of Space Travel*, which discussed the engineering requirements for a space station. Eugene Sänger of Austria developed basic concepts in rocketry and aerodynamics in his work *Rocket Flight Technology*, published in 1933. Sänger almost single-handedly invented the idea of an "aerospaceplane"—a direct ancestor of today's space shuttle. Germany's Fritz von Opel also contributed much to the field of rocketry. In 1929, he made the first documented flight of a rocket-powered airplane.

Von Braun, Clarke, and Beyond

In the post–World War II era, two important science fact and science fiction authors stood out. The first was the German-born Wernher von Braun. As a gifted young rocket engineer, von Braun was instrumental in building the V-2 rockets that Germany fired at Britain and Belgium late in the war. After World War II ended in 1945, he moved to the United States where he directed the design and construction of NASA's Saturn rockets, which propelled astronauts into space and to the Moon. In between these two periods in his life, von Braun penned numerous books, essays, and articles about spaceflight. In 1952 he published *Prelude to Space Travel*, which greatly expanded upon Noordung's research in space station development. Four years earlier, he had written *The Mars Project* (published in 1962). In this book, von Braun detailed the first fully comprehensive plan for a human mission to Mars. During the early 1950s, he contributed to a popular series of space-related articles in *Collier's* magazine.

The other key literary figure during this period was Arthur C. Clarke. In 1945 the British-born writer published a paper in *Wireless World*, titled "Can Rocket Stations Give Worldwide Radio Coverage?" This was the first work to discuss the concept of communications satellites that stay in the same position above Earth. Such satellites made instant worldwide television, telephone, fax, e-mail, and computer services possible. In 1968 the film based upon his science fiction book *2001: A Space Odyssey* captured the very mood and spirit of the space age.

Today, science fiction and fact authors continue the efforts begun by Verne, Goddard, Oberth, von Braun, and others. Through their imagination, knowledge, and words, the frontiers of space exploration are pushed forward. SEE ALSO ARTWORK (VOLUME 1); CAREERS IN WRITING, PHOTOGRAPHY, AND FILMMAKING (VOLUME 1); CLARKE, ARTHUR C. (VOLUME 1); MARS MISSIONS (VOLUME 4); OBERTH, HERMANN (VOLUME 1); ROCKETS (VOLUME 1); SÄNGER, EUGENE (VOLUME 3); SCIENCE FICTION (VOLUME 4); TSIOLKOVSKY, KONSTANTIN (VOLUME 3); VON BRAUN, WERNHER (VOLUME 3).

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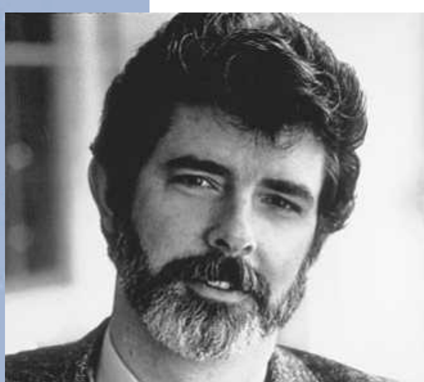

George Lucus, author and producer of the movie trilogy *Star Wars* (1977), *The Empire Strikes Back* (1980), and *Return of the Jedi* (1983), sees himself as a storyteller and filmmaker who works within the limitations of technology.

Lucas, George

American Screenwriter, Producer, and Director
1944–

Born on May 14, 1944, in Modesto, California, film director George Lucas studied film at the University of Southern California. His first feature film was *THX 1138.* The executive producer was Francis Ford Coppola, who would later gain fame directing *The Godfather* trilogy and *Apocalypse Now*. In 1973 Lucas cowrote and directed *American Graffiti*, which won a Golden Globe and garnered five Academy Award nominations.

Within the space fraternity Lucas is recognized for the Star Wars movies. *Star Wars*, the first in the initial trilogy of tales about life and conflict in the universe, was released in 1977. The film broke box-office records and won seven Academy Awards. Lucas went on to write *The Empire Strikes Back* (1980) and *Return of the Jedi* (1983), and was executive producer for both. Lucas worked for twenty years developing a prequel to the trilogy, *Episode 1: The Phantom Menace*, released in 1999, for which he was writer, director, and executive producer. A second prequel, *Attack of the Clones*, was released in May, 2002.

Lucas sees himself as a storyteller and professes not to be particularly keen on technology. He admits that he has had to invent the necessary technology to tell his tales and believes the mark of a talented filmmaker is how well one works within the limitations imposed by the available technology. SEE ALSO CAREERS IN WRITING, PHOTOGRAPHY, AND FILMMAKING (VOLUME 1); ENTERTAINMENT (VOLUME 1); *STAR WARS* (VOLUME 4).

Pat Dasch

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Lunar Development

The spectacular advances of science and engineering in the twentieth century established the basis for creating permanent human settlements in space in the twenty-first century. Since the Moon is our closest celestial neighbor and is in **orbit** around Earth, it will logically be the next principal focus of human exploration and settlement. The Moon is an excellent platform for astronomical and other scientific investigations, for technological development, and for human habitation. It also has access to the virtually unlimited energy and material resources of space, which can be applied to the development needs of both the Moon and Earth. These opportunities, combined with the universal desire of humankind to explore and settle new lands, assure that the global transformation of the Moon into an inhabited sister planet of Earth will become a reality in this century.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

A major impediment to the exploration of space is the high cost of delivering cargoes from the surface of Earth into space. For example, the cost of launching a **payload** into **low Earth orbit** by the space shuttle is approximately $22,000 per kilogram ($10,000 per pound), and that figure will be higher for missions to the Moon. Thus, it appears that lunar projects will be prohibitively expensive, even if launch costs to low Earth orbit are reduced to less than $2,200 per kilogram ($1,000 per pound).

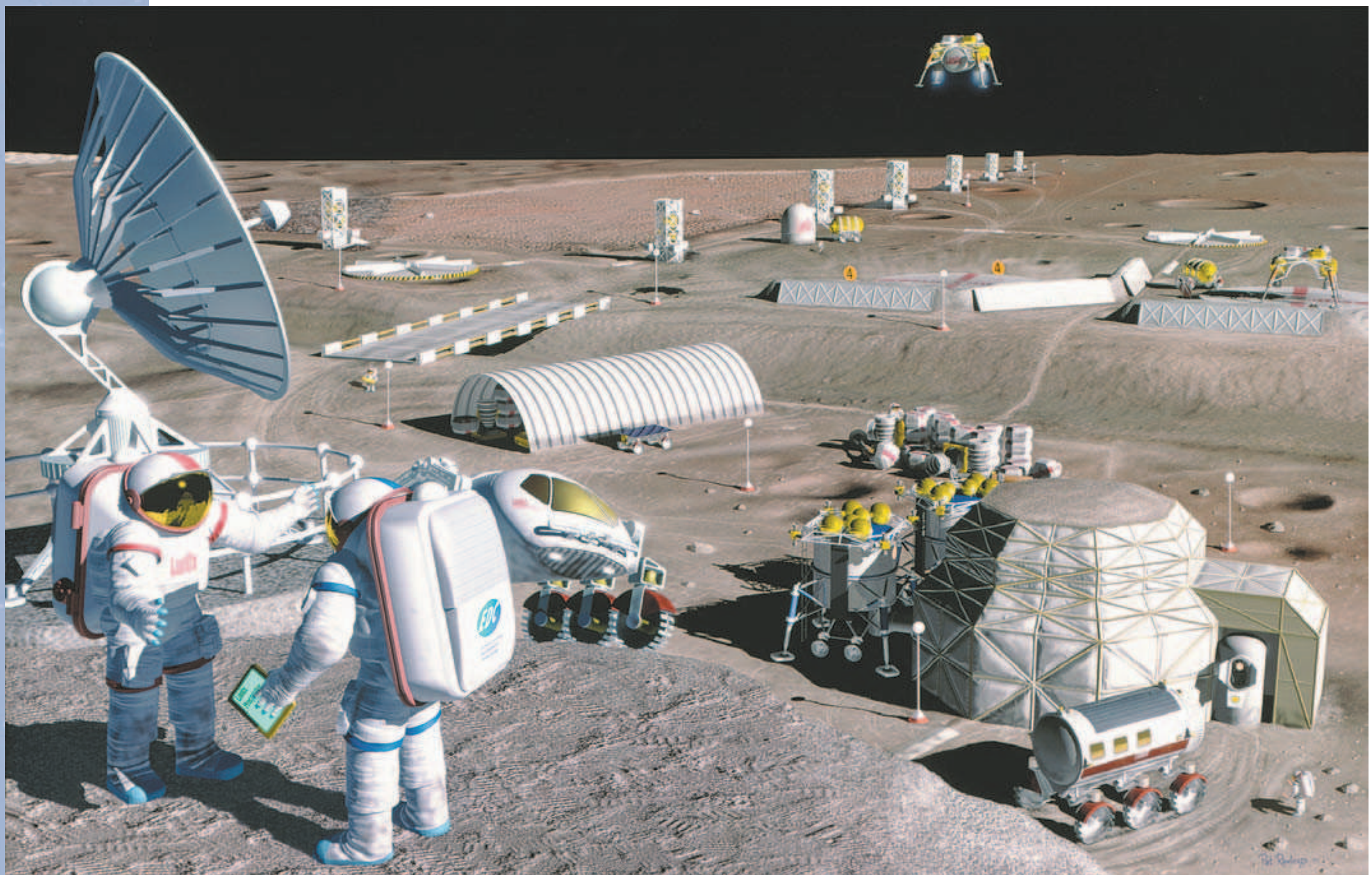
payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

The exploration and development of the Moon, however, will be marked by a dramatic reduction in the cost of space exploration through the process known as in situ resource utilization, which means "living off the land." Industrial processes on Earth use energy, raw materials, labor, and machines to manufacture sophisticated products such as computers, medical imaging devices, rockets, and communication satellites. By the end of the first or second decade of the twenty-first century, it will become possible to use lunar materials to manufacture equally sophisticated products on the Moon.

The Moon has a reliable supply of energy in the form of sunlight, and the lunar regolith (Moon dirt) contains abundant supplies of iron, silicon, aluminum, and oxygen as well as traces of carbon, nitrogen, and other light elements. In addition, the U.S. Lunar Prospector satellite detected increased hydrogen concentrations in the polar areas of the Moon, suggesting the presence of water-ice in those regions. Thus a significant reduction in the cost of space projects can be achieved by simply transporting the basic components of Earth's industrial base, such as lathes, drills, ovens, and control devices, to the Moon. The lunar industrial base will then use solar energy and lunar materials to manufacture the products that are needed for the exploration and human habitation of the Moon. By this means, the high cost of transporting materials from Earth to the Moon will be eliminated, and large-scale space projects will become possible.

Initially, tele-operated robots that have been delivered to the Moon will serve as the "labor" component for lunar industrial processes. Tele-operation is the process by which robots are controlled by scientists or technicians at remote locations using radio links and television monitors. Tele-operation procedures are widely used on Earth for diverse applications such as mining, undersea projects, and certain forms of surgery. It is fortuitous that the Moon always has the same face directed to Earth and that the round-trip time for communications between Earth and the Moon is less than three



An artist's conception of a lunar mining facility illustrates possible exploration programs for the future.

seconds. These conditions will allow Earth-bound operators of lunar robots to have a virtual presence on the Moon twenty-four hours per day, 365 days per year.

Establishing a Lunar Base

The site for the first unmanned base will likely be on the Earth-facing side of the south polar region of the Moon. There are several sites in this region that always have Earth in view for continuous telecommunications and that receive as much as 340 days of sunlight per year for the generation of solar electric power. A south polar base would also have access to increased concentrations of hydrogen (possibly water-ice), which would be useful for industrial operations and eventual human habitation.

Many countries have rockets that can be modified to place useful payloads on the Moon. In one scenario for the establishment of a lunar base, one or more of these existing rocket systems will be used to transport solar panels, communication systems, scientific equipment, and robots from Earth to the south polar region of the Moon. When these components are in place, tele-operated rover vehicles will explore and analyze the lunar surface. Protocols for the preservation of unique features of the lunar environment will be observed, and scientific data will be obtained before local materials are used for experiments. When surveys and analyses have been completed, tele-operated robots will then begin experiments with the production of bricks, wires, transistors, and glass products from lunar dirt.

In the preceding scenario, priority will be given to the fabrication of solar cells for the generation of electric power. The demonstration that electric power can be produced on the Moon from the first lunar-made solar cell will be a milestone in space exploration because it will mean that human enterprises can be self-supporting in space. From that beginning, lunar-made solar cells will be added to the electric power system of the lunar base. As electric power levels grow, additional scientific and manufacturing equipment will be delivered from Earth, and the lunar base will expand in all of its capacities. Iron rails may then be made from lunar iron to construct a simple two-track rail line from the first base to other areas in the south polar region, including the geographic south pole. A "southern rail line" would greatly expand the ability to carry out exploratory missions and would facilitate the growth of lunar power and communication networks.

Humans Return to the Moon

Within a decade after the first unmanned base has been established, humans will return to the Moon. During the build-up of the first unmanned lunar base, controlled ecological life support systems will undergo continued research and development on Earth and the International Space Station. Work will also commence on the development of reusable rocket systems that can ferry people between Earth and the Moon. When a reliable lunar electric power system is in place and underground chambers (for protection from radiation, temperature extremes, and micrometeorites) have been constructed, life support systems and agricultural modules will be delivered to the lunar base. Humans will then return to the Moon for sixty- to ninety-day periods, and all aspects of lunar base activities will be expanded.

As experience with lunar operations increases, the scientific and industrial capability of the Moon will reach parity with Earth, perhaps within two to three decades after the founding of the first base. Widely separated, permanent human settlements will be established, and the only cargoes that will need to be transported from Earth will be humans—the scientists, engineers, tourists, and immigrants who will explore, develop, and inhabit the Moon.

Future Lunar Development

Geological expeditions will explore the mountain ranges, mares (plateaus), craters, and rills (narrow valleys) of the Moon, and investigate lava tubes that have been sealed for billions of years. Thousands of lunar-made telescopes will be placed at regular intervals on the Moon so that any object of interest in the universe may be observed continuously under ideal viewing conditions. People will live and work in large underground malls that have Earth-like living conditions. A rail system will provide high-speed access to all areas of the Moon and lunar tourism will be a growth industry. Millions of megawatts of low-cost environmentally sound electric energy will be beamed from the Moon to Earth and other locations in space by the lunar power system.

By the mid-twenty-first century, thousands of spacecraft will be manufactured on the Moon and launched by electromagnetic "mass drivers" to all points of interest in the solar system, and robotic missions to nearby stars will be underway. Communication, power, and transportation systems will be built on the Moon and launched to Mars in support of the global human exploration and development of that planet. Asteroids and "burned out" comets in Earth's orbital vicinity, especially those that pose a threat of collision with Earth or the Moon, will be maneuvered out of harm's way and mined for their hydrocarbon, water, and mineral contents, which will then be delivered to Earth or the Moon.

The transformation of the Moon into an inhabited sister planet of Earth is an achievable goal that will be highly beneficial to the people of Earth. It will provide the following:

- An expansion of scientific knowledge;
- The advancement of all engineering disciplines;
- Access to the virtually unlimited energy and material resources of space;
- Job and business opportunities;
- International cooperation;
- A greatly expanded program of solar system exploration; and
- The opening of endless frontiers.

The binary Earth-Moon planetary system will thus draw upon and benefit from the vast energy and material resources of space, and the spacefaring phase of humankind will be firmly established. SEE ALSO LUNAR BASES (VOLUME 4); LUNAR OUTPOSTS (VOLUME 4); NATURAL RESOURCES (VOLUME 4); SETTLEMENTS (VOLUME 4); SPACE TOURISM, EVOLUTION OF (VOLUME 4); TELEPRESENCE (VOLUME 4); TOURISM (VOLUME 1).

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Made in Space

History characterizes the various eras of civilization in terms of available materials technology, leading to the recognition of such eras as the Stone Age, Bronze Age, Steel Age, and Silicon Age. One of the areas of intense research in the present era has been the processing of materials in the space environment to develop new or improved products for use on Earth. In the 1960s, during the early phase of this effort, the advent of a new industry was predicted based on the promising initial results obtained, and it was anticipated that by the 1980s "made in space" would be a common label on a large number of products.

That new manufacturing industry based in space is still in the future, primarily because of the high cost of placing the carrier vehicles into orbit—$35,000 per pound at the beginning of the twenty-first century. Advances in propulsion technology, however, will reduce the cost of transportation to space in the future. Currently the emphasis is on making better products here on Earth based on the knowledge and processes discovered through space research. To understand the great potential of space we must examine what it is that makes the space environment so unique in the processing of materials.

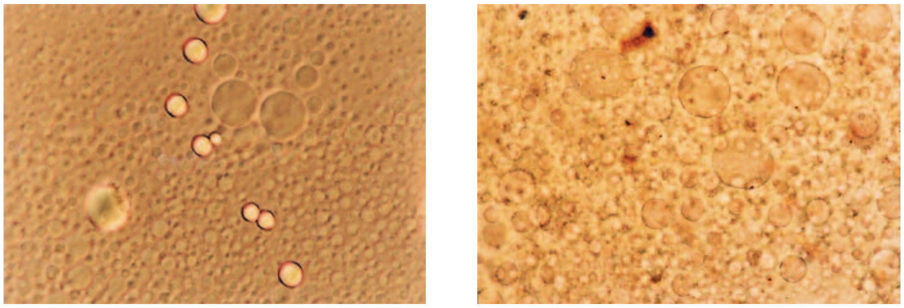
The Advantages of Space-Based Manufacturing

There are two primary effects on Earth that can be reduced to almost zero in the microgravity environment (nominally one-thousandth to one-millionth of Earth's gravitation) present in orbiting vehicles: sedimentation and thermal **convection**. Sedimentation makes heavier liquids or particles settle at the bottom of a container, as when sugar added to coffee settles at the bottom of the cup. Thermal convection establishes currents where cooler fluids fall to the bottom and warmer ones rise to the top.

convection the movement of heated fluid caused by a variation in density

Because many chemical, fluid-physics, biological, and phase-change (e.g., changing from a liquid to a solid state) processes are affected by the effects of sedimentation and thermal convection, the form and size properties of materials formed under these influences are different in space compared to those formed under the influence of Earth's gravitation. A close examination of the accompanying images shows the impact of things made in space.

A study conducted for the National Aeronautics and Space Administration (NASA) in the early 1970s identified seventy-seven representative unique products or applications that can be obtained in space. Since that early study, the list of potential applications has at least doubled. Most of the items have been the subject of many investigations conducted on rockets, the space shuttle, and the Mir space station by scientists and engineering teams from many countries, particularly the United States, Germany, Russia, France, Italy, Canada, and Japan (see table on page 141 for a representative subset of the space applications that have been investigated or are in the process of being investigated). The following two examples in the medical area serve to illustrate the current research.



Microgravity encapsulation of drug experiments conducted in space (image on the left) have more uniform size and sphericity, plus unique multilamellar microspheres. By contrast, Earth experiments (image on the right), show random size and single-walled unilamellar microcapsules. The space data were obtained in ITA's automated laboratory flown on shuttle flight STS-56 on the CMIX-2 payload.

Bence-Jones protein crystals grown in space. The picture on the left was taken on the CMIX-5 payload, on shuttle flight STS-80, while the image on the right was taken on the CBIX-1 payload, on shuttle flight STS-95.

Protein Crystal Growth

Growing crystals in microgravity has the advantage of virtually eliminating the thermal convection that produces poor crystal quality and increases the time required to grow a useful crystal. This advantage of microgravity is particularly important in obtaining crystals that have the size and high degree of structural perfection necessary to determine, through X-ray analysis, the three-dimensional structure of those complex organic molecules. For instance, long before the space era the structure of **DNA** was determined using **crystallography**, but there are many protein crystals that are difficult to grow under the influence of gravitational forces. Urokinase, a significant protein in cancer research, is an example of a protein that is difficult to grow on Earth and that benefits from microgravity. Complete three-dimensional characterization, that is, determining the relative location of the approximately 55,000 atoms in this molecule, would permit pharmaceutical scientists to design drugs to counteract the harmful effects of urokinase in promoting the spread of cancer throughout the body, particularly in the case of cancerous breast tumors. Research being conducted in the space shuttle is seeking to grow urokinase crystals in space for subsequent X-ray analysis in Earth-based laboratories.

DNA deoxyribonucleic acid; the molecule used by all living things on Earth to transmit genetic information

crystallography the study of the internal structure of crystals

Microcapsules for Medical Applications

Experiments conducted in space have shown more spherical perfection and uniformity of size distribution in microcapsules, which are capsules with diameters of 1 to 300 micrometers (0.00004 to 0.012 inches). The size and shape of microcapsules are key factors in how effective they are at delivering medicinal drugs directly to the affected organs by means of injections or nasal inhalations. The feasibility of newly developed processes for producing multilayered microcapsules has been limited because of the effects of density differences in the presence of gravity. In order to circumvent this, a series of experiments has been performed onboard the space shuttle to produce superior microcapsules in space. If these experiments prove successful, large-scale demand for these types of microcapsules may require future development of ground manufacturing equipment that counteracts the effects of gravity.

Student Experiments in Space-Based Material Processing

Since the initial activity in materials processing in space, student participation has been an important part of the effort. Since the early space shuttle

EXAMPLES OF MATERIALS INVESTIGATIONS IN SPACE IN VARIOUS CATEGORIES

Category	Examples	Description
Materials Solidification	Vapor Deposition of Silicates	Vapor deposited on a substrate as a coating of metallic particles imbedded in a matrix.
	Crystal Growth	Organic or inorganic crystal growth in a liquid solution or through evaporation or osmosis.
	Directional Solidification of Metals	A metallic rod has a molten zone that is moved along the rod to produce a superior metal cell structure.
	Micro-encapsulation of Medicinal Drugs	Chemicals are combined in a chamber to form microcapsules containing various layers.
Chemical and Fluids Phenomena	Multiphase Polymers for Composite Structures	Very sensitive separation of cell group subpopulations using processes that do not work with the gravitation on Earth.
	Production of Catalysts	To use controlled gravitational acceleration in the formation of catalytic materials.
	Convective Phenomena Investigations	A family of experiments, dealing with convection due to surface tension, vibration, and electrical fields.
Ceramics and Glasses	Immiscible Glasses for Advanced Applications in Optics	Investigates the role of gravity in the inability to mix glasses having dissimilar densities.
Biological	Continuous Electrophoresis for Biological Separations	Provide continuously flowing separation of biological materials by *electrophoresis*, applying an electric field across the solution.
	Human Cell and Antibody Research	Determines the difference in cell behavior, for use in cancer research and investigation of aging processes.

flights, the NASA-sponsored Getaway Special program has provided experiment containers in the shuttle cargo bay capable of accommodating 50 to 200 **payloads** of 23 to 90 kilograms (50 to 200 pounds), with the primary focus on student experiments. Industry also plays an important role in student education. One U.S. space company pioneered a hands-on student experiment program for microgravity experiments onboard the space shuttle. Several industrial concerns have since donated space accommodations in scientific equipment on the shuttle and on rockets, as well as engineering and scientific manpower during integration of the experiments in the spacecraft.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The Role of the International Space Station

The advent of the International Space Station during the first decade of the twenty-first century will be an important milestone in the growth and maturing of the research phase of the materials processing in space program. The International Space Station will provide continuing, long-duration microgravity capability to conduct experiments with the participation of astronauts and cosmonauts. This is an international endeavor the scope of which reaffirms the important role that our society places on materials development. Our rapid technological advancement continues to place great demands on the development of new materials; space is an important tool in meeting those challenges. SEE ALSO Crystal Growth (volume 3); International Space Station (volumes 1 and 3); Microgravity (volume 2); Zero Gravity (volume 3).

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Made with Space Technology

To meet the many goals of space exploration and aeronautical development, the National Aeronautics and Space Administration (NASA) and the aerospace industry sought many innovations in a number of science and technology fields. This storehouse of knowledge has provided a broad technical foundation for stimulating secondary applications of these different developments. Each application is a result of "spinoffs" of both space and aeronautical research.

A spinoff is a technology that has been transferred to uses other than the purpose for which it was developed. In the early twenty-first century, it is difficult to find an area in everyday life into which a spinoff has not penetrated, yet many people are unaware of the existence of these breakthroughs.

Spinoffs in Medical Applications

Walking through the emergency ward of modern hospitals reveals many changes in equipment stemming from early U.S. manned space programs like **Apollo**.

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

Materials in Wheelchairs. The spacecraft and rockets used to take humans to the Moon were developed from new materials that were lightweight yet very strong. Engineers developed new methods of construction and new alloys and composite materials for these missions. Many of these new developments found use in everyday life here on Earth.

An advanced wheelchair is one example. To address the needs of the wheelchair user, researchers at the NASA Langley Research Center in Virginia and the University of Virginia's Rehabilitation Engineering Center developed a wheelchair made from aerospace composite materials much lighter but stronger than common metals.

This 25-pound wheelchair offers the strength and weight-bearing capability of a normal 50-pound wheelchair, which can also be collapsed for storage and transport. Robotic and teleoperator technologies for space-related programs have also been adapted to develop a voice-controlled

Christopher Cole, age 13, was born without sweat glands. A cool suit, orginally made for astronauts re-entering the atmosphere, can aid him in ordinary activities that would otherwise be life-threatening.

wheelchair and manipulator as an aid to paralyzed and severely handicapped people. At the heart of this system is a voice-controlled analyzer that uses a minicomputer. The patient speaks a command into a microphone connected to a computer that translates the commands into electrical signals, which then activates appropriate motors to cause the desired motion of the wheelchair or manipulator. The manipulator can pick up objects, open doors, turn knobs, and perform a variety of other functions.

The Unistick. Another breakthrough for the handicapped from the space program is called Unistick. For the later Apollo Moon landings in the early 1970s, NASA developed a Lunar Rover that allowed astronauts to drive around on the lunar surface, greatly enhancing their ability to explore more of the Moon around their landing site. The rover was designed to allow an astronaut to drive one-handed, using an aircraft-like joystick to steer, accelerate, and brake the vehicle. On Earth, this technology is being applied to a system that allows people who have no lower limbs to drive with the use of a joystick, which combines the functions of a steering wheel, brake pedal, and accelerator.

MRI Technology. Another spinoff into the medical field is magnetic resonance imaging (MRI), which enables magnetic field and radio waves to peer inside the body. Unlike X rays, MRI is able to see into bones. By applying computerized image enhancement technology developed to read Earth-resources satellite photographs, experts have been able to provide thermatic maps of the human body, using color to indicate different types of tissue, making tumors or blood clots easy to find.

Nitinol in Dentistry. In dentistry, straightening teeth requires months or even years of applying corrective pressure by means of arch wires, or braces. A new type of arch-wire material called Nitinol now helps reduce the number of brace changes because of its elasticity. This new material, an alloy of titanium and nickel, has an ability to return to its original shape after bending. Many satellite antennas or other hardware could be compacted inside

The suits worn by these firefighters at the Guiana Space Center were adapted from space suit technology. The varying protective gear has been specifically designed to be able to handle different types of emergency situations.

a satellite during launch, then later expanded to full size when in space. This same property allows braces made of Nitinol to exert continuous pull on teeth, reducing the number of dentist visits and changes in braces.

Spinoffs in Other Applications

The field of firefighting and fire prevention has benefited greatly from aerospace spinoffs. Spinoff applications include protective outer garments for workers in hazardous environments, a broad range of fire-retardant paints, foams and ablative coatings for outdoor structures, and different types of flame-resistant fabrics for use in the home, office, and public transportation vehicles. Many new flame-resistant materials, primarily developed to minimize fire hazards in the space shuttle, have resulted in new, lightweight substances that resist ignition. When exposed to open flame, the material decomposes. This same material is now used in the production of seat cushions and panels for doors, walls, floors, and ceilings. This new fire-resistant material has particular application to commercial aircraft, ships, buses, and rapid-transit trains, where toxic smoke is the major cause of fire fatalities.

One of the biggest fire-related technology transfers is the breathing apparatus worn by firefighters for protection against smoke inhalation. Until the 1970s the breathing apparatus used by firefighters was large, heavy, and restrictive. The Johnson Space Center in Houston, Texas, developed a breathing system weighing one-third less than conventional systems. The system included a face mask, frame and harness, warning device, and an air bottle. In the early twenty-first century, many breathing systems incorporate space technology in some form.

Anticorrosion paints, developed for many structures at the Kennedy Space Center in Florida, have found a market in an easily applied paint that incorporates a high ratio of potassium silicate, but which is water-based, nontoxic and nonflammable. With these properties, a hard ceramic finish with superior adhesion and abrasion resistance is formed within an hour of application. Once applied to many structures that are exposed to salt spray and fog (such as bridges, pipelines, and ships), the lifespan of these structures can be dramatically increased.

As of the early years of the twenty-first century, more than 30,000 applications of space technology have been brought down to Earth to enhance our everyday life. SEE ALSO Made in Space (volume 1).

Nick Proach

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Market Share

Although space commercialization in the United States began as far back as 1964, commercial initiatives did not begin to build momentum until the early 1980s. Worldwide, companies such as Arianespace in France and RSC Energia in Russia provide strong competition in the commercial marketplace to U.S. contractors such as Lockheed Martin Corporation. For the most part, large contract companies still share a large segment of the commercial marketplace.

The U.S. Department of Commerce reported total U.S. commercial space revenues in 1988 of an estimated $1.8 billion, primarily in the area of satellite communications and related ground support. This number doubled in 1990, with the United States retaining about 60 percent of the world market in communications satellites. By 2000, other services, such as remote sensing (photographic imaging from space), were still in their infancy commercially, but the market for such services was expected to grow substantially by 2005. The market for satellite imagery in the United States had already grown from a $39 million industry in 1988 to $139 million in 1998. The Carnegie Endowment for International Peace projected that remote sensing revenues would reach $420 million by 2005.

According to *Facts and Figures: The European Space Industry in 1998*, European companies generated $5.1 billion in total revenue in 1998, comprising 47 percent of the total European market. This was an increase from 1996 when government programs constituted two-thirds of the European market. Worldwide, the French consortium Arianespace held approximately 50 percent of the total market for launching satellites in 1988. Proven rocket families, such as the French Ariane, the U.S. Delta, and the Russian Proton, still maintain great success in the transportation industry. New partnerships by known industry leaders, such as the Sea Launch partnership of Energia and Boeing, are creating greater competition in the marketplace.

New Initiatives

Early in 2000, several media agreements were signed to provide wider public access to space through the Internet and high-definition television. The National Aeronautics and Space Administration inked a $100 million deal with an Internet start-up to create high-definition images from the space

The floor of the New York Stock Exchange on December 31, 1997, buzzed with activity. The market for satellite imagery in the United States increased by $100 million over the 10-year period between 1988 and 1998.

shuttle and the International Space Station (ISS), while the U.S. company Spacehab Incorporated signed with Russia's RSC Energia to form a commercial partnership to utilize future resources on the ISS. Other historical milestones are also being achieved commercially, such as the successful mission of two Russian cosmonauts to the space station Mir beginning in April 2000. This was the first privately funded, piloted space mission in history.

In 1999, 128 spacecraft were launched worldwide, with a total of seventy-six, or 59 percent, from commercial companies. Total space revenues for 1999 reached $87 billion, with the International Space Business Council estimating growth of 93 percent through 2005.

History has shown that one of the biggest hurdles for space commercialization in any country is a government's willingness and ability to implement policies to promote and assure commercial participation and success. Such cooperation will ensure diversity and competition in future technologies. Because of the complexities of space technology, new products influence such issues as national defense and international import and export policies. These issues will continue to influence progress and profit in space commerce. SEE ALSO Legislative Environment (volume 1); Marketplace (volume 1); Regulation (volume 1); Space Industries (volume 4).

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Marketplace

Since the 1960s, the market for commercial space operations has been limited almost entirely to communications satellites and commercial rocket launchers, with some tentative ventures in the areas of **remote sensing** and weather observation. Because of the value of the information they carry—television signals, some telephone links, and all sorts of digital data—communication satellites have been able to support a fleet of costly launch vehicles. Some time around the year 2007, the available radio frequency spectrum for communication satellites will be saturated. After that, the industry will consist only of maintenance and upgrades to the existing **infrastructure**.

remote sensing the act of observing from orbit what may be seen or sensed below Earth

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

Over the next few decades, the most lucrative industry in space will probably be tourism. On Earth in the early twenty-first century, tourism is the second largest export industry. (The largest is energy, in the form of oil.) A tourist industry in space will reduce the cost of getting into orbit because of the sheer volume of launches required. This industry will require launch vehicles not only for transporting people but also for transporting the space-borne facilities tourists will be visiting and for resupplying those facilities. Demand for low-cost launchers will increase by orders of magnitude, promoting competition and driving costs down.

Less costly launchers promise new markets for industrial processes in space. Many industrial processes may benefit dramatically from operating in the weightless environment. So far, no such venture has been cost-effective; the cost of getting the machines and materials into space and the finished products back exceeds the potential sales of the materials produced.

Electrophoresis is a process that uses electric fields to separate fluids; it is used especially in the pharmaceuticals industry to make very valuable (and very expensive) drugs. A team made up of Johnson & Johnson and McDonnell Douglas flew a prototype electrophoresis system on four space shuttle flights, with an eye to making it a commercial venture. Initially, it looked as if producing pharmaceuticals in orbit would make sense from a business standpoint, but the companies ultimately determined that it would be less costly to make their products on the ground. Dramatically lower launch costs would turn the business equations around.

Lower launch costs open space to a host of other industries. Most of the potential markets identified to date are in esoteric high-tech fields, such as super-strength drawn fibers, single-crystal metals, and protein crystals. Others are more familiar, such as movie and television production, for which space would provide an excellent shooting location. These markets are only forerunners of new markets that will open as commercial business moves into space. Current research in space processing methods might lead to some surprising markets for both industrial and consumer products.

New Markets

Transgenic plants, which are made by crossing the genes from diverse species, promise to create whole new species with new flavors and dramatically increased crop yields. In an experiment flown on the space shuttle, a rose plant produced some new, very desirable fragrances in the zero gravity environment. Moreover, several prototype systems have been developed that may one day lead to the deployment of huge electrical power plants in orbit, or even on the Moon, that collect energy directly from the Sun and transmit the power to Earth on microwave beams. Zeolite crystals are yet another product that might one day be produced in space. These crystals command high prices in the chemical processing industry because of their ability to selectively filter out specific chemicals. Though they are scarce on Earth, they can be manufactured efficiently in space.

Opportunities for new markets in space extend to the medical industry as well, which will benefit from improved efficiency in the production of pharmaceuticals and entire new technologies, such as components for bone replacement.

Finally, developing industries in space create new markets to meet the demands of the space-borne industries. People working in space need places to live, work, and play; they need food to eat, clothes to wear, and transportation systems to get around. In short, they need everything that people need on Earth, and each of these needs is a new market for the space entrepreneur. SEE ALSO LAUNCH INDUSTRY (VOLUME 1); LAUNCH SERVICES (VOLUME 1); MADE IN SPACE (VOLUME 1); SPACE TOURISM, EVOLUTION OF (VOLUME 4); TOURISM (VOLUME 1).

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McCall, Robert

American Illustrator
1919–

Robert T. (Bob) McCall, one of the world's leading illustrators of space themes, was named to the Society of Illustrators Hall of Fame in 1988. His bold, colorful canvases depict the visions of America's space program since its beginnings.

McCall was born in 1919 in Columbus, Ohio, and now lives in Paradise Valley, Arizona. During World War II, McCall enlisted in the Army Air Corps and became a bombardier instructor. After the war, he and his wife, artist Louise McCall, moved to Chicago and later New York, where he worked as an advertising illustrator. Through the Society of Illustrators, McCall was invited to produce paintings for the U.S. Air Force.

In the early 1960s, McCall was one of the first artists selected for the National Aeronautics and Space Administration's (NASA) fine arts program after producing future space concepts for *Life* magazine. This connection has led to a number of patch designs for space missions, a U.S. Postal Service commemorative stamp set, and murals at NASA field centers. Several astronauts include his artwork in their collections.

McCall's most visible work is a six-story mural in the Smithsonian's National Air and Space Museum in Washington, D.C., which is seen by over six million visitors annually. His most widely recognized work is the painting of a massive double-ringed space station for the Stanley Kubrick and Arthur C. Clarke film *2001: A Space Odyssey* (1968).

McCall's training included studies at the Columbus School of Art and Design and the Art Institute in Chicago in the late 1930s. see also Artwork (volume 1); Bonestell, Chesley (volume 4); Rawlings, Pat (volume 4).

Pat Rawlings

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Military Customers

The military space program is a significant but largely unseen aspect of space operations. Nearly a dozen countries have some kind of military space program, but the U.S. program dwarfs the efforts of all these other countries combined.

reconnaissance a survey or preliminary exploration of a region of interest

meteorology the study of atmospheric phenomena or weather

Military space operations are divided into five main areas: **reconnaissance** and surveillance, signals intelligence, communications, navigation, and **meteorology**. Only the United States and Russia operate spacecraft in all five areas. Several other countries have long used communications satellites for military purposes. In the 1990s, several countries in addition to Russia and the United States began developing reconnaissance satellites.

Reconnaissance and Surveillance

Reconnaissance and surveillance involve the observation of Earth for various purposes. Dedicated reconnaissance satellites, like the United States's Improved CRYSTAL and the Russian Terilen, take photographs of targets on the ground and relay them to receiving stations in nearly real time. These satellites, however, cannot take continuous images like a television camera. Instead, they take a black-and-white photograph of a target every few seconds. Because they are in low orbits and are constantly moving, they can photograph a target for only a little over a minute before they move out of range. The best American satellites, which are similar in appearance to the Hubble Space Telescope, can see objects about the size of a softball from hundreds of miles up but they cannot read license plates. The Russians also occasionally use a system that takes photographs on film and then returns the film to Earth for processing. This provides them with higher-quality photos. The United States abandoned this technology in the 1980s after developing superior electronic imaging technology.

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

wavelengths the distance from crest to crest on a wave at an instant in time

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

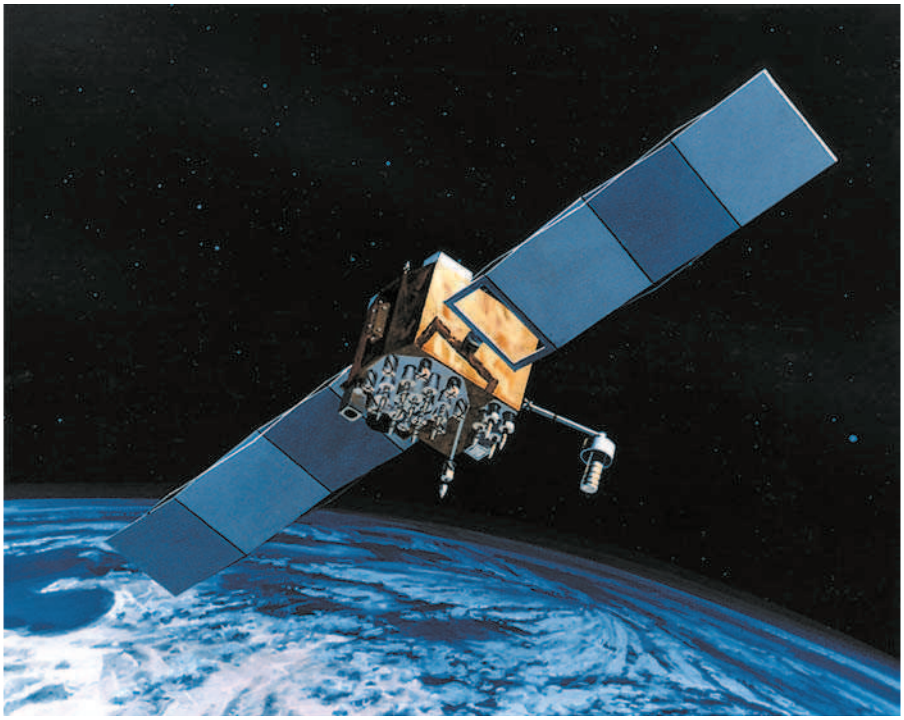
geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Other nations, such as France and Japan, operate or plan on operating reconnaissance satellites that can see images on the ground about one to three feet in length. From the late 1970s until the mid-1990s, China had a film-based system, which is no longer operational. India, Israel, and Brazil also operate satellites capable of making visual observations of the ground. Some private companies operate commercial imagery satellites and sell images on the World Wide Web. These satellites are much less capable than the larger military satellites but their products have improved significantly and are in demand.

Other surveillance satellites, such as the American DSP and Space-Based Infrared System (SBIRS, pronounced "sibirs") and the Russian Oko (or "eye"), are equipped with **infrared** telescopes and scan the ground for the heat produced by a missile's exhaust. They can be used to warn of missile attack and can predict the targets of missiles fired hundreds or thousands of miles away. There are also satellites that look at the ground in different **wavelengths** to peer through camouflage, try to determine what objects are made of, and analyze smokestack emissions.

Signals Intelligence

Signals intelligence satellites can operate either in **low Earth orbit** or in extremely high, **geosynchronous orbit**, where they appear to stay in one



Satellites such as this artist's rendering of an Air Force NAVSTAR Global Positioning System (GPS) BlockIIF, are used increasingly in military operations by countries with global interests.

spot in the sky. These satellites listen for communications from cellular telephones, walkie-talkies, microwave transmissions, radios, and **radar**. They relay this information to the ground, where it is processed for various purposes. Contrary to popular myth, these satellites do not collect every conversation around the world. There is far more information being transmitted every day over the Internet than can be collected by even the best spy agency.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Communications

Communications satellites operate in several different orbits for various purposes. The most common communications satellites operate in geosynchronous orbit. Some, like the U.S. Navy's UHF-Follow On satellite, are used to communicate with ships at sea. Others, like the air force's massive Milstar satellite, are used to communicate with troops on the ground and submarines equipped with small dish antennas. Still other communications satellites are used to relay reconnaissance pictures to ground stations or to troops in the field. Some satellites are used to relay data and commands to and from other satellites.

Russia operates a number of military communications satellites, including some that store messages for a brief period before relaying them to the ground. Several other countries, such as the United Kingdom, Spain, and France, have either military communications satellites or a military communications package installed on a commercial satellite. But few countries have the global military communications requirements of the United States.

Navigation and Meteorology

Navigation satellites are also vital to military forces. Sailors have used the stars to navigate for centuries. Beginning in the early 1960s, the U.S. Navy

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

meteorology satellites satellites designed to take measurements of the atmosphere for determining weather and climate change

developed a satellite system to help it navigate at sea. This was particularly important for **ballistic** missile submarines that stayed submerged for most of their patrols and could only occasionally raise an antenna above the waves to determine their position.

In the 1980s the U.S. Air Force started operating the Global Positioning System (GPS), which allowed anyone equipped with a receiver to locate his or her position on Earth to within about thirty feet or less. GPS uses a constellation of twenty-four satellites that circle Earth every twelve hours. From any point on Earth, there are usually three or four GPS satellites above the horizon at any one time. A handheld receiver detects radio emissions from these satellites.

Commercial receivers are available in sporting goods stores and in many new cars. Using a special civilian GPS signal, they provide less precise location information than the military receivers but still allow a user to navigate accurately. Civilian users can locate their position on Earth to an accuracy of about thirty feet. Russia operates a system similar to GPS, but virtually every military on the planet uses the civilian GPS signal.

Accurate weather information is critical to military operations. The United States and Russia operate **meteorology satellites** for military use. However, since the end of the Cold War, separate military and civilian meteorology satellites have been viewed as an unnecessary expense, and the military systems have gradually been merged with their similar civilian counterparts.

Antisatellite Defense ("Star Wars")

Antisatellite (ASAT) and missile defense (Strategic Defense Initiative [SDI] or "Star Wars") satellites are not currently part of any nation's arsenal. ASAT weapons are difficult to develop and operate and they have limited usefulness. It is extremely precarious to use a satellite to shoot down ballistic missiles. In the future, satellites may be used to intercept missiles, but it is unlikely that this will happen for a long time.

During the Cold War, both superpowers studied the possibility of placing nuclear weapons in orbit, but neither country did so. A bomb in orbit will spend most of its time nowhere near the target it needs to hit, unlike a missile on the ground, which will always be in range of its target. In addition, controlling a system of orbiting bombs would be difficult.

Military Role of Humans in Space

There has never been a clear military role for humans in space, despite decades of study by both superpowers. During the 1960s, the United States explored several piloted military space systems. One of these was the Dyna-Soar spaceplane, which was canceled in 1963 after the air force could find no clear mission for it. Another of these was the Manned Orbiting Laboratory (MOL). MOL was to carry a large reconnaissance camera, and two astronauts were to spend up to a month in orbit, photographing objects on the ground. The United States canceled MOL in 1969 after it became clear that humans were not needed for the job and robotic systems could perform the task reliably and in many cases better than humans. The Soviet Union briefly operated crewed space stations similar to MOL but abandoned these for the same reason as the United States.

Summary

Around the world, military operations are increasingly using commercial satellites to accomplish their missions. Commercial communications satellites are particularly useful and cheap. In addition, commercial reconnaissance satellites are finding many military uses, enabling countries that cannot afford their own satellites to buy photos of their adversaries.

Satellites are not required for many local military operations. But if a country is operating far from its borders or has global interests, they are a necessity. Only a few countries are willing to pay the expense of operating military space systems, but that number is growing. SEE ALSO Global Positioning System (volume 1); Military Exploration (volume 2); Military Uses of Space (volume 4); Navigation from Space (volume 1); Reconnaissance (volume 1); Satellites, Types of (volume 1).

Dwayne A. Day

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Mueller, George

American Engineer and Corporate Leader
1918–

George E. Mueller is an American engineer and corporate leader whose work and career span the development of the U.S. space program. Born July 16, 1918, Mueller holds a master's degree in electrical engineering from Ohio State University, and worked at Bell Laboratories before subsequently earning his doctorate degree in physics from Purdue University. His career has focused on the development and success of the U.S. space program.

As head of the National Aeronautics and Space Adminsitration's (NASA) Apollo Manned Space Flight Program from 1963 to 1969, Mueller led the program that put Americans on the Moon. He was in charge of the **Gemini**, **Apollo**, and Saturn programs. In addition, he coordinated the activities of 20,000 industrial firms, 200 universities and colleges, and hundreds of thousands of individuals into one concerted effort. His leadership made it possible to meet the challenge set in 1961 of not only landing men on the Moon before the end of the decade, but also their safe return to Earth.

After the successful completion of the second landing on the Moon by Apollo 12, Mueller returned to industry where he was senior vice president of General Dynamics Corporation and chairman and president of System Development Corporation. At press time, he is the chief executive officer of Kistler Aerospace Corporation, and has been leading the development

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

George Mueller headed NASA's Apollo Manned Space Flight Program from 1963 to 1969. He is known as the "Father of the Space Shuttle."

and operations of the Kistler K-1, the world's first fully reusable aerospace vehicle. Mueller is the recipient of many prestigious awards, including the Rotary National Award for Space Achievement, which was awarded to him in 2002. SEE ALSO Apollo (Volume 3); Apollo Lunar Landing Sites (Volume 3); Gemini (Volume 3); NASA (Volume 3).

Debra Facktor Lepore

Internet Resources

Kistler Aerospace Corporation. <http://www.kistleraerospace.com>.

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Navigation from Space

For hundreds of years, travelers have looked to the sky to help navigate their way across oceans, deserts, and land. Whether using the angle of the Sun above the horizon or the night stars, celestial bodies guided explorers to their destinations. In the twenty-first century, people still look to the sky for direction, but now they are using satellites that orbit Earth to determine their location. In fact, it is quite common to see people using what is called the Global Positioning System (GPS), which is a satellite navigation system, to answer the age-old question: Where am I?

Evolution of Satellite Navigation

The idea of using satellites for navigation was conceived when the satellite Sputnik 1 was launched in 1957. At that time, U.S. scientists developed a way to track Sputnik's orbit using the time delay or Doppler shift of the radio signal being broadcast by the satellite. The scientists proposed that this process could be used in the opposite way for navigation. Specifically, using a satellite with a known orbit, one's position could be determined by observing the time delay or Doppler shift of a radio signal coming from that satellite.

The concept of being able to determine a position from satellites appealed to the U.S. Navy. To test the idea, they developed the Transit satellite navigation system. By 1964 Transit was being used by Polaris submarines to update the inertial navigation systems onboard the submarines. During roughly the same period, the U.S. Air Force also had a satellite navigation program under development. In the early 1970s, the navy and air force programs merged into one program called the Navigation Technology Program. This program evolved into the NAVSTAR (Navigation System with Timing and Ranging) GPS—the space navigation system used today.

The position that this soldier obtains through his Global Positioning System receiver is communicated through the triangulation of the signals of twenty-four orbiting satellites.

How the Global Positioning System Works

GPS uses twenty-four satellites that circle Earth in a 20,000–kilometer high (12,400–mile high) orbit. The satellites are in orbits that are inclined at 55 degrees with respect to the equator. The satellites are in six orbital planes, each of which has four operational satellites. In March 1994 the full twenty-four-satellite constellation was in place in orbit and the network became fully functional the following year. Users of this navigational system need a

GPS receiver. There are many commercial manufacturers of these devices. They are sold in most stores that sell electronic equipment and cost as little as $150.

Each satellite in the GPS transmits a signal with information about its location and the current time. Signals from all of the satellites are transmitted at the same time. These signals are received at different times by a GPS receiver because some satellites are closer than others. The distance to the satellite is determined by calculating the amount of time it takes the signal to reach the receiver. The position of the receiver is determined by triangulation, except that in this case, the distance to four GPS satellites is used to determine the receiver's position in three dimensions.

Alternatives to the Global Positioning System

The United States allows anyone around the world to use the GPS system as a free resource. For many years, however, there has been a concern in other countries that the United States could deny access to the GPS system at any time. This has led to attempts by other nations at developing alternative satellite navigation systems. The most notable of these emerging systems is a European Space Agency venture called Galileo. The European Union transport ministers approved the initial funding of 100 million euros in April 2001. Proposed as a civilian satellite navigation system, Galileo may be fully operational by 2008. One difference between Galileo and GPS is that some of the satellites in Galileo's constellation will be in orbits with greater inclination to the equatorial plane than the GPS satellites. This will give northern Europe better coverage than that provided by GPS today.

Russia has developed a military satellite navigation system called Glonass. This system, which entered service in 1993, used twenty-four satellites when it began operation. Because of the country's financial problems that began later in the 1990s, however, older satellites were not replaced. As a result, by 2001 only six of the original twenty-four satellites were still in use, although Russia had plans to launch three new satellites in the early twenty-first century.

China is also planning to develop its own satellite navigation system. In 2000 China launched two experimental navigational satellites. These satellites, called the Beidou navigation satellites, are named after the constellation the Big Dipper. They continue to be used for some limited functions. China hopes to build a more extensive satellite navigation system by around 2010. SEE ALSO Global Positioning System (volume 1); Military Customers (volume 1); Navigation (volume 3); Reconnaissance (volume 1); Satellites, Types of (volume 1).

Salvatore Salamone

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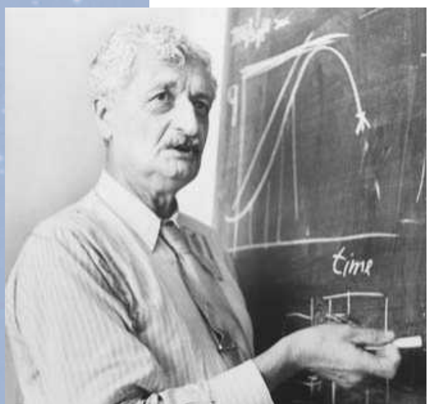
TWO FOR ONE

The GPS system was originally developed for use by the military and government agencies, but the U.S. government has made it available for commercial use. The first nongovernment users were surveyors and commercial trucking and seagoing shipping firms. Today, with GPS receivers becoming increasingly affordable, their use has expanded to the general public, allowing recreational boaters, hikers, even people just driving their cars, to determine their location via satellite. This dual-purpose role is supported through the use of two different GPS services levels. The Standard Positioning Service (SPS) is available to nongovernment users, while military and federal government users utilize the more accurate Precise Positioning Service.

Oberth, Hermann

Austro-Hungarian Physicist
1894–1989



Hermann Oberth, in his office at the Army's Redstone Arsenal in Alabama, working on a mathematical formula in 1958. Oberth came to the United States in 1956 from Germany as a consultant on space travel.

Hermann Julius Oberth, who was born on June 25, 1894, in the Transylvanian town of Hermannstadt, is considered a founding father of rocketry and astronautics. In the 1920s Oberth, whose childhood fantasies had been inspired by the novels of Jules Verne, wrote an influential publication *The Rocket into Planetary Space*, which discussed many aspects of rocket travel. Later he expanded that work into a larger volume, *The Road to Space Travel*, which won wide recognition.

After World War I, Oberth studied physics at the University of Munich, where he realized that the key to space travel was the development of multistage rockets. Despite this important insight, Oberth's doctoral thesis on rocketry was rejected in 1922. However, in 1923, he published *The Rocket into Planetary Space*, which was followed by a longer version in 1929. In the final chapter Oberth foresaw "rockets . . . so [powerful] that they could be capable of carrying a man aloft."

In the 1930s, Oberth proposed to the German War Department the development of liquid-fueled, long-range rockets. Oberth worked with the rocket pioneer Wernher von Braun during World War II to develop the V-2 rocket for the German army. During this period Robert Goddard was launching liquid-fueled rockets in the United States. After the war Oberth and von Braun collaborated again at the U.S. Army's Ballistic Missile Agency in Huntsville, Alabama. Oberth contributed many important ideas regarding spaceflight, including the advantages of an orbiting telescope. Oberth died in 1989 at the age of 95. SEE ALSO Goddard, Robert Hutchings (volume 1); Verne, Jules (volume 1); von Braun, Wernher (volume 3).

John F. Kross

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Payloads and Payload Processing

The machines, equipment, hardware, and even people that are carried into space atop rockets or inside space shuttles are often called payloads. The term originated in World War I (1914–1918) during efforts to determine the amount of cargoes and people that could be carried by land tanks. The term is also often applied to the amount of useful weight that can be lifted

Space shuttle payloads can include experiment packages, satellites for deployment, or space station hardware or supplies.

by airplanes and inside trucks. Without a useful amount of payload—the "pay" carrying load—any transportation system would be of minimum value since the objective of a transport is to carry cargoes from destination to destination. This is true whether the transport in question is a rocket or a car and the payload consists of satellites or groceries. Payloads can consist of nearly anything that researchers, government, or industry seek to place into space. Satellites, robotic probes, or instrument packages can act as payloads. In human spaceflight programs, payloads can be the astronauts themselves, along with their life-sustaining equipment and supplies.

Mission specialists assemble a structure in the payload bay of space shuttle Endeavour.

In space transportation, payloads arrive in space with minimum activity involving people. If the transport is an expendable, throwaway rocket, there are no people present when the craft arrives in space. Even if the space shuttles are used for launching the payload, astronaut interaction with the payload during a flight is kept at a minimum except under unusual circumstances. Thus all of the payloads sent into space are carefully prepared before the launching and their checkouts and activation automated to the maximum extent possible. Because people will not be present when these payloads arrive in space, payload processing and prelaunching preparation is an important part of the flight itself.

Payload Design and Storage

Payload preparation actually begins when the payload is under design. Space engineers often design a satellite to absorb the types of effects that the launching system—a rocket or shuttle—places upon the machine. These can include the effects of the thrust of the rocket and the amount of gravity that its thrust into space generates on the payload and everything else aboard the rocket. Depending on the flight path chosen, the type of rocket, and the final destination planned for the payload, this can be many times the pull of gravity experienced on Earth's surface. Other effects, such as friction, heat, vibration, and **vacuum**, also affect the payloads as they rise through the atmosphere and move out into the space environment.

vacuum an environment where air and all other molecules and atoms of matter have been removed

Once the craft reaches its planned destination in space, designers must factor in the final environmental conditions, such as radiation and the surface conditions of a planet if a landing is planned. If the planetary destination is far away, engineers must build the craft to sustain the long flight. If the spacecraft is flying toward the Sun, it must be shielded from the harsh and continuous heat streaming out from the Sun. If the craft is flying in the opposite direction, then the craft and its electronics must be heated to keep warm during its long cruise in the cold dark of space.

Once a payload has been designed and manufactured, it must be kept in storage until the time draws near for its launch. Usually the manufacturer prepares a storage container and location that maintains the payload in environmentally friendly conditions as the launch is awaited. This is a period that could last months or even years. For example, when the space shuttle Challenger exploded in 1986 all shuttle missions were placed on hold. Their payloads had to be stored for several years because of this unexpected delay. Such large satellites as the Hubble Space Telescope and other military spacecraft bound for a shuttle ride had to be specially stored during the delay.

Preparation for Launch

As the date of a planned launch draws nearer, payloads are shipped to the launching base where the flight will take place. Following its arrival from the manufacturer, the payload is rechecked to assure that it has not been damaged or affected in transit. Sometimes this includes partially dismantling the payload and conducting extensive recheckouts. More complicated payloads such as the Russian modules to the International Space Station are shipped only partially built, with construction completed at the launching site itself. Once engineers have assured themselves that the payload has arrived at the launch site without damage, the next phase of preparation usually consists of readying the payload for mating with its rocket transport.

Shuttle Launches. If the launching vehicle is a space shuttle, much of the preparation process serves to ensure that the payload poses no risk to astronauts on the shuttle. Careful review of the payload's fuels, its electrical systems, and any rocket engines that might be part of its design are conducted. Once that step is completed, the craft is then checked for the method by which it is to be attached to the shuttle's cargo bay. Attachments, release mechanisms, and other devices that will act to deploy the payload away from the shuttle or allow it to be operated while still attached inside the bay are tested and verified ready for flight.

At a certain stage in the final launch preparations the payload is moved from its preparation facility to the launching pad and installed inside the shuttle. Once in place, many of the tests and verifications are repeated to assure workers that the payload and its shuttle interfaces are working together. Unlike cargoes that fly inside commercial airliners, cargoes that are launched aboard the space shuttles are partially integrated with the shuttle itself. This even includes the selection of the location where the payload is attached to the shuttle bay.

When all of these steps have been completed, a complete dress rehearsal of the final days of the countdown and liftoff is conducted. Called a Terminal Countdown Demonstration Test, this simulated launching even includes suiting up the astronaut crew and having them board the shuttle just as they will do on the day of the actual flight. The payload is activated at the same level it will be on launch day, and the test goes all the way up to the point where the rocket engines would be ignited to start the actual mission into space. If all goes well with this test, the payload and the shuttle are deemed ready for their space mission.

Expendable Rocket Launches. If the launching vehicle is an expendable rocket, the process is somewhat less complex. Once at the launching site, the checkout and testing is conducted and the craft made ready for installation atop the rocket. In the United States, France, and China, the test and integration procedure is done with the rocket and payloads stacked vertically. Russian space launch vehicles use a horizontal integration technique. Whichever method is used, the payload is attached to the final propulsive stage of the rocket or to its own rocket stage, and the completed assembly is carried to the rocket pad or final assembly building and becomes part of the overall launch vehicle.

As is the case with the shuttle, tests are conducted to verify that the attachments have been correctly made and that the rocket's computers are "talking," or exchanging data, with the payload computers. A dress rehearsal of the launch is also conducted, although it is usually less extensive than that done for the shuttles. A successful completion of this test clears the way for the final countdown. Rocket fuels and explosive devices to separate the rocket's stages in flight or to destroy the craft if it veers off course are loaded into the rocket. Checks of the weather along the vehicle's flight path are also conducted.

When liftoff occurs, information on the health of the payload is sent by radio to tracking stations along the path that the rocket takes towards space. When the point in the flight is reached where the payload becomes active, it comes alive through radio commands, and begins its own role in achieving its space mission goal. If a malfunction occurs, radio data give mission controllers and engineers information on the cause, so that future versions of the rocket and payload can be redesigned to avoid the trouble.

Present-day launching rockets have an average of one chance in ninety-five or ninety-seven of experiencing an actual launching disaster. The most reliable rockets thus far designed have been the Apollo Saturn lunar boosters and the space shuttles. The Saturns had a perfect flight record in their missions from 1961 through 1973. The space shuttle has failed once in 100 missions. SEE ALSO Launch Services (volume 1); Launch Vehicles, Expandable (volume 1); Launch Vehicles, Reusable (volume 1); Payload Specialists (volume 3); Payloads (volume 3); Satellites, Types of (volume 1); Spaceports (volume 1); Space Shuttle (volume 3).

Frank Sietzen, Jr.

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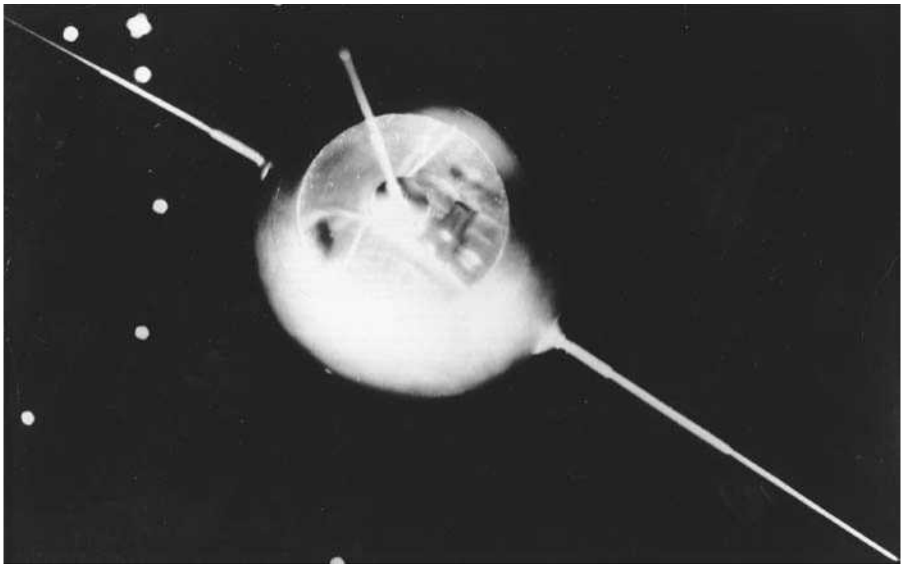
Planetary Exploration

The exploration of space has been of interest to people since Nicholas Copernicus (1473–1543) and Galileo Galilei (1564–1642) discovered and described the true nature of the solar system. About 100 years ago, Russian Konstantin Tsiolkovsky (1857–1935) was the first scientist to describe the modern concepts of rocket engines and space travel. Tsiolkovsky, who wrote books about space travel, stated: "Earth is the cradle of humanity, but one cannot remain in the cradle forever."

In 1957 the Soviet Union surprised everyone by launching the world's first satellite, Sputnik. Only four years later, American amateur radio operators (hams) built and launched the world's first volunteer- and citizen-built satellite, Oscar I. Oscar I weighed about 3.7 kilograms (10 pounds) and transmitted the word "Hi" in Morse code as it orbited Earth.

Government-Backed Exploration

In the beginning, national space programs were exclusively military. While Robert H. Goddard (1882–1945) was experimenting with small and unsuccessful rockets in the United States, the German Nazi war effort progressed to the point where the Nazis were able to bomb downtown London with their V-2 rockets. When the Nazis were defeated, the armed forces of the Soviet Union and the United States raced to obtain valuable German



A model of Sputnik 1 at the Prague, Czechoslovakia, exhibition on October 7, 1957, in celebration of the 40th anniversary of Russia's October Revolution. The real Sputnik 1 was launched three days earlier, becoming the first human-made object launched into space, starting the space race between the Soviet Union and the United States.

U.S. President Dwight D. Eisenhower (1890–1969) urged the formation of the National Aeronautics and Space Administration (NASA).

engineers to gain their knowledge of advanced rocketry. After World War II (1939–1945), the programs of both countries were based on former German rocket scientists, such as Wernher von Braun (1912–1977), who was brought to the United States.

The National Aeronautics and Space Administration (NASA) was formed in 1958 at the urging of President Dwight D. Eisenhower (1890–1969). President Eisenhower wanted a civilian and not a military agency to challenge the Soviet Union in the race to space. NASA's first challenge was to beat the Soviet Union to the Moon, which it successfully accomplished with the Apollo 11 mission in 1969.

Moving Beyond Government-Sponsored Space Programs

The excitement generated by humans walking on the surface of another planetary body resulted in many nongovernment people dreaming and working toward the private exploration and development of space. A leader during the 1970s was Gerard O'Neill of Princeton University, who imagined and described the possibility of people working, living, and playing in space. Much research was done on his concepts of space colonies orbiting Earth, but because his designs depended on large amounts of materials being launched to Earth orbit, and because of the very high cost of government technology and launches, such space colonies never materialized.

In 1965, Comsat launched the first commercial communications satellite. Today, college students design, build, and launch smaller, more powerful satellites. These "nano-sats" and other small microsatellites are usually launched as "hitchhikers" on large expensive rockets. Many space entrepreneurs today believe that a revolution may be happening with the introduction of smaller, more modern technology into space products. With college students building 1-pound satellites, and with the introduction of the concept of formation-flying dozens or hundreds of nano-satellites in orbits close to each other, it is possible to think of small satellites being like the personal computers linked together in local area networks that replaced the big expensive mainframe computers.

Also during the mid-1990s, a number of companies were started with the hope of designing and producing dramatically less expensive launch vehicles. Each company began with the hope that it had some kind of breakthrough technology that would revolutionize launch vehicles and reduce the cost of orbiting material from $22,000 per kilogram ($10,000 per pound) to as little as $220 per kilogram ($100 per pound). Because of the expense and risk involved in developing new technologies, these companies have not yet made much progress.

While many people are beginning to understand that space is a place and not a government program, there are many hurdles to overcome in making space happen for large numbers of nongovernment people—workers, tourists, and others wanting to experience space. Those interested in seeing space blossom feel that there are two primary paths. The first involves more government spending on large programs, such as an Apollo-like human mission to Mars. It appears, however, that taxpayers are not willing to fund such an expensive program. The other commercial and entrepreneurial paths to space may be encompassed in the slogan: "If we want to go to space to stay, space has to pay."

Difficult and expensive ventures often need to start with baby steps: learning to crawl and then walk before being able to run. Space may be like that. Many companies are starting with the goal of finding ways to make space pay in order to generate profits that can be used to conduct increasingly bolder and larger space ventures, without government intervention or taxpayer subsidies. Sources of revenue include planetary science data, returned samples, delivery of science instruments to planetary destinations, use of the abundant natural resources in space, delivery of television and Internet content in the form of photos and videos, manufacture of materials in space, and space tourism. All of these can be done commercially.

Robert A. Heinlein (1907–1988), an American writer and scientist, said that getting to Earth orbit is halfway to anywhere in the solar system. He meant that the energy required to lift off the ground and get up enough speed to achieve Earth orbit is about the same amount of energy required to leave Earth orbit and head for any other destination in the solar system. In other words, when we reach Earth orbit today, we are running on empty, our tanks are empty, and about the best we can do is go around in circles, as with the shuttle. Even with more expensive, larger rockets, we can just manage enough energy to break away from Earth's gravity. Our deep-space missions then coast, on empty, to their destination whether it is Venus, Mars, Jupiter, or the boundaries of the solar system itself.

What some believe is needed for serious exploration of space are filling stations in Earth orbit where a spacecraft could refill its tanks and could then power its way through space and not just coast for years. Earth-bound society is dependent on concentrated, portable energy such as gasoline, petroleum (black gold), natural gas, and coal. Space is no different: concentrated, portable energy is needed to explore space. Water is the most abundant substance in the universe and in the solar system. Scientists know that Earth travels in a cloud of inner belt asteroids called near-Earth objects. Many planetary scientists, such as John S. Lewis of the University of Arizona in Tucson, believe that 20 percent or more of these objects may be **dormant comets**. These space icebergs, then, might be considered "white gold."

dormant comet a comet whose volatile gases have all been vaporized, leaving behind only the heavy materials

With the cost of lifting anything into space at about $22,000 per kilogram ($10,000 per pound), it can be understood that anything already in space is already worth $10,000 per pound. If private exploration companies were to find water in near-Earth asteroids, the water could be extracted and converted to its constituent parts—oxygen and hydrogen—with simple electrolysis. Like Earth, space is filled with **diffused** energy: solar energy. This energy could be captured by satellite **solar arrays** and converted into electricity to power spacecraft, and could also be used to generate rocket fuel: specifically, hydrogen and oxygen, which, for example, are used in the main engines of the space shuttle.

diffused spread out; not concentrated

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

By 2000 the international space sector of the global economy exceeded $100 billion per year with about one launch per week somewhere in the world. Since about 1998 over half of that space activity has been commercial and not military or governmental. With smaller modern technology and entrepreneurial space companies starting, we may be on the verge of the real space age. SEE ALSO Apollo (volume 3); Data Purchase (volume 1); Earth—Why Leave? (volume 4); Exploration Programs (volume 2); Planetary Exploration, Future of (volume 2); Satellite Industry (volume 1).

James W. Benson

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Privatization *See Commercialization (Volume 1).*

R

Reconnaissance

The first military space mission was reconnaissance, and that remains the most important mission, offering capabilities that cannot be obtained by any other means. A number of countries possess military satellite reconnaissance systems, including the United States, Russia, France (in cooperation with Germany, Italy, and Spain), and Israel. China apparently has abandoned its reconnaissance satellite system. Japan has plans to develop an extensive reconnaissance satellite capability, and Canada, India, and Brazil operate "civilian remote sensing satellites" that have limited military uses. Since the late 1990s several private companies have offered to sell satellite imagery of increasingly high quality. Virtually any country can now buy detailed pictures of any place it wants to see.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

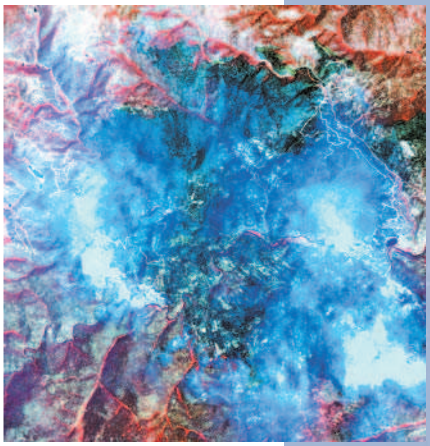
At the most basic level, reconnaissance involves looking at an area of Earth to determine what is there. Among the ways this can be done from space, the primary methods are visual and **radar** reconnaissance. Visual reconnaissance can be conducted in black and white or in color, although black-and-white images provide more detail. The major problem is that visual reconnaissance is impossible when the target is covered by clouds. Radar can penetrate cloud cover, but the images it returns are of lower quality. Radar reconnaissance is more challenging, and fewer countries operate dedicated radar satellites.

The United States was the first country to consider the use of satellites for reconnaissance. In 1946 the RAND Corporation conducted a study for the U.S. Air Force of the potential military uses of satellites, and reconnaissance was high on the list. However, the high cost of launching a satellite into orbit was prohibitive. In 1954 RAND conducted a much more extensive study of reconnaissance satellites and their capabilities. RAND proposed an atomic-powered satellite carrying a television camera. When the U.S. Air Force began a reconnaissance satellite program, the television camera proved impractical, and a "film-scanning" system was chosen instead. That system would take a photograph, develop the film aboard the satellite, and then scan the image and transmit it to Earth. Solar panels were substituted for the atomic power supply. The Atlas ICBM was to be used to launch the satellite into orbit, but the U.S. Air Force was unwilling to fund the program until after Sputnik was launched in October 1957.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

After the advent of the space age, satellite reconnaissance received much more attention in the United States, which feared that the Soviet Union had large numbers of **ballistic** missiles at sites deep within that country. The U.S. Air Force funded a series of film-scanning satellites called SAMOS, and the Central Intelligence Agency was placed in charge of an "interim" program called CORONA. Unlike SAMOS, CORONA returned its film to Earth in a small capsule that was caught in midair by an airplane trailing a cable.

After a string of failures, the first CORONA satellite returned its film to Earth in 1960. The pictures were grainy and showed relatively little detail but provided a wealth of information on the Soviet Union, including the fact that the Soviet Union did not have more missiles than the United States did. CORONA became more successful, and its images improved in quality, whereas SAMOS experienced numerous failures. At its best CORONA could photograph objects on the ground that were a minimum of 6 to 9 feet long. That did not allow observations and measurements, and so the U.S. Air Force canceled SAMOS and began a satellite program called GAMBIT. GAMBIT, like CORONA, returned its film to Earth, but it could photograph much smaller objects. CORONA was discontinued in 1972, but GAMBIT kept flying until 1985, and late models of the satellite could photograph objects as small as a baseball.



From space, the examination of an area of Earth to determine what is there can be accomplished through visual and radar reconnaissance.

Developments in Reconnaissance Technology

The next major leap in reconnaissance satellite technology occurred in 1976, when the United States launched a satellite known as KENNAN, later renamed CRYSTAL. KENNAN could transmit images directly to the ground, using a camera similar to a common digital camera. The images were black and white and took several minutes to transmit, but this was far faster than the days or weeks required with the film-return system. These satellites could see objects no smaller than a softball. With the increase in speed came a change in the ways the satellites were employed. Instead of being used to prepare long-range plans and studies, they could now be used in crisis situations, and the president could make instant decisions based on satellite photographs.

Later versions of KENNAN probably are still in use, but these satellites are limited by their inability to see through clouds. In the late 1980s the United States launched a radar satellite called LACROSSE (later renamed ONYX) that could look through clouds and smoke. The major drawback of LACROSSE was that it could see objects no less than 3 three feet long.

Soviet Reconnaissance Satellites

The Soviet Union developed similar systems, usually trailing about three to seven years behind the United States. Its first reconnaissance satellite, Zenit, was similar to the first Soviet spacecraft to launch a man into orbit, Vostok. Unlike CORONA, Zenit returned both the film and the camera to the ground in a large capsule. The Soviets later developed a higher-resolution system called Yantar. It was not until the 1980s that the Soviets had a satellite, Terilen, capable of transmitting images to the ground in "real time." The Russians still use modified versions of Zenit and Yantar, although economic problems have limited the number of satellites they can launch.

The United States is gradually shifting from using a few large reconnaissance satellites to employing more smaller satellites as part of its Future Imagery Architecture. The purpose of this shift is to decrease the amount of time it takes to photograph any spot on the ground. It now requires a day or more before a photograph of a potential trouble spot is taken by a reconnaissance satellite.

Commercial Reconnaissance Technology

The United States will be helped in this shift by the proliferation of commercial reconnaissance satellites. In the early twenty-first century, commercial satellites such as Ikonos-1, operated by an American company, can provide satellite imagery of virtually any place on Earth for a fee. Commercial satellites generally show objects on the ground that are as small as 3 feet long, and this is useful for many civilian and military purposes. As with the military satellites, these images are still pictures, not the moving images shown in spy movies. They sometimes are referred to as "the poor man's reconnaissance satellite," but they can dramatically increase the power of a military force by allowing the users to know what their adversaries are doing from a vantage point that the vast majority of the world cannot reach. SEE ALSO GLOBAL POSITIONING SYSTEM (VOLUME 1); MILITARY CUSTOMERS (VOLUME 1); MILITARY EXPLORATION (VOLUME 2); MILITARY USES OF SPACE (VOLUME 4); REMOTE SENSING SYSTEMS (VOLUME 1); SATELLITES, TYPES OF (VOLUME 1).

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Regulation

remote sensing the act of observing from orbit what may be seen or sensed below Earth

Commercial space activities conducted by U.S. companies are regulated by the federal government in four major areas: space launches, **remote sensing**, communications, and limitation of the transfer of technology for reasons of national security and industrial policy.

Communications are regulated by the Federal Communications Commission (FCC). The FCC was established in the 1930s to regulate radio (and later television) and the use of spectrum, assuring that the signals from one station would not interfere with those from another station. When commercial communications satellites arrived in the mid-1960s, the FCC had had three decades of regulatory experience.

The office within the FCC that issues licenses for satellites is the Satellite and Radiocommunications Division of the International Bureau. Licensing assures that any proposed new satellite will not interfere with other satellites or with any other operating radio applications, on Earth or in space. All commercial launches, reentries, or landings conducted by U.S. companies are regulated by the Commercial Space Launch Act (CSLA). Under the CSLA, each launch or reentry must have a license. FAA/AST, the Office of Commercial Space Transportation, is part of the Federal Aviation Administration and is the federal government agency that issues these licenses. Its web site (ast.faa.gov) contains all the relevant rules, laws, regulations, and documents needed to obtain a launch license. FAA/AST conducts a policy review, a **payload** review, a safety evaluation, an environmental review, and a financial responsibility determination based on the data in the license application before issuing or refusing a license. The purpose of a launch license is to assure that "the public health and safety, safety of property, and the national security and foreign policy interests of the United States" are properly considered.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Commercial remote sensing from space is regulated under the 1992 Remote Sensing Policy Act and its associated regulations and administration policies. The act directs the secretary of commerce to administer its provisions, and those duties have been delegated to the National Environmental Satellite, Data, and Information Service (NESDIS) of the National Oceanic and Atmospheric Administration (NOAA), an agency of the Department of Commerce. NESDIS runs the nation's weather satellites, and the International and Interagency Affairs Office (IIAO) within NESDIS issues the licenses needed to operate private space-based remote sensing systems (www.licensing.noaa.gov/).

NESDIS/IIAO reviews these applications in consultation with the Department of Defense (national security), the Department of State (foreign policy), and the Department of the Interior (which has an interest in archiving remote sensing data). Once an application has been determined by NESDIS/IIAO to be complete (all the required documents and data have been submitted), by law NOAA has to issue an up-or-down license determination within 120 days. Documents, background data, instructions, and examples are available at NESDIS/IIAO's web site to aid license seekers.

Under the law, a licensee must operate its space-based remote sensing system(s) so that the national security interests of the United States are respected and the international obligations of the nation are observed. A licensee must maintain positive control of its system(s) and maintain clear records of the sensing those systems have done. A U.S. licensee also must agree to "limit imaging during periods when national security or international obligations and/or foreign policies may be compromised." This is called "shutter control": The federal government can, in time of international stress (war or conflict) tell licensees what they can and cannot take pictures of.

The major law in the area of trade control is the Arms Export Control Act (AECA) and its associated regulations, the International Traffic in Arms Regulations (ITAR). Virtually anything involving space falls under ITAR. Equipment for ground stations for satellite control; transmitters; rocket engines; computer software for controlling a rocket, a satellite, or a ground station; rockets; and satellites are all subject to control and licensure under ITAR.

Licenses and regulation under the AECA and ITAR are administered by the U.S. Department of State and its Office of Defense Trade Controls (DTC), which is part of the Bureau of Political Military Affairs. These organizations are aided in their work by the Defense Threat Reduction Agency of the Department of Defense. DTC's web site (www.pmdtc.org) contains documents, background data, and instructions to aid license seekers, including electronic means for the filing and tracking of license applications.

The United States is a party to the Missile Technology Control Regime (MTCR), to which twenty-eight other countries, including Russia, Greece, Hungry, and Spain, also belong. Equipment and technology are controlled under this regime to limit the proliferation of weapons of mass destruction through efforts to control the availability of delivery systems (rockets). The State Department and the Department of Defense attempt to assure that space companies that export services or products adhere to the goals of the MTCR.

During most of the 1990s, space-related trade control was the responsibility of the Department of Commerce, specifically the Bureau of Export Administration (www.bxa.doc.gov) and the International Trade Administration (www.ita.doc.gov). Both of these agencies now play a reduced role in regulating the export of space-related trade products and services, but their main role at present is primarily to support the activities of the Department of State.

The shift of the regulation and licensing of space-related trade from the Department of Commerce to the Department of State resulted from a law passed by Congress, which wanted to eliminate what it felt was a looseness in U.S. trade control that had led to the transfer of sensitive space technology. This statutory change had unintended consequences, making it extremely difficult for a company such as Orbital Sciences Corporation to communicate with a division of its own company based in a foreign country. Under this regime, satellite engineers cannot talk to their counterparts in the United Kingdom without a license. These restrictions became so stringent that Orbital sold its Canadian-based division because of the difficulties presented by these mandated trade restrictions. Congress has since passed new legislation to address this problem. SEE ALSO Law (Volume 4); Law of Space (Volume 1); Legislative Environment (Volume 1); Licensing (Volume 1).

Timothy B. Kyger

Internet Resources

Office of Commercial Space Transportation. Federal Aviation Administration. <http://ast.faa.gov>.

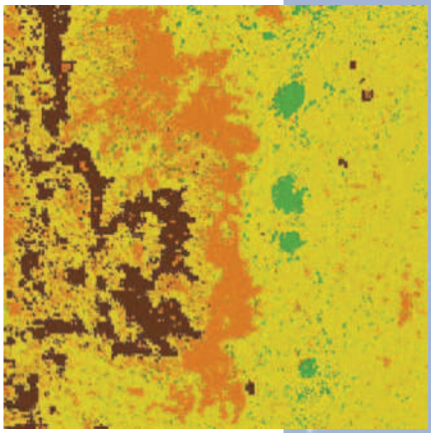
Satellite and Radiocommunications Division of the International Bureau. Federal Communications Commission. <http://www.fcc.gov/ib/srd>.

Remote Sensing Systems

International research efforts have been undertaken to study the complex and interconnected processes that affect Earth's atmosphere, oceans, and land. Essential information for this research is provided by fleets of satellites and aircraft equipped with sensors that collect enormous amounts of Earth data. These systems are called remote sensing systems.

The variety of data that can be obtained through remote sensing systems is vast. The world scientific community uses remote sensing systems to obtain information about ocean temperature, water levels and currents, wind speed, vegetation density, ice sheet size, the extent of snow cover, rainfall amounts, aerosol concentrations in the atmosphere, ozone levels in the

stratosphere, and many other important variables to better understand how natural phenomena and human activities impact global climate. Remote sensing systems may also be used by decision makers such as environmental resource managers, city planners, farmers, foresters and many others to better run their businesses and to improve people's quality of life. This article presents a number of applications of remote sensing systems to farming, water quality analysis, water resources in arid regions, noxious weed detection, urban sprawl, urban heat islands, and many others. This field is in rapid evolution and many new applications may appear in the years to come.



Data obtained through remote sensing systems show some of New Mexico's variegated terrain. Remote sensing systems can also be used to collect data varying from vegetation density to aerosol concentrations in the atmosphere.

stratosphere a middle portion of Earth's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

Satellite Remote Sensing

Space is an excellent vantage point from which to study air, sea, and land processes both locally and globally. It provides the bird's-eye view that captures all the information in a single image. Satellite observations have definite advantages over ground or aircraft observations. Ground observations are labor intensive, time consuming, and costly. Aircraft observations require less labor and time but are still costly. In spite of their high initial cost, satellites are a cheaper way to do observations as they may take data continuously during their lifetime over the whole globe. Satellites can also observe areas difficult to access on the ground and provide regular revisits of the same areas showing surface feature changes over time.

Satellite observations are made with sensors that measure the brightness of electromagnetic radiation either reflected or emitted by ground features. Electromagnetic radiation includes not only visible light with its various colors but also many colors invisible to the human eye such as **ultraviolet** and **infrared**, as well as radar and radio waves.

Resolution refers to the smallest size object that can be identified. A 1-kilometer (0.6-mile) resolution satellite will produce images made of small squares with uniform brightness representing 1-kilometer by 1-kilometer squares on the ground. In general, objects smaller than 1 kilometer cannot be distinguished in such an image.

Whereas visible and near-infrared radiation observed by sensors is actually **solar radiation** *reflected* by ground features, thermal infrared radiation is radiation *emitted* by ground features. Thermal infrared radiation provides information about the temperature of the emitting objects. Other sensors actively illuminate Earth and measure the reflected signal. Radar is an active remote sensing system that is very useful in areas that are often covered with clouds. Whereas visible and infrared radiation is blocked by clouds, radar waves penetrate clouds, thus enabling observations of Earth from space in almost all weather conditions.

Remote sensing data can be compared to an ore that contains gold (information) from which a piece of jewelry can be made (knowledge). Remote sensing is at its best when it is used to answer specific and well-posed questions. The end result of the processing of data, information extraction, and analysis is the answer to these questions.

Many remote sensors are placed onboard aircraft. Satellites may take several days, even weeks before revisiting a specific area on Earth, whereas aircraft can be commissioned to take remote sensing data over that area on a moment's notice. They also operate at significantly lower altitudes and produce higher resolution data than satellites when fitted with the same type of sensor. Finally, many new National Aeronautics and Space Administration (NASA) sensors are tested on aircraft before being put on satellites. Aircraft remote sensing has an important role to play both for global climate change studies and for more immediate applications such as the ones described below.

Global Environmental Observations

We live in a rapidly changing world facing major global challenges. A rapidly increasing world population demanding accelerated economic development strains Earth's resources. Remote sensing systems are being used to investigate a number of areas related to the global environment, including global climate change, rain forest deforestation, the health of the oceans, the size of polar ice covers, and coastal ecosystem health.

Global Climate Change. One of the most ambitious and far-reaching programs of environmental investigation is the U.S. Global Change Research Program. This effort is part of a worldwide program to study global climate change, which involves changes in the global environment that could affect Earth's ability to support life.

A strongly debated climate change issue is global warming, which results from increased atmospheric levels of greenhouse gases—such as carbon dioxide—that trap heat in the lower atmosphere, preventing it from escaping into space.

The Carbon Dioxide Information Analysis Center estimates that fossil fuel use and other industrial activities have resulted in the release of 265 billion tons of carbon into the atmosphere since 1751, with half of the total occurring since the mid-1970s. Worldwide levels of carbon dioxide in the atmosphere have increased by 25 to 30 percent since 1850. The average global surface temperature of Earth is up. The year 1997 was the warmest of the twentieth century and possibly the warmest of the past 1,000 years. The question that some people debate is whether this warming is directly related to the human production of carbon dioxide or due to natural processes. Whatever the answer to this question, the trend is clear and the consequences may be severe for the human species.

Plants grow by absorbing atmospheric carbon dioxide, storing the carbon in their tissue. Rain forests and ocean phytoplankton are great carbon dioxide absorbers. So are corals and shellfish, which make calcium **carbonates** that end up in the bottoms of oceans.

carbonates a class of minerals, such as chalk and limestone, formed by carbon dioxide reacting in water

Trees and plankton may grow faster—left to themselves—if the level of carbon dioxide in the atmosphere increases. This could provide a mechanism limiting atmospheric carbon dioxide concentrations. Unfortunately, people pollute the oceans, which kills phytoplankton and coral reefs, and destroy tropical rain forests.

Scientists worldwide inventory and monitor rain forests, phytoplankton, and coral reefs in an effort to estimate their impact on the concentration of carbon dioxide in the atmosphere. Their main sources of information are from satellite remote sensing data. The warming of Earth's lower atmosphere results in the melting of glaciers and polar ice sheets. The extra liquid water produced raises ocean water levels. Indeed, sea level rose 10 to 25 centimeters (4 to 10 inches) during the last century and glaciers are melting. Data from a number of satellites are used by the National Oceanic and Atmospheric Administration (NOAA) to measure the rate of ice melting in Antarctica and Greenland, two major causes of sea level rising.

Rain Forests. The Global Observations of Forest Cover is an international effort to inventory worldwide forest cover and to measure its change over time. From these observations, which are based on high-resolution satellite remote sensing, scientists produce digital deforestation maps.

Deforestation is a politically sensitive topic. Developed nations pressure developing countries such as Brazil and Indonesia to stop the deforestation process, arguing that the rain forests in these countries are virtual lungs for the world's atmosphere. Developing countries with tropical rain forests argue that the deforested areas are important and necessary sources of revenue and food as they are used for agricultural activities. The debate prompted an international meeting, the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, in June 1992. This conference resulted in the Rio Declaration on Environment and Development that sets the basis for a worldwide sustainable development—an economic development that does not deplete natural resources and that minimizes negative impact on the environment.

Oceans. Phytoplankton and coral reefs in the oceans significantly contribute to the removal of atmospheric carbon dioxide. Acid rain and other pollutants adversely affect coral reefs and phytoplankton. Satellite remote sensing is used to inventory coral reefs and phytoplankton worldwide.✶ Indeed, because of their wide distribution and remote locations, coral reefs can practically be inventoried and monitored only from space.

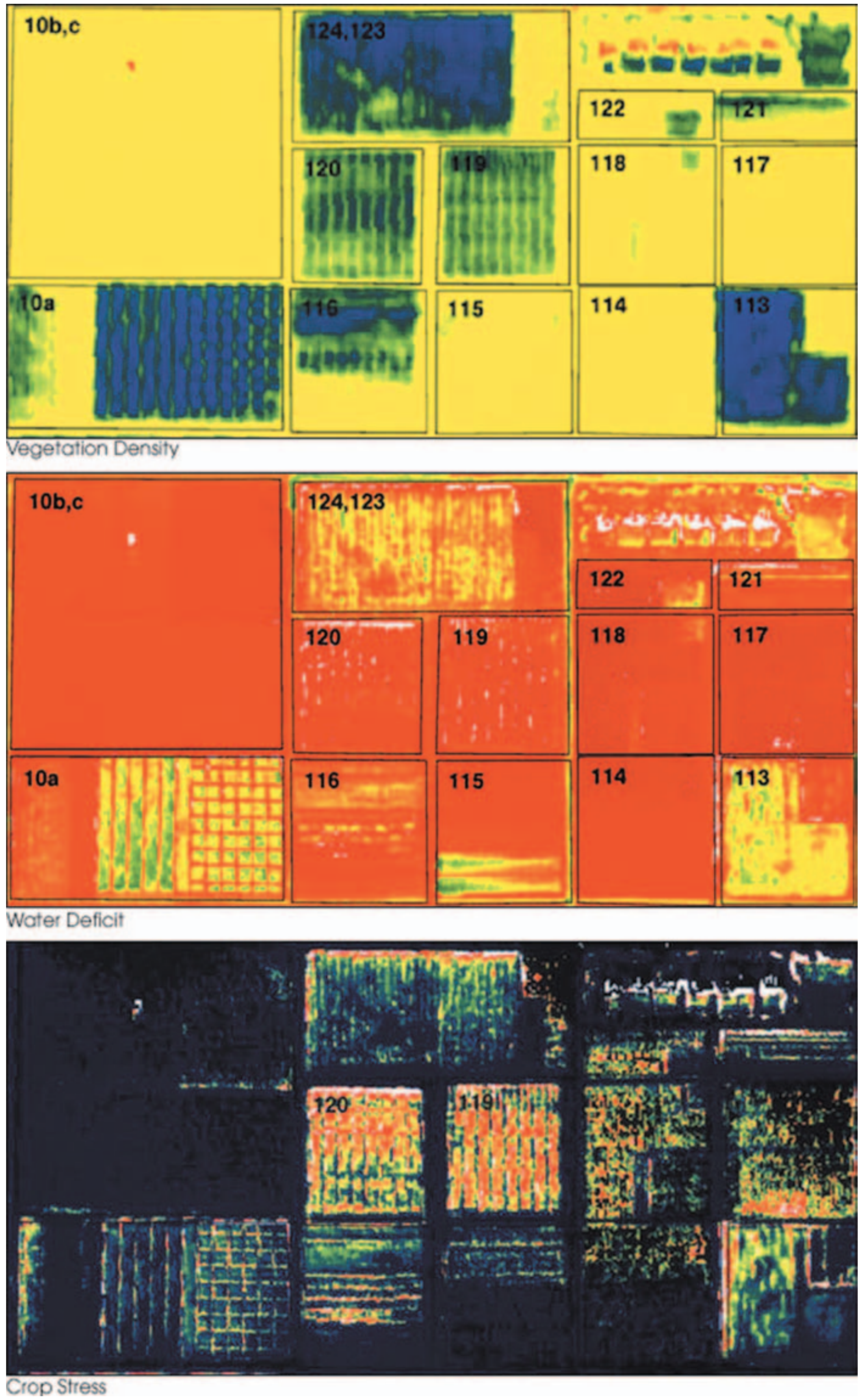
✶**Phytoplankton is easy to recognize from space because it has a distinctive green color.**

Satellite sensors are also used to measure other ocean characteristics such as topography and ocean temperature. For example, a partnership between the United States and France developed *TOPEX-Poseidon*, a satellite that monitors global ocean circulation and global sea levels in an effort to better understand global climate change, specifically the links between the oceans and the state of the atmosphere.

Ocean monitoring by satellites enables NASA and NOAA to predict the El Niño weather patterns. El Niño is a global weather pattern that is driven by conditions in the Pacific Ocean. During an El Niño, countries in the western Pacific experience severe droughts, whereas the eastern Pacific is drenched by torrential rains, leading to mudslides in California and South America.

Ocean observations are undertaken not only to estimate pollution and ocean health but also for commercial purposes. The OrbImage company, for example, provides fish finding maps to fishing companies based on plankton concentration information from their OrView-2 satellite and on sea surface-temperature information from U.S. weather satellites. This information is radioed to the boats that use it for their fishing operations.

Radar remote sensing has several important uses over oceans. Reflected signals from radar are sensitive to water surface roughness. The rougher areas reflect the radar signal better and appear brighter. Smooth areas are dark as they barely reflect radar signal. This feature helps locate and monitor oil



Remote sensing can be used to aid farmers in making decisions about irrigation and fertilization. Color variations show crop density in the top image, whereas the middle and bottom images indicate water deficits. Fields 120 and 119 indicate a severe need to be irrigated.

radar images images made with radar illumination instead of visible light that show differences in radar brightness of the surface material or differences in brightness associated with surface slopes

spills on the ocean surface because oil makes the ocean surface smooth and thus appears dark on **radar images**.

Polar Ice Covers. The U.S. Landsat satellites, the Canadian RADARSAT spacecraft, and the European radar satellite ERS have been actively used to monitor the ice sheets in Antarctica and Greenland. The Landsat program has been ongoing since the early 1970s and has shown a significant modification of coastal regions in Antarctica during that period. Although it is not clear if there is a net gain or loss of ice volume in Antarctica, some of the ice shelves present in 1970s images have since disintegrated.

The Land-Sea Interface. Beaches provide a lively, productive habitat for wildlife and a buffer against coastal storms. Salt marshes produce nutrient-rich "sludge" as a basis for the food chain while providing nurseries for juvenile fishes and habitat for shrimp, crabs, shellfish, turtles, and waterfowl. Coastal habitats are essential to the feeding, reproduction, and migration of fish and birds. But development, and the sand pumping, jetties, and seawalls that come with it, is overwhelming beaches. Salt marshes are under constant threat from short-sighted development schemes that require they be drained and filled.

NOAA has a Coastal Remote Sensing program that is using remote sensing, along with other technologies, to help coastal resource managers improve their management of aquatic and coastal ecosystems. The data sets and products provided by this program include ones dealing with ocean color, coastal topography and erosion, water quality, and the monitoring and tracking of harmful algal bloom.

Satellite remote sensing can thus play a central role in monitoring the health of coastal waters. The challenge is to provide decision makers with the knowledge derived from the remotely sensed data and to educate them about the mechanisms at work in coastal waters using satellite images.

Several commercial companies also provide remote sensing images and data from satellites for **littoral** water and ocean monitoring. The DigitalGlobe company will launch 1-meter (39-inch) resolution satellites that are intended to show detailed coastal features, including beach structure, sandbars, and wave patterns.

littoral the region along a coast or beach between high and low tides

OrbImage has launched a commercial satellite, OrbView-2, to measure phytoplankton and sediment concentration in oceans and inland lakes, data that are useful for environmental applications such as coastal pollution monitoring and "red tide" tracking. Red tides are the result of dying **algae** producing a rapid multiplication of the bacteria that feed on them. These bacteria in turn deplete the water of its oxygen, killing marine life. Red tides can make mussels and oysters dangerous to eat as they produce toxins that can be life threatening to consumers.

algae simple photosynthetic organisms, often aquatic

These examples are by no means exhaustive of the many applications of satellite remote sensing, the numerous satellites in orbit, or the large number of new satellites planned. Satellite remote sensing is a business in rapid expansion, particularly on the commercial side. Earth data have been provided mainly by government-sponsored satellites until recently, but commercial satellite providers have entered the scene and will play an increasingly important role. This in turn has spurred the geographic information business.

Land Features

Satellite remote sensing was first used by the intelligence communities of the United States and the Soviet Union to spy on each other's military targets, starting in the early 1960s. In the 1970s, the United States initiated the Landsat program—a civilian program monitoring Earth's land resources—and in the 1980s NASA launched the Mission to Planet Earth program with an emphasis on understanding the global climate and monitoring the human impact on it.

In the late 1970s and in the 1980s, several other countries—such as India and France—launched remote sensing satellites to gather land surface data in an effort to monitor their agriculture and land use processes. Remote sensing information helps these countries establish national policies and monitor compliance. Since these satellites **orbit** over the whole Earth, they can provide data about many other locations. Both Indian Remote Sensing and the French Satellites Pour l'Observation de la Terre (SPOT) data are sold in the United States. Radar remote sensors have been put into space by Canada, the European Union, and Japan. Recently, several U.S. companies (Space Imaging, OrbImage, and DigitalGlobe being the leading companies) have obtained permission from the U.S. government to launch very-high-resolution satellites capable of seeing objects on the ground as small as 1 meter (39 inches). This may spur another information revolution similar to the personal computer explosion of the 1980s and the burgeoning of the Internet in the 1990s.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

The enabling factors this so-called spatial information revolution include higher resolution, more reliable sensors, more powerful personal computers, the Internet, the civilian use of the Global Positioning System (GPS), and significantly improved geographic information system (GIS) software. Very-high-resolution, color images of any part of the world are predicted to become available on the Internet in almost real time for a modest fee. Anyone with a computer connected to the Internet would then be able to monitor his or her crops in a field, observe traffic jams in a big city in real time, and so forth.

Environmental Observations. Land observations from space have an endless list of applications. A few examples are watershed analysis (including water resources inventory and water quality analysis), noxious weed detection, monitoring land use change over time, tracking urban sprawl and the loss of agricultural land, erosion monitoring, observing desertification in semiarid lands, tracking natural hazards such as floods and fires, agricultural land inventory, and crop yield prediction. Many of these observations have a significant economic impact and enhance the quality of life of citizens and user communities.

In the Middle East and in Africa water scarcity has become a serious geopolitical issue. Ecosystems rarely recognize political boundaries and several countries share common water resources. The Nile River, for example, flows through eight countries before reaching Egypt, a country that experiences very little rainfall and relies almost entirely on the waters of the Nile for its agriculture and drinking water resources. Actions upstream by other governments can severely impact Egypt. Similar problems exist in the Middle East between Syria, Jordan, and Israel, countries that share common aquifers (natural underground water reservoirs) and other water resources.

Satellite remote sensing may play an essential role for peace by providing information about new water resources as well as accurate maps of existing known resources and a means to monitor use. Radar remote sensing in particular can be helpful in discovering new water resources in arid areas. For instance, the Canadian RADARSAT system has discovered new underground water flows in the African desert.

THE POWER OF RADAR

Radar can penetrate 1 to 4 meters (3 to 13 feet) of sand, revealing covered-up structures invisible to the eye and to other remote sensing bands. Radar remote sensing from the space shuttle has uncovered lost cities under the desert sands of Egypt and Arabia.

In the American West, noxious weeds spread at an alarming rate, overcoming other species of vegetation, destroying ecological balance, and even killing livestock. It is very impractical and costly to locate these weeds from the ground in the semiarid expanses of Arizona, New Mexico, and Utah. Satellite remote sensing helps locate these weeds either through their spectral reflectance pattern or by observing their blooming at specific times of the year when no other vegetation blooms. This information can then be used to eradicate the weeds.

Agricultural Applications. The agricultural applications of remote sensing are particularly useful. French SPOT satellites are used to determine what crops are planted where and how many acres of a given crop are planted in a region. Crop health is monitored over time, and claims of crop loss to drought or other natural disaster can be verified using satellite images.

The Earth Satellite Corporation uses remote sensing data to provide weekly information about worldwide crop conditions on the Internet. The company, for example, claims to make 95 percent correct yield predictions for cocoa, sugar, and coffee crops, two months ahead of harvest. Information such as this is extremely useful to growers needing to decide what crops to plant. If a wheat glut is predicted in South America in winter, informed farmers in the Northern Hemisphere will not plant wheat in early spring. Spatial technologies also give farmers new tools to better manage crops. A yield map over a field shows areas of higher and lower productivity.

In precision farming, a field is not treated as a homogeneous whole. Rather, as conditions—such as soil composition and soil fertility—vary across fields, the farmer's treatment of the field also varies. Thus irrigation, liming, fertilizers, and pesticides are not applied uniformly across a field but are varied according to need using a variable spreader with a GPS antenna and a computer program that has in its memory information about the local needs of the field. High-resolution satellite images can provide information about crop health. This information is put on a GIS used by the farmer to divide his fields into zones, each zone being treated differently. Precision farming has several advantages over traditional farming. As a result of differential treatment of field zones, there is less fertilizer, water, and/or pesticides used because applications are made in response to local needs only. There is thus economic benefit to the farmer. There is also less impact on the environment because fertilizer is not squandered in areas where it is not needed, reducing leaching into runoff water.

In the late 1990s thermal remote sensing data of fields in Alabama and Georgia showed a strong correlation between temperature maps of corn fields in June and yield maps of the same fields at harvest, at the end of August. These data were obtained using the NASA ATLAS sensor onboard a Stennis Space Center Lear Jet. Results indicate that thermal infrared remote sensing may predict crop yields with high accuracy several months before harvest. Thermal infrared emission from plants is a measure of their temperature. A healthy plant pumps water from the ground, vaporizes it (perspires), and stays cool by doing so. Less-healthy plants exposed to the hot summer Sun cannot keep cool and show a "fever."

Urban Observations. Whereas in 1950 less than one-third of the world's population lived in urban areas, almost half the population lives in cities at the beginning of the twenty-first century. Projections indicate that in 2025 two-thirds of the growing world population will be city dwellers. Most of the city population increase will occur in developing countries where serious challenges are expected. In rich countries such as the United States, city development is characterized by urban sprawl using up an ever-increasing proportion of available land. A 1997 U.S. Department of Agriculture study reported that nearly 6.5 million hectares (16 million acres) of American forestland, cropland, and open spaces were converted to urban use between 1992 and 1997.

Rapid growth and changes of urban geography require detailed, accurate, and frequently updated maps. Such maps can be produced faster, cheaper, and with considerably less manpower by using very-high-resolution satellites such as Space Imaging's IKONOS than by using ground-based data acquisition. A number of satellite remote sensing companies, such as the French company, SPOT, provide services and products for land and urban planners and for businesses such as real estate and insurance companies.

This information may be used to decide in which region to expand urbanization, where to build roads, and how to develop transportation infrastructure. Frequently updated and accurate maps from very-high-resolution satellites will also be useful for infrastructure designs—power cables, water lines, sewer lines, urban transportation systems, and so on.

Businesses can use very-high-resolution urban satellite observations in conjunction with other data—such as demographics—to choose the right location for a franchise or a new store by extrapolating information about urban growth trends. Construction companies can use images taken by satellites, such as Space Imaging's IKONOS or DigitalGlobe's QuickBird to plan large-scale construction projects. These very-high-resolution satellites are able to identify and locate, with a great deal of accuracy, such surface features as buildings, parking lots, and their elevation.

Urban expansion and loss of farmland can also be monitored using radar remote sensing, such as that provided by the Canadian RADARSAT system. The advantage of radar is that it "sees" through clouds and at night. Thus, regions that are often covered with clouds and do not lend themselves to visible light and near-infrared remote sensing can be imaged using radar illumination.

Wireless communications in cities require a judicious distribution of relays atop tall buildings to avoid blind spots. A three-dimensional model of the cityscape is thus essential. Currently, such models are produced from radar and stereoscopic remote sensing from aircraft. Since cityscapes change rather quickly as new skyscrapers or other tall buildings are built, there is a need for updates. High-resolution radar or stereoscopic visible data from space-based satellites may in the future prove cheaper than aircraft for such applications.

REMOTELY SENSING THE HEAT ISLAND EFFECT

The replacement of vegetated areas with concrete cover in high-density urban areas has a number of environmental drawbacks. One of these problems is known as the heat island effect. Pavement and concrete-covered areas can raise the temperature of cities 10°C (50°F) above the temperature in surrounding areas that have kept their vegetation. Such microclimates in cities are not only uncomfortable for the people who live there but also significantly increase power consumption for cooling purposes and increase levels of harmful ground-level ozone. The heat island effect has been studied extensively with remote sensing data obtained from airborne sensors over cities such as Atlanta, Sacramento, Salt Lake City and Baton Rouge.

Conclusion

This rapid tour of satellite and airborne remote sensing applications shows how useful this technology can be to resolve global, regional, or very local challenges when combined with GIS. It also gives a flavor of a future where **geospatial** information will permeate all activities on Earth and create tremendous business opportunities. SEE ALSO Global Positioning Sys-

geospatial relating to measurement of Earth's surface as well as positions on its surface tem (volume 1); Military Customers (volume 1); Military Uses of Space (volume 4); Natural Resources (volume 4); Reconnaissance (volume 1); Satellites, Types of (volume 1).

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RLV ***See Launch Vehicles, Reusable (Volume 1).***

Rocket Engines

From the first rockets built by the Chinese over a millennium ago to the precision engines used by modern missiles, rocket engines all work in accordance with Isaac Newton's Third Law of Motion: For every action there is an opposite and equal reaction. In a rocket engine, hot gas expelled at high **velocity** generates thrust in the opposite direction. The most common means of doing so uses chemical reactions to produce the hot gas. The first rockets used solid propellants, such as black powder, but they were very inefficient. Liquid-propellant rocket engines, first developed in 1926 by Robert H. Goddard, are much more powerful and opened the way to spaceflight.

velocity speed and direction of a moving object; a vector quantity

The Origins of Modern Engines

Atlas and Delta launch vehicles were originally U.S. Air Force (USAF) rockets developed in the 1950s. To power these missiles, Rocketdyne developed a family of rocket engines that burned kerosene and liquid oxygen (LOX) based on German V-2 rocket technology obtained after World War II. As

A close-up view of a space shuttle's main engine test firing shows how hot gas is expelled. At a high velocity the expelled gas generates thrust in the opposite direction, enabling liftoff.

these rockets were adapted to their new role as launch vehicles in the 1960s, still larger versions of their engines (such as Rocketdyne's 1.5 million-pound thrust F-1) were built for the Saturn rockets that sent Apollo missions to the Moon.

Delta II and III use the 200,000-pound thrust RS-27A, which is an updated descendant of the MB-3 used in the original Delta. The Rocketdyne-built MA-5 power plant in the Atlas 2A, in use since 1961, has also been upgraded. The Atlas has a distinctive stage-and-a-half design, which allows it to **jettison** a pair of booster engines when they are no longer needed, leaving a smaller sustainer engine to power the stage. The booster engines of the new MA-5A are a pair of RS-27 thrust chambers, giving the core of the new Atlas 2AS a liftoff thrust of 490,000 pounds. The Russians have also incrementally improved their long-used launch vehicles' engines over the decades. Energomash, the corporate descendant of the Soviet design bureau that developed many Russian rocket engines, worked with the American firm Pratt & Whitney to build the 585,000-pound thrust RD-180 to power the American Atlas 3 and 5.

jettison to eject, throw overboard, or get rid of

Boosting Performance

While modern solid rockets are less efficient than liquid-propellant engines, their simplicity and relatively low cost make them ideal for certain roles. For decades many American launch vehicles used solid rocket upper stages. The Delta II, with its Star 48B motor built by Thiokol, continues this series's use of solid rocket third stages. Some small launch vehicles, such as the American Pegasus, Taurus, and Athena, as well as the Japanese J-1 and M-5, use solid rockets in all their stages to reduce costs.

Solid rocket motors strapped to the first stage of a launch vehicle have also proved to be an economical means of increasing a rocket's **payload** capability. Since 1964 the Delta has used increasingly larger clusters of Castor solid rocket motors built by Thiokol to help enhance the design's performance. The new Delta II and III use as many as nine GEM-40 motors built by Alliant Techsystems. Even the Atlas 2AS uses four Castor 4A rockets to increase liftoff thrust, a first for this series.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The use of solid rocket boosters is most apparent in the Titan family of launch vehicles. A pair of 120-inch-in-diameter solid rocket motors made by Thiokol were attached to the USAF Titan II missile core in 1965 to produce the Titan IIIC, which had over four times the payload capability. The Titan uses Aerojet-General LR87 and LR91 engines burning liquid **hypergolic** propellants that ignite spontaneously on contact. Successive Titans have used more powerful solid boosters attached to upgraded cores to further increase the payload. The Titan 4B uses a pair of solid rocket motor units built by Alliant Techsystems to produce 3.4 million pounds of thrust at liftoff.

hypergolic fuels and oxidizers that ignite on contact with each other and need no ignition source

Another means of boosting rocket performance is by using **cryogenic** propellants, such as liquid hydrogen and LOX, which have twice the efficiency of most other propellants. The first engine to use these cryogenic propellants was the 15,000-pound thrust RL-10 engine built by Pratt & Whitney and used in the high-performance Centaur upper stage since 1960. The Centaur, with improved versions of the RL-10, has been used in combination with the Atlas and Titan. The RL-10B-2 has been used in the second stage of the Delta III and IV.

cryogenic related to extremely low temperatures, the temperature of liquid nitrogen or lower

The most efficient engines have been nuclear ones. While other engines use chemical reactions to produce heat, in nuclear engines a compact nuclear reactor heats liquid hydrogen or other fluid to generate thrust with more than twice the efficiency of conventional chemical rocket engines. During the 1960s the National Aeronautics and Space Administration (NASA) developed the Nuclear Rocket for Rocket Vehicle Applications (NERVA) with a reactor built by Westinghouse Electric and the engine itself built by Aerojet-General. Before work stopped in 1972, in part due to post-**Apollo** budget cuts, NERVA was intended for use in advanced lunar and interplanetary missions.

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

A New Generation

The space shuttle makes the ultimate use of solid rocket motor technology and high-efficiency cryogenic rocket engines. A pair of solid rocket motors built by Thiokol generate 5.3 million pounds of thrust for liftoff while a trio of Rocketdyne-built space shuttle main engines (SSMEs), generating

375,000 pounds of thrust each, supply most of the energy needed to reach orbit. Other launch vehicles use similar arrangements of solid boosters and cryogenic engines, such as the European Ariane 5 and Japanese H-2. The Delta IV uses the cryogenic RS-68 engine with various boosters. Built by Rocketdyne, the RS-68✶ was the first totally new American rocket engine design since the SSME was designed in 1971.

✶The RS-68 will fly for the first time on the maiden flight of the Delta IV scheduled for July 2002.

More innovations are in store for launch vehicles. One of the more novel designs is the XRS-2200 linear aerospike developed by Rocketdyne for the X-33. Here the engine's nozzle is replaced with an exhaust ramp, allowing the engine to work efficiently at all altitudes, unlike conventional engines. A larger version of the linear aerospike would power the VentureStar single-stage-to-orbit vehicle. SEE ALSO Launch Industry (volume 1); Launch Services (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Rockets (volume 3).

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Roddenberry, Gene

American Writer and Futurist
1921–1991

Gene Roddenberry sits with creatures from his television series *Star Trek,* the first television series to have an episode preserved in the Smithsonian Institution.

Gene Roddenberry, creator of the television series *Star Trek*, saw space as a place for learning new ideas and ways of thinking. Born in El Paso, Texas, on August 19, 1921, Roddenberry was a pre-law student in college for three years before becoming interested in aeronautical engineering. In 1941 he trained as a flying cadet in the U.S. Army Air Corps. During World War II, he took part in eighty-nine missions and sorties and was decorated with the Distinguished Flying Cross and the Air Medal.

During the war Roddenberry began to write, selling stories to flight magazines. Back in the United States, he went to Hollywood intending to write for television. He joined the Los Angeles Police Department to gain life experiences and soon sold scripts to such shows as *Goodyear Theater*, *Dragnet*, and *Have Gun Will Travel.*

Roddenberry's creation, the series *Star Trek*, debuted in 1966. The series developed a loyal following and was the first television series to have an episode preserved in the Smithsonian Institution, where a 3.3-meter (11-foot) model of the U.S.S. Enterprise is also exhibited on the same floor as the Wright brothers' original airplane. The first space shuttle was named Enterprise in honor of this fictional spacecraft.

While making *Star Trek*,✶ Roddenberry gained a reputation as a futurist, speaking on the subject at universities, the Smithsonian, meetings of the National Aeronautics and Space Administration, and Library of Congress gatherings.

✶***Star Trek* became a motion picture in 1978, leading to a number of movie sequels and prompting a popular new series, *Star Trek: The Next Generation,* in the late 1980s. Three other spinoff series would follow, the most recent, *Enterprise,* debuted in 2001.**

Roddenberry died in 1991. A year later a canister of his ashes was taken into space aboard the space shuttle Columbia. SEE ALSO BURIAL (VOLUME 1); CAREERS IN WRITING, PHOTOGRAPHY, AND FILMMAKING (VOLUME 1); ENTERTAINMENT (VOLUME 1); STAR TREK (VOLUME 4).

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Satellite Industry

When you watch the Olympics do you think of satellites? Maybe you should. For many years satellites have been televising sporting events such as the Olympic games, which popularized the phrase "live via satellite" and helped create a common impression of what commercial satellites do for us here on Earth. It was, in fact, a boxing match pitting Muhammad Ali ("The Greatest") against ("Smokin") Joe Frazier in 1975 when satellites were first used to broadcast a single sporting event to the entire world. While satellites still bring us sports, news, and entertainment programming from around the world each day, the commercial satellite industry can and will do much, much more—from delivering high-speed Internet content to taking pictures from space of objects on Earth that are as small as a soccer ball.

Historical Development of the Industry

While you are probably familiar with movies such as *Apollo 13* (1995) and *The Right Stuff* (1983), which chronicled the beginnings of the National Aeronautics and Space Administration (NASA) and its civilian space program, you probably did not know that the commercial satellite industry actually developed right alongside the government space program in the early 1960s. The satellite industry got kick-started back in July 1962, when scientists at AT&T Bell Laboratories decided to build the world's first commercial satellite, dubbed Telstar, after losing a competition for NASA's active satellite program. NASA later offered to launch the Telstar satellite into a two-hour and forty-minute **elliptical** orbit during which it transmitted brief live television transmissions across the Atlantic Ocean for the first time. Telstar had a tremendous worldwide impact by showing the amazing potential of satellite communications.

elliptical having the shape of an ellipse (curved oval)

A few years later, in April 1965, the International Telecommunications Satellite Organization (INTELSAT) launched Early Bird, the world's first

This Intelsat VI satellite, one of five contracted to replace less capable satellites, can carry up to 120,000 two-way telephone calls, along with three television channels.

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

commercial **geosynchronous** satellite. So-called "GEO" (geosynchronous Earth orbit) satellites **orbit** Earth at 35,786 kilometers (22,300 miles) in a belt directly above Earth's equator. At that point in space, the satellite orbits Earth at the same speed as Earth's rotation—making the satellite appear to be fixed in the same location in the sky. It was futurist Arthur C. Clarke, author of *2001: A Space Odyssey* (1968), who first predicted back in 1945 that you could connect the world by placing three communications satellites in geosynchronous orbit.

The Early Bird satellite was built by Hughes Aircraft, the company founded by eccentric billionaire Howard Hughes. The satellite had a total capacity to carry only 480 telephone channels (240 simultaneous calls) and had the power of an ordinary household light bulb. It was impressive considering that the largest undersea transoceanic telephone cable at the time carried only 256 channels. By comparison, today's largest telecommunications satellites are more than 500 times more efficient and generate more than 15 kilowatts of power, allowing a single spacecraft to carry ten of thousands of simultaneous telephone calls or hundreds of channels of television programming to dishes on the ground as small as 46 centimeters (18 inches).

It was really in the 1990s that we observed the greatest changes in satellite technology and with them fundamental changes in the commercial industry. For the first two decades of its existence, the satellite industry worked to connect large companies to other large companies across oceans, deserts, and great distances. Telephone companies first employed satellites to connect calls where there were no undersea cables. Later it was television networks, such as ABC, NBC, and CBS in the United States, which used satellites to transmit programs to their local affiliate stations—so-called point-to-multipoint distribution—and helped the satellite industry grow. In the late 1970s cable television companies began to get into the act, using satellites to downlink channels such as CNN and MTV, and then retransmit the signals over coaxial cables to homes.

The satellite industry can mark 1976 as the year it began to evolve from a purely business-to-business model to one that also included business-to-consumer or so-called retail services. That year a Stanford University professor named Taylor Howard designed and built the first backyard satellite dish. Howard used his 4.9-meter (16-foot) home satellite dish to receive HBO and other television programs that previously were carried only by cable television companies. By 1980 Howard had sold the blueprints on how to build his dish to over 5,000 people, and the direct-to-home (DTH) satellite industry was born. By 1985 several DTH equipment companies were shipping more than 500,000 home satellite systems to consumers across the United States.

The introduction in 1994 of high-powered direct broadcast satellite (DBS) services, which used new digital compression technology and more powerful spacecraft, allowed consumers to receive hundreds of channels of digital-quality programming on a dish about the size of a pizza pan. The DTH industry has since continued to grow with more than 14 million American homes and another 25 million homes outside the United States subscribing to DTH satellite television services by the early twenty-first century.

Key Segments of Today's Satellite Industry

History aside, the best way to understand the satellite industry today is to divide it into four key segments: satellite services—transmitting voice, data, and television signals to businesses and consumers; ground equipment—designing and manufacturing satellite dishes, large Earth stations, software, and consumer electronics; satellite manufacturing—building spacecraft, components, and electronics; and launch—building space launch vehicles and carrying satellites into orbit.

Each year, the Satellite Industry Association (SIA) surveys over 700 companies around the world to determine the state of the industry. The SIA reports worldwide employment and revenue in each of the segments. The SIA reported in 2001 that the commercial satellite industry generated $69.1 billion in revenue in 1999, an 8 percent increase over adjusted 1998 revenue. The U.S. satellite industry accounted for $31.9 billion of the total, or roughly 46 percent of worldwide revenue.

Satellite Services. The largest and fastest growing segment of the industry is satellite services, which generated $30.7 billion in revenue in 1999, a 25 percent increase over 1998. More than $8 billion in revenue in this sector was generated by companies that lease **transponder** capacity to programming companies such as the Discovery Channel and ESPN, as well as to long-distance telephone companies such as MCI WorldCom and AT&T. The bulk of the services revenue, nearly $23 billion, comes from consumer/retail services including DTH satellite television.

transponder bandwidth-specific transmitter-receiver units

While traditional satellite service providers such as PanAmSat, Eutelsat, GE American Communications, and SES Astra continue to lease ca-

point of presence an access point to the Internet with a unique Internet Protocol address; Internet service providers like AOL generally have multiple POPs on the Internet

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

pacity to television and telephone companies, a growing portion of their business now comes from data services. Internet service providers (ISPs) are now using satellites in countries throughout the developing world to link directly to the Internet backbone in the United States. Those providers set up a small 1- to 3-meter (3.3- to 10-foot) dish and in one hop can link directly to a **point of presence** (POP) on a fiber-optic backbone. Another new application being pursued by satellite operators is to broadcast common content—such as Stephen King's latest short story or streaming audio/video clips—over the web to local ISPs around the world where the content can be retrieved by nearby web surfers. In using satellites for the same kind of point-to-multipoint distribution service used by television broadcasters, popular web sites can manage the flow of traffic on the World Wide Web and avoid crashing their servers or networks.

Mobile satellite services such as those offered by Globalstar, ICO, Inmarsat, Motient, and ORBCOMM are yet another emerging part of the services business. These companies provide voice and data service to thousands of ships, planes, cars, and people in parts of the world that are not served by cellular or traditional wired telephone networks. These systems often use constellations of satellites in either GEO or **low Earth orbit** to serve laptop- and handset-sized mobile terminals. Such systems allow pipeline workers, merchant ships, and other mobile users to communicate even in the most remote places on Earth.

A new service offering launched in 2001 is satellite digital audio radio services (DARS). Three new companies—XM Satellite Radio and Sirius in the United States and WorldSpace in other regions of the world—began delivering hundreds of channels of digital music, news, sports, and entertainment programming to cars, homes, and boom boxes. Satellite-ready radios will become standard equipment in many new cars sold in the United States starting in 2003, and the subscription-based service—at approximately $10 per month—is expected to be popular with commuters and others who spend a lot of time in their cars.

Ground Equipment. Along with the growth in new services, we have seen a corresponding increase in the demand for more earthly products such as satellite dishes, mobile satellite phones, and Earth stations that control satellites in orbit. The manufacture of satellite-related ground equipment in 1999, from satellite control systems to DBS dishes, accounted for $16 billion of the industry's total revenue—an increase of 15 percent over 1998. An increasing portion of the ground equipment market is made up of DTH systems. Since its introduction to American consumers in 1994, DBS dishes and set-top boxes have been the fastest-selling consumer electronics product of all time—outselling VCRs, personal computers, and color televisions during their first year on the market.

Companies such as Hughes, RCA, Sony, and Gilat manufacture these dishes for both consumers and large corporations that own private satellite networks called very small aperture terminals (VSATs). VSATs are a little-known but important part of our telecommunications network. They allow retail companies, such as Target and Blockbuster, as well as gas stations such as those run by Exxon Mobil, to verify credit cards and control their inventories. More than 2,200 shopping malls in America use VSAT dishes to transmit and receive data. Prices for VSAT dishes dropped from $10,000 to

Television networks that used satellites to transmit programs to their local affiliate stations helped the satellite industry grow.

$20,000 per terminal in 1980 to $1,000 to $3,000 in 2001, helping fuel sales to many large and small corporations. Next time you are at a gas station or grocery store, look up at the roof and you will likely see a small satellite dish at work connecting that business to its corporate headquarters.

Satellite Manufacturing. Exciting new satellite services, such as DBS and DARS, would not be possible without advances in satellite manufacturing. In terms of power, capacity (bandwidth), and lifetime in orbit, large telecommunications satellites at the turn of the millennium were twenty times more capable than satellites manufactured only a decade previous. This capability figure was expected to increase by another factor of five by 2002 when new larger satellites incorporating **spot beam technology** are put into full production. While the prices of communications satellites have stayed relatively constant during this period, and were possibly declining when factoring in inflation, their capabilities increased dramatically.

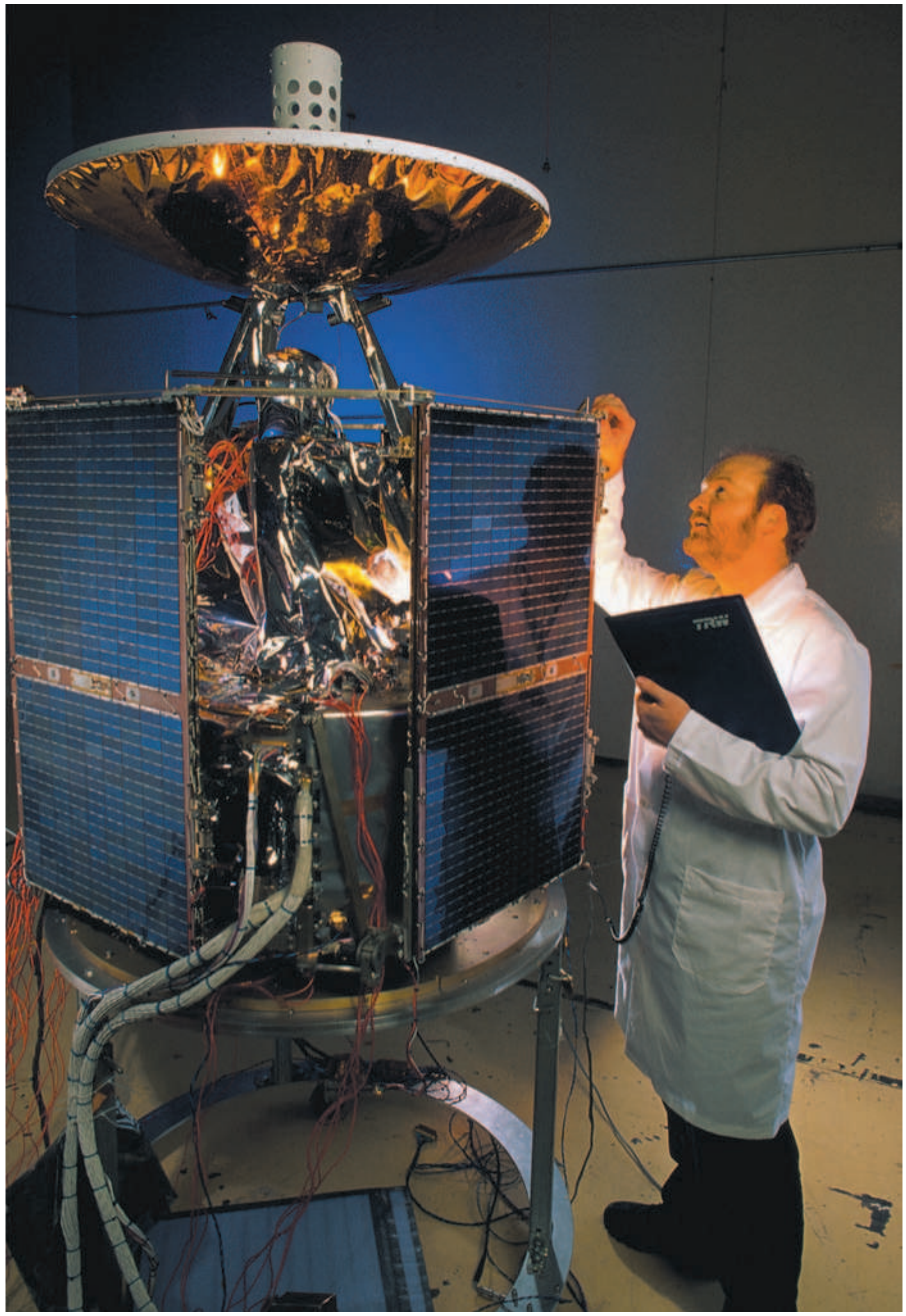
spot beam technology narrow, pencil-like satellite beam that focuses highly radiated energy on a limited area of Earth's surface (about 100 to 500 miles in diameter) using steerable or directed antennas

Both the number of transponders and the overall power of satellites increased. Each transponder that used to be able to carry a single analog channel can now carry several simultaneous digital channels. Increases in power are tied to more efficient solar panel and battery technology. By increasing the power of the satellite in space, satellite operators can dramatically reduce the size of receiving dishes on Earth. Another major achievement is the use of **ion propulsion** technology for satellite station-keeping. By using ion propulsion to generate the thrust that keeps the satellite oriented towards Earth, satellite manufacturers have been able to increase the number of years that a satellite is able to provide service before it runs out of fuel. Altogether, these technologies have had a major impact on the ability of satellites to compete with terrestrial telecommunications technologies.

ion propulsion a propulsion system that uses charged particles acclerated by electric fields to provide thrust

Satellite manufacturing, including payments to prime contractors and their subcontractors, accounted for $10.4 billion of the $69.1 billion industry total in 1999. Leading satellite manufacturers include Astrium, Alcatel, Hughes, Lockheed Martin, Motorola, Orbital Sciences, Space Systems Loral, and TRW. This segment of the industry has experienced rapid

At the Goddard Spaceflight Center, a TRW worker examines a satellite. TRW, as well as Astrium, Alcatel, Hughes, Lockheed Martin, Motorola, Orbital Sciences, and Space Systems Loral, is a leading satellite manufacturer.



consolidation in the past few years as several European companies have merged in order to compete with U.S. companies, which have historically built over two-thirds of the communications satellites in orbit.

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

Launch. Of course, the satellite industry would not exist if it were not for the **expendable launch vehicles** (ELVs; commonly called rockets) that launch commercial spacecraft into orbit. The worldwide launch industry generated revenues of $6.6 billion in 1999, with $4.3 billion paid to launch service providers and another $2.3 billion earned by subcontractors engaged in vehicle construction. Companies such as Arianespace, International Launch Services, Boeing Launch Services, Sea Launch, Orbital Sciences, Rocket Systems Corporation, and China Great Wall sell rides into outer space.

The launch segment of the industry has also changed dramatically since the 1970s when U.S. Air Force rockets were used to launch commercial satellites. The U.S. decision to shift all satellite launches from ELVs to the space shuttle helped spur the Europeans to develop their own ELV—the Ariane rocket. In the wake of the space shuttle Challenger tragedy in 1986, the United States decided to fly satellites aboard ELVs once again, and U.S. companies got back into the launch services market. In the 1990s, Chinese, Russian, and Ukrainian rockets began to be used to launch commercial satellites. The market in the early twenty-first century is more competitive than ever, resulting in lower launch costs for satellite operators.

Meanwhile, launch service companies have worked steadily to increase the lift capabilities of their rockets to accommodate the heavier, more powerful satellites. Vehicles such as the Ariane 5 rocket are capable of delivering 6.5 metric tons (7.2 tons) to **geostationary orbit**, and their ability is expected to only increase in the coming years. Sea Launch—an international cooperative venture including Boeing (United States), RSC Energia (Russia), Yushnoye (Ukraine), and Kvaerner (Norway)—launches satellites from a converted offshore oil drilling platform and command ship that motor to a site on the equator in the middle of the Pacific Ocean in an effort to increase lift capability. International Launch Services now uses powerful Russian-built RD-180 engines to increase the lift capability of the workhorse Atlas ELV.

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Emerging Technologies

Outside of the four major industry segments—communication services, ground equipment, satellite manufacturing, and launch—there are a host of other emerging technologies that are beginning to generate revenue and interest. Commercial remote sensing satellites, such as Space Imaging's Ikonos spacecraft, are now capable of taking pictures from space clear enough to see objects on the ground less than 1 meter (39 inches) in size. Such images are used by farmers, geologists, and urban planners to assist them in their jobs. Software that links these images with maps generated using coordinates from the U.S. Air Force global positioning satellite fleet provides an important new source of information to businesses that use scarce natural resources here on Earth.

The satellite industry has come a long way since AT&T's Telstar satellite first proved that space could be used for moneymaking commercial ventures. The continued growth in Internet data and new information technologies are expected to drive the commercial satellite industry in the coming decades. The growth in these services markets will fuel demand for more satellites, dishes, and launches. Arthur C. Clarke's vision of a world connected via satellite has become a reality. Today's visionaries see viable markets for solar power generation and tourism within our reach. Do not count them out—many people thought President John F. Kennedy's pledge to put a man on the Moon would never be fulfilled. SEE ALSO Communication Satellite Industry (volume 1); Navigation from Space (volume 1); Reconnaissance (volume 1); Remote Sensing Systems (volume 1); Satellites, Types of (volume 1); Small Satellite Technology (volume 1).

Clayton Mowry

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Satellites, Types of

Not long after the Soviet Union launched the first satellite in 1957, satellites began to play an increasingly important role in our lives. The first satellites were small because of the lack of powerful launch vehicles, and almost all had scientific missions. However, as larger rockets became available and engineers used new technologies to build more efficient **payloads**, the first prototypes of many of the satellites that were still in use in 2001 were launched and changed our world.

Observing Earth

One of the earliest classes of satellites was designed to observe Earth from orbit. Among the first were military **reconnaissance** satellites, such as the American Corona and the Soviet Zenit, which took photographs with film that had to be returned to Earth to be developed. Over the years more sophisticated electronic imaging technology made it possible for spy satellites to obtain very high-resolution images and transmit them almost immediately to analysts. This technology has been useful in gauging a potential adversary's intentions, for verifying compliance with treaties, and in other important ways.

In 1960 early television surveillance technology was used for the first weather satellites. By 2001 those satellites (flying in **polar orbits** and **geosynchronous orbits**) were equipped not only with cameras but with a range of sensors that employed the latest **infrared** technology. In addition to providing the weather pictures that people see every day on television, these satellites supply meteorologists with the highly detailed information they need to track storms and predict the weather. This application of satellite technology alone has saved countless lives.

Starting in the 1970s some of this technology was applied to **remote sensing** satellites such as Landsat. Instead of monitoring military targets at high resolution, these satellites monitor Earth's natural resources on a more moderate scale. These data provide the information needed to locate new sources of raw materials and determine the effects of natural disasters and pollution on the environment. Because this information is so valuable, many commercial remote sensing satellites, such as the French SPOT, have been launched and their data have been sold to a wide range of government and private users.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

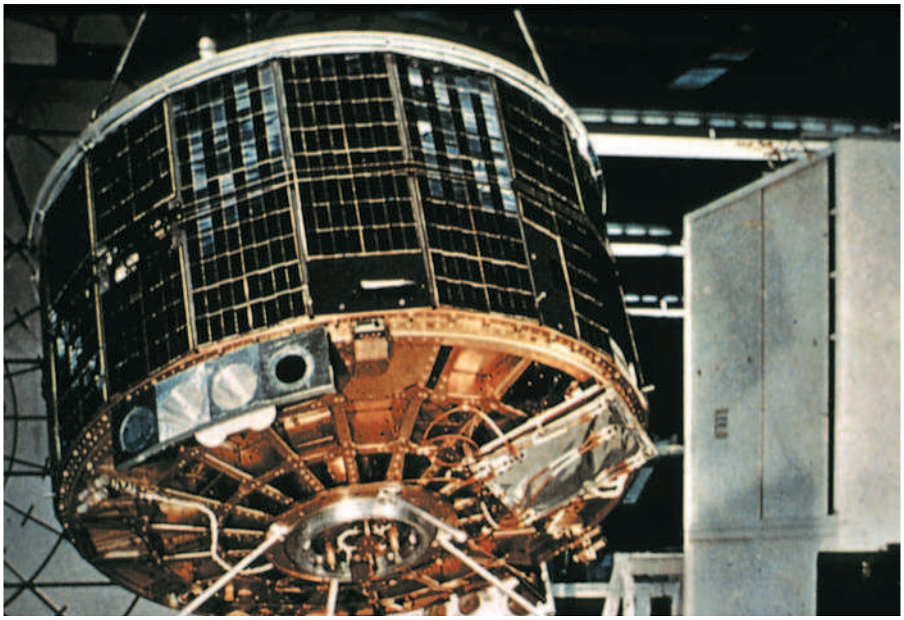
reconnaissance a survey or preliminary exploration of a region of interest

polar orbits orbits that carry a satellite over the poles of a planet

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

remote sensing the act of observing from orbit what may be seen or sensed below Earth



This early weather satellite used television surveillance technology of the 1960s.

Recently declassified reconnaissance and **cartographic** photographs from American and former Soviet spy satellites are now available, giving researchers more varied long-term data on the environment. Radar mapping technology originally used by the military to make observations through clouds has found numerous civilian applications.

cartographic relating to the making of maps

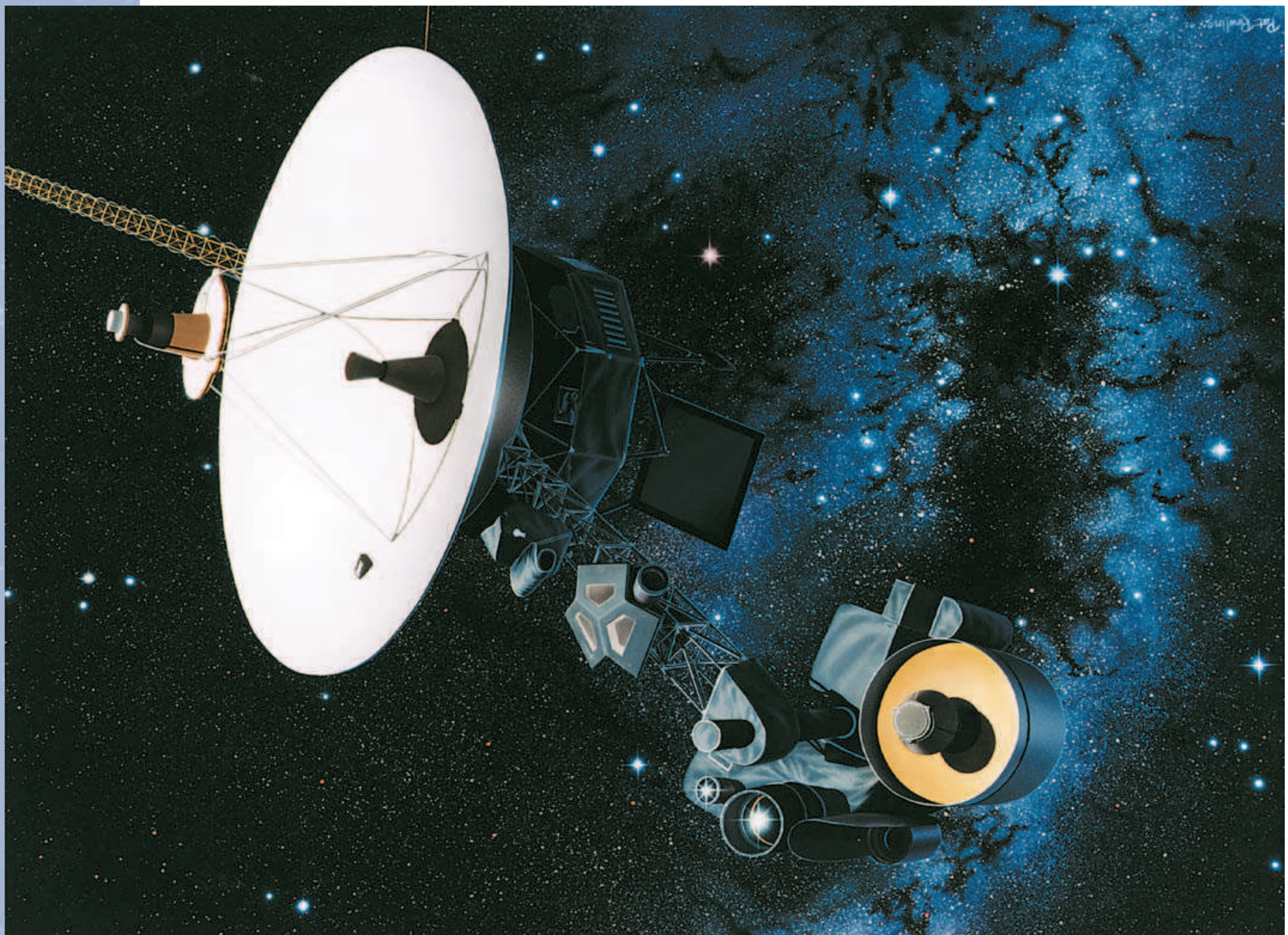
Voices in the Sky

By far the most common satellite type launched, and perhaps the one that has had the greatest impact on people's lives, is the communication satellite, or "comsat." Beginning in 1958 early experimental comsats operated as relays or repeaters in relatively low orbits, in part because of the lack of powerful launch vehicles and the crude nature of their electronics. Although such low orbiting comsats still have a place, a large number of them are required to provide continuous coverage around the globe.

As early as 1946 the space visionary and author Arthur C. Clarke recognized the value of placing comsats in geosynchronous orbits. From an altitude of 35,786 kilometers (22,300 miles) above the equator, satellites match Earth's spin and appear to hang motionless in the sky. From this great height over one-third of the planet's surface can be seen, allowing a satellite to relay signals over long distances. After several successful experiments the first commercial geosynchronous comsat, Early Bird, was launched in 1965. In the succeeding decades, improved rockets allowed larger comsats to be launched. Combined with major advances in microelectronics, each of the dozens of active comsats in orbit in 2001 had thousands of times the capacity of their earliest ancestors.

Although geosynchronous comsats are useful at low latitudes, they appear too close to the horizon at high or polar latitudes. To overcome this problem, since 1965 the Soviet Union (and later Russia) has launched Molniya satellites into highly **elliptical** 12-hour orbits inclined to the equator. This type of orbit allows them to be seen high above the horizon over most

elliptical having the shape of an ellipse (curved oval)



Voyager 2 is an example of a science satellite, designed to collect data that enabled scientists to discover more about the outer solar system.

of Russia's territory for long periods. From this vantage point, Molniya satellites can relay television and telephone signals across that nation's vast expanses. During the Cold War, such orbits were used by some signal intelligence, or sigint, satellites to intercept radio signals. Sigint satellites also are used to track ships at sea, locate radar installations, and monitor other activities such as various types of radio transmissions.

A type of comsat known as a navigation satellite, or navsat, has become important to military and civilian users. Operating in precisely known orbits thousands of miles above Earth, these satellites broadcast a precise timing signal. Signals from three or more navsats can be used to determine a position on or above the Earth's surface within a few feet. The first experimental navsats were built by the U.S. Navy in the 1960s and were used by ships to determine their exact positions at sea. Today a constellation of satellites forming the Global Positioning System (GPS) allows military and civilian users to accurately determine their locations anywhere in the world.

Science in Space

Whereas a large number of satellites with practical applications have been launched, science satellites still provide important information about the space environment and the universe beyond. Satellites monitoring Earth's **magnetosphere** can provide warnings about communications blackouts and other effects of solar storms. Since the 1960s larger, more capable observatories employing increasingly advanced technologies have been launched to observe the Sun and the rest of the heavens over the entire **electromagnetic spectrum**. The Hubble Space Telescope is a well-known example. As a result of the data returned from these satellites, much more has been learned about everything from the Sun and how it affects Earth to the origins of the universe. SEE ALSO CLARKE, ARTHUR C. (VOLUME 1); NAVIGATION FROM SPACE (VOLUME 1); RECONNAISSANCE (VOLUME 1); REMOTE SENSING SYSTEMS (VOLUME 1); SATELLITE INDUSTRY (VOLUME 1); SATELLITES, FUTURE DESIGNS (VOLUME 4); SMALL SATELLITE TECHNOLOGY (VOLUME 1).

Andrew J. LePage

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field; it is formed by the interaction of the solar wind with the planet's magnetic field

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

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Search and Rescue

Commercial search and rescue missions to retrieve and repair valuable satellites may become commonplace in the twenty-first century. Telecommunications companies and other businesses typically spend between $50 million and $300 million to manufacture and launch a new satellite. If all goes well, the spacecraft may function reliably for ten to twenty years. In the harsh environment of space, however, satellites may fail prematurely because of mechanical breakdowns, damage from **solar flares**, or collisions with orbiting debris. Companies may reduce their economic losses from such perils by salvaging damaged or obsolete satellites at a cost lower than what they would pay for replacement spacecraft.

solar flares explosions on the Sun that release bursts of electromagnetic radiation, such as light, ultraviolet waves, and X rays, along with high speed protons and other particles

The National Aeronautics and Space Administration (NASA) successfully performed the first satellite search and rescue missions in 1984. In April of that year, astronauts on the space shuttle Challenger rendezvoused with the Solar Maximum satellite, walked in space, and replaced electronics and other parts on the damaged spacecraft. They then released it back into orbit to continue its scientific mission of solar flare observations. Six months later, the crew of the space shuttle Discovery captured two commercial communications satellites and stowed them in the shuttle's cargo bay for return to Earth. Equipment malfunctions in February 1984 had left these satellites, the American Westar-6 and the Indonesian Palapa-B2, in improper orbits.

Technicians on the ground repaired both satellites and successfully launched them back into orbit in April 1990.

NASA reconsidered astronaut safety after the Challenger explosion on January 28, 1986. The agency decided to reduce the risk to astronauts by restricting most shuttle operations to scientific or military missions that required a human presence in space. In the fourteen-year period following the Challenger disaster, NASA rescued only one more commercial satellite, the International Telecommunication Satellite Organization's Intelsat VI F-3.

Despite NASA's successes, satellite salvage is not one of its primary missions. Furthermore, NASA does not have enough shuttles to meet the growing demand for search and rescue operations. The revenues generated by space commerce exceeded government expenditures for space exploration for the first time in 1996. Rapid growth of global telecommunications swelled space business revenues to about $80 billion by 2000, more than five times NASA's annual budget. That same year, about 200 commercial satellites were insured for more than $16 billion, and industry analysts predicted that space commerce would grow steadily, with about seventy new satellites launched annually.

Satellite owners and insurance companies are therefore motivated to find new and creative ways to safeguard their business assets. In 1998, for example, insurers declared a loss on the HGS-1 Asian television satellite, which had been stranded in a useless orbit after launch. Later, engineers at the Hughes Space and Communications Company found a way to boost the satellite on two looping orbits around the Moon, finally placing it in a useful parking orbit around Earth.

Because commercial salvage may be a profitable venture, several start-up space businesses began offering new products and services to satellite owners by 1999. To be successful, however, these companies must find inexpensive solutions to the difficult challenge of search and rescue operations in space. For example, one company developed a wire tether that may be attached to a satellite prior to launch. If the tether is later extended in space like an antenna, an electric current will be generated as it passes through the Earth's magnetic field, and enough power may be produced to operate the spacecraft or to change its orbit. A valuable satellite that is stranded in space, or at risk of burning up in a premature reentry into Earth's atmosphere, may yet be saved by this simple and elegant solution. SEE ALSO SATELLITES, TYPES OF (VOLUME 1); SERVICING AND REPAIR (VOLUME 1); TETHERS (VOLUME 4).

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Servicing and Repair

When the space shuttle system became operational in the 1980s, access to space began to take on a whole new outlook. Space was about to become a place to carry out work as well as to explore. A key element in America's newest human-rated space vehicle was the ability to provide access to space on a number of commercial fronts, including in-orbit satellite and spacecraft servicing and repair.

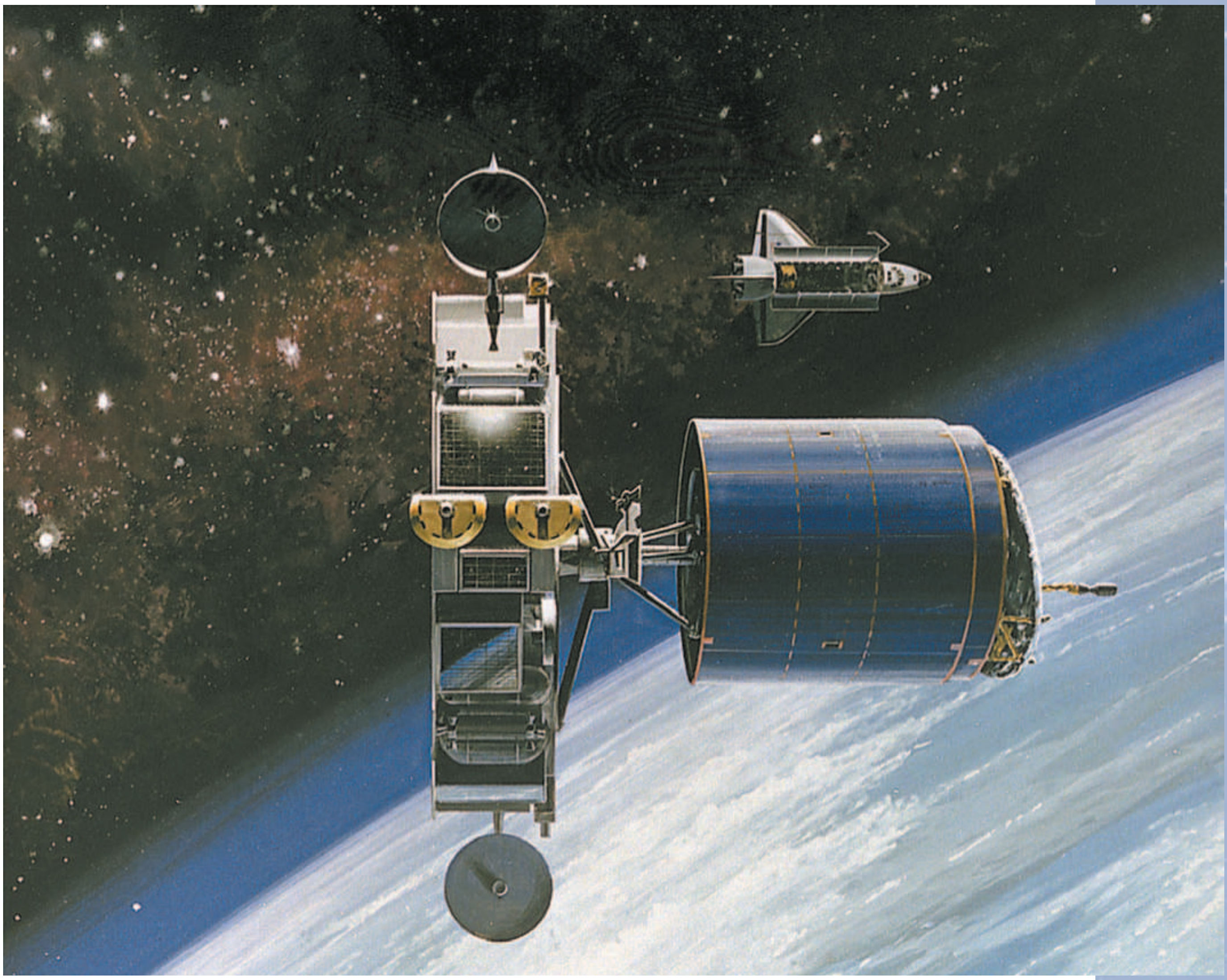
One of the workhorses onboard the shuttle is the robot arm called the Remote Manipulator System (RMS). The RMS is capable of placing large items in or removing them from the shuttle's cargo bay. This 15-meter (50-foot) robot arm was used for a number of satellite repair and retrieval missions during the shuttle's first twenty years of operations.

During shuttle mission 41-C in April 1984, the Long Duration Exposure Facility (LDEF) was left in orbit, deployed by the remote arm. During that same mission, astronauts were able to retrieve the ailing Solar Max satellite and repair it in the **payload bay** of the shuttle. Later that year two communications satellites stranded in a useless **low Earth orbit** (LEO) were

payload bay the area in the shuttle or other spacecraft designed to carry cargo

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

This artist's concept of a Orbital Transfer Vehicle (OTV) illustrates a vehicle that would serve as a free-flying "space tug," and it is shown here towing a satellite.



successfully retrieved and brought back to Earth by the shuttle. Eventually, these two satellites, Westar 6 and India's Palapa B-2, were successfully relaunched and deployed. In 1985 the Syncom IV-3 communications satellite, also stranded in a useless orbit, was retrieved, repaired, and deployed by a shuttle crew in Earth orbit.

In the 1990s, there was a crucial repair mission carried out on the Hubble Space Telescope. Hubble had been deployed in 1990 with what was later discovered to be a flawed imaging system. In December 1993 astronauts carried out an emergency repair mission aboard the shuttle to correct Hubble's fault. During a series of space walks, the crew successfully repaired the imaging system, and the Hubble Space Telescope was able to continue its mission, making many outstanding astronomical discoveries over the next decade.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

The shuttle, however, is capable of achieving a maximum altitude of only 1,125 kilometers (700 miles) and is not designed to restart its main engines in order to attain escape velocity beyond LEO. Many satellites, such as communications satellites, are in **geosynchronous orbit** 35,786 kilometers (22,300 miles) above Earth and require upper stages to boost them from LEO to their geosynchronous orbit and beyond to begin their operational missions. If a satellite failed to operate at this distance, it would be a total loss for its owners. In the early 1980s, business and government started to look at ways of solving this problem. One concept was a variant of a Martin Marietta Aerospace design of an Orbital Transfer Vehicle for a 1980s U.S. space station concept. This vehicle would be able to take an astronaut to geosynchronous orbit to service satellites already in place.

As newer, more powerful geosynchronous satellite systems are built, companies have designed satellites and their upper stages with preventive maintenance in mind. SEE ALSO Accessing Space (volume 1); Long Duration Exposure Facility (LDEF) (volume 2); Robotics Technology (volume 2); Satellite Industry (volume 1); Satellites, Types of (volume 1); Search and Rescue (volume 1); Space Shuttle (volume 3).

Nick Proach

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NASA Goddard Space Flight Center. *The Hubble Project.* <http://hubble.gsfc.nasa.gov/>.

Prime Online NASA Resources for Educators. *Remote Manipulator System.* <http://prime.jsc.nasa.gov/ROV/rms.html>.

Small Satellite Technology

radiation belts two wide bands of charged particles trapped in Earth's magnetic field

The first satellites built by people were very small. The Soviet Union's Sputnik, which opened the Space Age in 1957, weighed only 84 kilograms (185 pounds). The American response, Explorer-1, weighed 14 kilograms (31 pounds). These early small satellites proved that it was possible to put equipment in orbit and use it, providing the first opportunities for scientific observation outside Earth's atmosphere. Explorer provided the data that led to the identification of the Van Allen **radiation belts** that surround Earth. Bell Labs's Telstar, about the size of a car tire, provided the first transatlantic television link, and Pioneer 10, weighing about 270 kilograms (595

Low launching costs and rapid development makes small satellites suitable for new applications that are not possible with larger spacecraft. This small 590-pound satellite, called SAC-A, was ejected from the shuttle STS-88 and carried five technology experiments.

pounds), was launched in 1972, and is the first satellite to leave the solar system. Thirty years after its launch, Pioneer is still functioning and was more than 7 billion miles from Earth.

Almost all satellites are powered by sunlight, and small satellites, which intercept less of this resource, are limited in power as much as they are in size, mass, and budget. However, the modern revolution in digital electronics and portable computing technologies has enabled engineers to build satellites weighing just a few kilograms that have capabilities rivaling those of older, larger satellites. Because launch costs have remained virtually constant since the beginning of the space age, small satellites and their lower costs are receiving renewed attention.

What Is a Small Satellite?

Small satellites are defined as those weighing less than 1,000 kilograms (2,204 pounds). Those below 100 kilograms (220 pounds) are referred to as microsatellites, those with a mass less than 10 kilograms (22 pounds) are known as nanosatellites, and those under 1 kilogram (2.2 pounds) are called picosatellites. However, the major difference between small and large satellites is not their weight but the way they are built. Small satellites are built by small, highly interactive teams that work with the satellite from conception through launch and operation. Large satellites are built in larger, more formally structured organizations. Small satellite teams typically have fewer than twenty members, whereas large satellites may be built by organizations with tens of thousands of people.

The small satellite team has the advantages of speed and efficiency, the ability to evaluate the implications of each design decision for the entire satellite, and the insight into all aspects of the satellite's design and application. The combination of low cost, rapid development, and low launch costs makes small satellites suitable for new applications that are not possible with larger spacecraft.

Students and hobbyists gain hands-on experience in space by building, launching, and operating satellites. Student-built satellites have hosted advanced communications experiments, astronomical and Earth-observing instruments, and video cameras that can be used to look at themselves and the satellites launched with them. Most amateur satellite activity focuses on building novel voice and digital communications links.

A very promising new application of small satellites is the inspection of larger satellites. A low-cost nanosatellite can observe the target spacecraft as it separates from its launch vehicle, deploys solar panels, and begins operations. Any problem during the initialization of operations, or later in the spacecraft's life, can be diagnosed by the escorting nanosatellite, which would have visible and **infrared** cameras as well as radio-based diagnostics.

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

Early exploration of the solar system relied on small spacecraft such as those in the Mariner series (200 kilograms [441 pounds]), the first spacecraft to visit Mars and Venus, and the Ranger (360 kilograms [794 pounds]) lunar missions. Modern interplanetary spacecraft explore their target planets and moons with the aid of robots, and these robots are also becoming very small. The Mars Sojourner, a robotic rover, weighed just 11 kilograms (24 pounds), and its host spacecraft, the Mars Pathfinder, weighed just 570 kilograms (1,257 pounds) plus 320 kilograms (705 pounds) of propellant to guide its flight from Earth to Mars. Although the development teams were large, the small size of these interplanetary spacecraft is remarkable, especially compared with large spacecraft such as the space shuttle that are needed to take human crews a few hundred miles into low Earth orbit.

The Future of Small Satellites

Because small satellites require only a corner of a laboratory, basement, or garage, plus some basic equipment for their construction, there are hundreds of small satellite developers around the world. By contrast, developers of large satellites include a few major corporations and government laboratories in the largest and wealthiest countries. The proliferation of developers and users of small spacecraft has unleashed the same creative forces that propelled the personal computer to its dominant position in the computer market.

The leading commercial developers of small satellites include AeroAstro and Surrey Satellite Technology Limited. University-based developers of small satellites include Stanford's Starlab, Weber State, the Technical University of Berlin, Technion (Israel), the University of Stellenbosch (South Africa), and the University of Mexico. Governments are building small spacecraft in labs in the United States, Canada, the United Kingdom, Israel, Spain, France, Sweden, Finland, Norway, Denmark, Russia, Japan, Australia, Malaysia, and almost 100 other countries.

The future of small satellites, and in large part the future of space exploration and application, will rely on the creativity of this diverse population of developers. SEE ALSO COMMUNICATIONS SATELLITE INDUSTRY (VOLUME 1); SATELLITE INDUSTRY (VOLUME 1); SATELLITES, FUTURE DESIGNS (VOLUME 4); SATELLITES, TYPES OF (VOLUME 1).

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Space Access *See Accessing Space (Volume 1).*

Space Shuttle, Private Operations

In the early twenty-first century, more than twenty years after the successful maiden voyage of space shuttle Columbia, the National Aeronautics and Space Administration's (NASA) Space Transportation System—commonly known as the space shuttle—remains the only U.S. transit system capable of supporting human spaceflight. The shuttle is also the world's only largely reusable launch vehicle, comprised of an airplane-shaped **orbiter**, which returns to Earth with its human crew for refurbishment and re-flight; two solid rocket boosters, which are recovered for reuse after they separate from the rest of the shuttle system during ascent to orbit; and an irrecoverable fuel tank. (In contrast, the stages of so-called **expendable launch vehicles**—which launch most of the world's satellites as well as passenger-carrying Russian Soyuz capsules—are **jettisoned** to disintegrate in Earth's atmosphere or are left as debris in space.)

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

jettisoned ejected, thrown overboard, or gotten rid of

Capable of sustaining a crew in Earth orbit for several days to weeks, the versatile shuttle has served NASA in such efforts as the deployment, repair, and retrieval of satellites; the conduct of medical, materials, and other scientific research; and the ferrying of astronauts and supplies to and from the former Russian space station Mir. Although NASA is studying options for retiring its aging fleet of four orbiters and developing a new reusable launch vehicle, plans call for continuing shuttle flight at least until the mid-2010s. Shuttle operations will be critical in upcoming years as NASA transfers crews and supplies between Earth and the International Space Station.

The Space Shuttle's Limitations

Despite the shuttle's remarkable achievements and unique capabilities, those familiar with the shuttle program have come to realize that the shuttle has failed to meet many of NASA's original objectives and expectations. At the program's beginning in the early 1980s, NASA expected the shuttle would

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

diffused spread out; not concentrated

fly some twenty-four times annually, launching astronauts, satellites, and other **payloads** for the U.S. government as well as for other nations and private companies. By the mid-1990s, however, the shuttle's average annual flight rate was a fraction of the predicted level. Also, fewer government payloads than expected had flown on the shuttle, and as a result of policy made after the 1986 space shuttle Challenger explosion that killed seven astronauts, commercial payloads had been effectively banned from the vehicle. Perhaps the greatest disappointment was that the costs of operating and refurbishing the shuttle were far higher than NASA's original projections.

Outsourcing Shuttle Operations to Reduce Costs

Throughout the shuttle's history, NASA considered placing shuttle operations under private industry's control to reduce costs. That idea was continually rejected on grounds that NASA needed to maintain control of the shuttle for national security reasons. But in 1995, then NASA administrator Daniel Goldin, who had previously spent twenty-five years at a private aerospace firm, asked a team of NASA, other governmental, and industry leaders to study shuttle operations management and propose a new, safe approach to reducing operations costs. The team found that shuttle operations tasks, as then assigned, were **diffused** among many contractors and that no single entity was responsible for streamlining operations and reducing costs. After considering multiple management options, the commission recommended that NASA give a single, private contractor responsibility for shuttle operations. Goldin agreed, and NASA began soliciting bids from companies to take charge of shuttle operations.

Two companies that then held contracts to manage major elements of shuttle operations, Rockwell International and Lockheed Martin Corporation, recognized that failing to secure the prime contract under NASA's new management scheme would result in a substantial economic loss. As a result, the two companies decided to compete for the contract as a single entity. In August 1995, Rockwell and Lockheed Martin agreed to form a joint venture called United Space Alliance (USA). From the forty companies that responded to NASA's search for a shuttle prime contractor, NASA chose to award USA the contract. USA took over the individual Rockwell and Lockheed Martin contracts and on September 30, 1996, signed the Space Flight Operations Contract (SFOC), by which NASA designated USA as prime contractor for shuttle operations. That December, Rockwell sold its aerospace business to the Boeing Company, which took over Rockwell's share of USA.

A New Way of Doing Business

The SFOC was an unprecedented step for NASA. Never before had the space agency given so much authority and responsibility to a contractor for such a major program. Under the contract, which was set up for six years with options for two, two-year extensions, USA took over operations and maintenance of both ground and flight systems associated with the shuttle at NASA's two primary centers for human spaceflight activity. At Johnson Space Center in Houston, Texas (the control and training center for shuttle missions), USA employees gained responsibility for flight operations, astronaut and flight controller training, mission control center management and operations, mission planning, flight design and analysis, and flight software development. Those at Florida's Kennedy Space Center (the shuttle's

Rockwell International workers prepare the cockpit of space shuttle Endeavour for extended flights.

launch and processing site) took charge of vehicle testing and checkout, launch operations, **procurement** and repair of shuttle hardware and ground support equipment, payload integration, and retrieval of the solid rocket boosters that were jettisoned into the Atlantic Ocean after launches. The SFOC also made USA responsible for training astronauts and planning for operations aboard the International Space Station.

procurement the process of obtaining

NASA emphasized that its expectations for USA under the contract included, in order of importance, maintaining safety of the shuttle system, supporting NASA's planned mission schedule, and reducing shuttle operating costs. In order to ensure that USA would meet these objectives, the SFOC was designed to reward USA on its quality of performance. The $7-billion contract—which could grow to a total of $12 billion with the extensions—was made contingent on the company's ability to meet safety standards, achieve mission and schedule objectives, and find more efficient ways to operate the shuttle program. Failure to meet these objectives could result in financial penalties.

The SFOC has presented USA with many challenges. As the first and only company in the world to be fully responsible for maintaining and operating a reusable launch system, USA has had to develop, from scratch, methods of fulfilling the basic contract requirements while finding ways to make operations less costly and more efficient. With accountability and quality of performance dominating the contract, USA has been forced to accept a new way of earning a profit. Nonetheless, USA has proven its ability to

NASA's Space Transportation System, commonly known as the space shuttle, is the only American transit system that is capable of supporting human spaceflight.

manage successfully the new type of contract and the responsibilities it has brought. Since managing its first shuttle mission in November 1996, USA has kept safety and reliability as top priorities: The shuttle has had no major operational problems under USA's oversight. Both NASA and USA have recognized that cost savings have been realized through the SFOC, with USA reporting a reduction in operations costs of nearly $400 million between the fiscal years 1996 and 1998. NASA has also pointed to more on-time launches and smoother prelaunch operations as indicators of USA's success in managing the shuttle program. USA keeps building on that success as it continues to absorb contracts for NASA's human spaceflight needs.

Prospects for the Future

While USA takes increasing responsibility for day-to-day shuttle operations, the SFOC made no provisions for ever giving USA ownership of the shuttle fleet. NASA still maintains ownership and ultimate control of the shuttle program. With the government still in charge, NASA determines the nature of each shuttle mission and flies only government payloads. USA would like that to change. The company's vision is to pioneer human spaceflight as an affordable, viable business. USA would like to see the shuttle fully privatized—that is, given to the private sector to own, control, and fund—and commercialized, which would open the shuttle for use by paying customers from outside the U.S. government. USA also wishes to become increasingly involved in operations of the International Space Station as well as any new space vehicles NASA develops.

Many people—including NASA as well as USA officials—believe that privatization and commercialization of the shuttle would bring numerous benefits to NASA, private industry, and taxpayers alike. By either turning over this asset to private hands or opening its use to commercial customers—or both—NASA could cut costs, which in turn could translate into savings for taxpayers. These measures could also allow NASA to focus more attention on and apply some of the funds saved to activities such as exploring the solar system and universe. By fully owning, managing, and commercializing the shuttle fleet, a private company potentially could realize revenues that far exceed NASA's current budget for operating the shuttle. As a result, the managing company could afford to conduct more shuttle missions and other space activities, in turn stimulating the growth of businesses whose satellites, experiments, or other hardware it launches.

Whether or not USA's vision of complete shuttle privatization becomes reality will depend on NASA's willingness to relinquish control of its assets and functions. NASA has been reluctant to give up control of the shuttle for reasons of national security and public safety. The agency is also aware that giving a single company full control of the shuttle could be viewed by companies that manufacture, develop, and market other launch vehicles as a transfer to one company of government assets that were already paid for with public funds, which creates unfair competition. NASA, nonetheless, recognizes the benefits of privatization and thus intends, at the very least, to increase the private role in shuttle management and operations in upcoming years. It is likely that, in any privatization scenario, the space agency will continue to maintain ownership and management of some launch infrastructure, play an active role in assuring safety of the program, and financially back the private company in the case of catastrophic disaster involving the shuttle.

NASA also believes that increasing the private role in shuttle management will enable future commercialization opportunities. By 2001, NASA had begun to explore opportunities for commercializing its various programs and assets, allowing USA to solicit payloads of private customers for two shuttle missions. Regardless of who owns the shuttle, however, commercialization will succeed only if potential customers find the shuttle's capabilities and prices attractive compared to other launching options. Moreover, the shuttle must be made available for commercial use: NASA's goal of completing work on the International Space Station now dominates the shuttle's schedule.

It is almost certain that NASA will, to some extent, privatize and commercialize the space shuttle. As the space agency will be looking for the most competent and efficient company to assume the job, USA must continue to perform at its best if it wishes to fulfill its vision of opening up the human spaceflight business. SEE ALSO Challenger (volume 3); Commercialization (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); NASA (volume 3); Reusable Launch Vehicles (volume 4); Solid Rocket Boosters (volume 3); Space Shuttle (volume 3).

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Spaceports

Spaceports are facilities used to launch, and in some cases land, spacecraft. Spaceports are similar to airports and seaports but have some unique features and requirements. They have to be able to support the assembly and launch of large, powerful rockets and the satellites or other cargoes that they carry. There are only a handful of spaceports around the world, although more may be built as the demand for launches grow and the types of launch vehicles evolve.

Spaceport Components

The most familiar element of a spaceport is the launch pad. Originally just a patch of ground where rockets were hastily set up and launched, launch pads have evolved considerably as rockets became larger and more complex. Most launch pads have a tower, known as a gantry, which stands next to the rocket. Through the gantry, technicians have access to various levels of the rocket so they can check and repair systems, add propellant, and in the case of piloted rockets, provide a way for crews to get in and out.

Below the pad itself are pathways called flame trenches, which allow the hot exhaust from the rocket to move away from the pad at the time of the launch, so that it does not damage portions of the pad or the rocket itself. Some launch pads, such as the ones used by the U.S. space shuttle, have water towers nearby that spray water onto the pad at launch. The water is designed to suppress the noise and vibration of the launch, which otherwise could reflect off the pad and damage the shuttle.

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

The launch pad itself, though, is only a small part of a spaceport. Other facilities at spaceports include hangars on which sections of rockets are put together before moving them to the launch pad. The Vehicle Assembly Building at the Kennedy Space Center, built for the **Apollo** program and

used by shuttles today, is one of the largest buildings in the world when measured by volume.* The shuttle and some other rockets are transported vertically from the assembly building to the launch site using large, slow-moving flatbed transporters. In Russia, launch vehicles are carried out to the pad horizontally on conventional rail lines. In some cases rockets are assembled, stage by stage, at the launch site itself.

Space shuttle STS-1 is illuminated by Launch Pad A, Complex 39, at one of the best-known spaceports in the world, NASA's Kennedy Space Center, at Cape Canaveral, Florida.

***The Vehicle Assembly Building is the first visible landmark at NASA's John F. Kennedy Space Center. It can be seen from at least ten miles in every direction.**

Spaceports also operate control centers where the progress of a countdown and launch is monitored. Nearby is **radar** that keeps tracks of both the rocket in flight as well as any planes or boats that may venture too close to the launch site. Spaceports usually notify pilots and ship captains of the regions of the ocean that will be off-limits during a launch because rocket stages or debris could fall there.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Spaceports of the World

One of the best-known spaceports in the world, the National Aeronautics and Space Administration's (NASA) John F. Kennedy Space Center, is located at Cape Canaveral, Florida. There are actually two separate spaceports there: NASA's Kennedy Space Center (KSC) and the U.S. Air Force's Cape Canaveral Air Force Station (CCAFS). NASA uses KSC exclusively for launches of the space shuttle, from two launch complexes: 39A and 39B. The same pads were used to launch the Saturn 5 rockets for the Apollo Moon missions. CCAFS is home to a number of launch facilities for unmanned military and commercial rockets, including the Atlas, Delta, and Titan.

There are several other spaceports in the United States. Vandenberg Air Force Base in southern California is used for launches of several types of unmanned rockets, including Delta and Titan boosters, for NASA, the military, and private companies. Vandenberg is used for launches into polar orbit because the only clear path for launches is south, over the Pacific Ocean.

The Kodiak Launch Complex, located on Kodiak Island in Alaska, was used for the first time for an unmanned orbital launch in 2001. Wallops Island, Virginia, has a launching pad for an expendable rocket, as well as runways for aircraft carrying the Pegasus small-winged rocket.

Outside of the United States there are several very active spaceports. Europe established a spaceport near Kourou, French Guiana, on the northeast coast of South America in the late 1960s for European launches. The European Space Agency and the commercial firm Arianespace use Kourou for launches of the Ariane 4 and 5 boosters.

Russia's primary launch site is at Baikonur, in Kazakhstan, formerly part of the Soviet Union. Baikonur is used by a number of Russian rockets, including manned Soyuz missions. Unlike other spaceports, Baikonur is located in the middle of a continent, far from the ocean; spent rocket stages are dropped on desolate regions of Kazakhstan and Siberia rather than in the ocean. Russia also operates spaceports in Plesetsk, in northern Russia, and Svobodny, which it uses for some unmanned flights and military missions.

The Future

Like the rockets that use them, spaceports are evolving. As reusable launch vehicles, which launch and return, become more common, spaceports will have to support pre-launch preparations and post-landing operations. KSC handles both because most shuttle missions end with a landing back at the center. Spaceports will also have to develop facilities to maintain these vehicles and prepare them for their next flights, much like at airports.

Currently even the busiest spaceports, such as Kourou and Cape Canaveral, handle only a couple dozen launches a year, which is near the maximum supportable with current technology. In the late 1990s a study by NASA found that new technologies and an improved infrastructure would be needed to support higher flight rates.

Greater demand for spaceflight should also lead to the creation of new spaceports. The development of single-stage reusable launch vehicles—which travel from the ground to space without dropping any stages along the way—would make it possible for spaceports to be located in many areas, not just near oceans. In the United States alone over a dozen states, including inland states such as Idaho and Oklahoma, have expressed an interest in developing spaceports for future reusable launch vehicles. The creation of these new spaceports could be a major step toward making space travel as routine as air travel. SEE ALSO Launch Services (volume 1); Launch Sites (volume 3); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Rocket Engines (volume 1); Vehicle Assembly Building (volume 3).

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Spinoffs ***See Made with Space Technology (Volume 1).***

Sputnik

Sputnik is the name given to a series of scientific research satellites launched by the Soviet Union during the period from 1957 to 1961. The satellites ranged in size and capability from the 83.6-kilogram (184.3-pound) Sputnik 1, which served only as a limited radio transmitter, to Sputnik 10, which weighed 4,695 kilograms (10,350 pounds). Together the Sputnik flights ushered in the space age and began the exploration of space by orbital satellites and humans. Sputnik 1 is the most famous in the series.

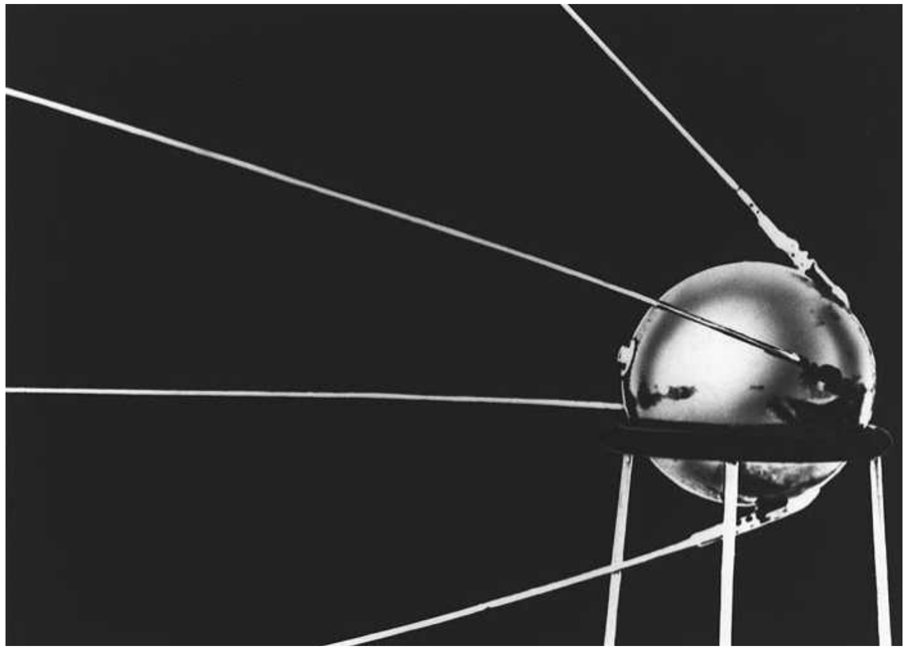
In August 1957 the Soviet Union conducted a successful test flight of a stage-and-a-half liquid-fueled intercontinental **ballistic** missile called the R-7. Shortly thereafter Soviet scientists were quoted in the news media inside the Soviet Union saying that they were planning for the launch of an Earth satellite using a newly developed missile. Western observers scoffed at the accounts. In the late summer of 1957 Soviet scientists told a planning session of the International Geophysical Year celebrations that a scientific satellite was going to be placed into orbit, and they released to the press the radio frequency that the satellite would use to transmit signals. Again, the statements were widely dismissed inside the United States as Soviet propaganda.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

Late in the evening in the United States (Eastern Standard Time) on Friday, October 4, 1957, Radio Moscow announced that a small satellite designated Sputnik 1 had been launched and had successfully achieved orbital flight around Earth. The U.S. Defense Department confirmed the fact shortly after the reports reached the West.

Sputnik 1 was the first artificial satellite to reach orbit. Launched from a secret rocket base in the Ural Mountains in Soviet central Asia, it weighed 83.6 kilograms (184.3 pounds), was 0.58 meter (1.9 feet) wide, and carried four whip-style radio antennas that measured 1.5 to 2.9 meters (4.9 to 9.5 feet) in length. Aboard the tiny satellite were instruments capable of

The Sputnik 1 satellite carried four whip-style radio antennas that measured 4.9 to 9.5 feet long, and can be seen in this 1957 photograph.



ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

measuring the thickness and temperature of the high upper atmosphere and the composition of the **ionosphere**, and the satellite was also capable of transmitting radio signals. The Soviet news agency Tass released the final radio frequency of the Sputnik and the timetables of its broadcasts, which were widely disseminated by news media worldwide. Sputnik 1 transmitted for twenty-one days after reaching orbit and remained in orbit for ninety-six days. It burned up in the atmosphere on its 1,400th orbit of Earth.

Sputnik 2 was launched into orbit a month later on November 3, 1957. It was a much larger satellite, weighing 508 kilograms (1,120 pounds), and contained the first living creature to be orbited, a dog named Laika. The dog, its capsule, and the upper part of the rocket that launched it remained attached in space for 103 days before burning up after making 2,370 orbits. However, there was only enough oxygen, food, and water to keep Laika alive for a week. There were no provisions to either save the dog or return its capsule to Earth.

Sputniks 3 through 10 were research craft aimed at obtaining design data for the construction of a human-carrying spacecraft. Sputnik 3 was launched on May 15, 1958, Sputnik 4 on May 15, 1960, Sputnik 5 on August 19, 1960, Sputnik 6 on December 1, 1960, Sputnik 7 on February 4, 1961, Sputnik 8 on February 12, 1961, Sputnik 9 on March 9, 1961, and Sputnik 10 on March 25, 1961. Sputnik 10 was a full test version of the Vostok human-carrying space capsule, which carried the first human into space two weeks later on April 12, 1961. Sputniks 5, 6, 9, and 10 carried dogs. Sputnik 10's canine passenger, Zvezdochka, was successfully recovered. Sputnik designations were briefly given to a series of interplanetary probes but these were renamed as part of the Luna series in 1962 and 1963. SEE ALSO Animals (volume 3); International Space Station (volume 1 and volume 3); Satellites, Types of (volume 1); Space Shuttle (volume 3).

Frank Sietzen, Jr.

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Thompson, David

T

American Aeronautics Company Executive
1954–

David W. Thompson is the chairman and chief executive officer (CEO) of Orbital Sciences Corporation (OSC), a space technology and satellite services company he cofounded in 1982. Before starting OSC, Thompson was a project manager and engineer who worked on advanced rocket engines at the National Aeronautic and Space Administration's (NASA) Marshall Space Flight Center.

David Thompson, CEO of Orbital Sciences Corporation, cofounded his company with the vision of commercial companies forming the driving force in the space industry, instead of government agencies.

As a graduate student, Thompson worked on the first Mars landing missions at the Jet Propulsion Laboratory. Thompson and his cofounders of OSC met at Harvard Business School, where they shared an interest in the commercial uses of space. OSC was founded on the concept of commercial companies, not government agencies, being the driving force in the space industry. Whereas most established space companies' commercial businesses have evolved from government- or military-funded programs, OSC is devoted exclusively to the commercial aspects of the space industry.

OSC is one of the world's ten largest space-related companies, with over 5,000 employees. The company has its headquarters in Dulles, Virginia, and maintains major facilities in the United States, Canada, and several locations overseas. OSC's business activities involve satellites, the Pegasus and Taurus launch vehicles, space robotics, and software. In addition, OSC provides mobile data and messaging services (ORBCOMM) and satellite imaging of Earth. SEE ALSO Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Remote Sensing Systems (volume 1); Reusable Launch Vehicles (volume 4); Satellites, Types of (volume 1).

John F. Kross

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Tourism

It is highly likely that the general public will be traveling, touring, and living in space at some time in the twenty-first century. If history is to be followed, the human expansion into space, on a large scale, is a foreseeable prospect for humankind. One possible scenario begins with 30-minute suborbital flights by the year 2005, followed by orbital flights of two to three revolutions (three to four-and-a-half hours) by about 2010. Surveys have shown that people would like to have a specific destination in space. That desire suggests a destination such as a resort hotel that can provide several days of accommodation in **low Earth orbit**, and a hotel like this may be available in about 2020. Beyond that, space hotels could be followed by or-

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

The space travel and tourism market must attract investors and businesspeople in order to become economical and efficient. American millionaire Dennis Tito (center), the first "space tourist," and Russian cosmonaut Talgat Musabayev (right) are welcomed aboard the International Space Station by commander Yury Usachev (left).

aeroballistic term used to describe the combined aerodynamics and ballistics of an object, such as a spacecraft, in flight

catalysts chemical compounds that accelerate a chemical reaction without itself being used up; any process that acts to accelerate change in a system

biting sports stadiums and lunar cruises with excursions to the Moon's surface by 2040. After suborbital rides become commonplace, a new **aeroballistic** cargo and human transportation system could begin operation, leaving no major transportation hub on Earth more than an hour's flight time away.

Just exactly how and when these new modes of transportation and resorts will materialize is difficult to predict. However, there is an organized effort underway between the private and public sectors to assure that the right ingredients and the proper **catalysts** are brought together. This effort is multifaceted and includes the government, business, and the general public.

Human space activity to date has been the exclusive domain of the Russian and U.S. governments. But this situation has changed, at least to a small degree. The Russian Aviation and Space Agency has made available one to three seats per year on its Soyuz taxi flights to the International Space Station to anyone who can mentally and physically qualify and pay the ticket price of $20 million. In April 2001 American Dennis Tito became the world's first space tourist by qualifying and paying the required fee for transportation and a week's stay at the station. Mark Shuttleworth, a South African, became the second space tourist to the station in April 2002. The exact size of this market remains to be seen. At the stated price, an extremely small proportion of the population will be able to experience space in this new international facility. However, this is a start and this activity will likely encourage others to act.

Barriers and Obstacles to Space Travel and Tourism

Before space travel and tourism can be made economical, reliable, efficient, and safe for everybody, several obstacles must be overcome and many barriers will have to be removed, as detailed next.

Market Research and Development. The space travel and tourism market must attract investors and businesspeople. Although there have been a number of space travel and tourism market surveys and analytic studies, a carefully thought-out market survey should be designed and conducted by professionals in the market research field. In addition, ways to enhance the credibility of space tourism by piquing the interest of nontraditional space businesses, which stand to profit from its development, must be realized.

Legislative Measures. Several legislative measures have been discussed, including three bills that have already been introduced in Congress, that could create favorable conditions for investors and entrepreneurs to join in new commercial space ventures. U.S. Senator John Breaux (D-LA) introduced a bill to make Federal Government insured loans available to space transportation companies; Congressman Nick Lampson (D-TX) introduced a bill to make Federal Government insured loans available to space tourism companies; and Congressman Ken Calvert (R-CA), et al., introduced a bill to provide tax credits to purchasers of space transportation vehicle provider stock. These bills are being evaluated along with other initiatives to be studied including relief from taxes on company-expended space research and development funds, and tax breaks for profits earned during a venture's start-up years.

Technology and Operations. There is a need to go far beyond space shuttle technology and operational capabilities. The shuttle's costs, depending on the annual budget and flight rate, are between $500 million and $750 million per flight, and it takes approximately six months to process **orbiters** between flights. From these baseline parameters, it is essential to lower the unit cost and decrease the turnaround time between flights. Furthermore, reliability must be increased before space travel and tourism can become safe and affordable for the vast majority of the general public.

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

Medical Science. There are volumes of recorded data about how a nearly physically perfect human specimen reacts to the space environment but no information about people with common physical limitations and treatable maladies. For example, how would the medicines taken by a large percentage of the general public act on the human body in a state of weightlessness? Astronauts and cosmonauts are physiologically screened for their ability to react quickly and correctly under extreme pressure in emergency situations, but early living in space will be characterized by cramped living conditions, common hygienic and eating facilities, and semiprivate sleeping quarters. Such conditions are conducive to unrest and conflict among certain individuals, making screening of early space tourists for temperament and tolerance a must.

Regulatory Factors. Methods must be devised through public and private sector efforts that will allow an orderly, safe, and reliable progression of certification and approval of a venture's equipment without the imposition of potentially crippling costs. Initially it will not be possible to match the safety and reliability levels of conventional aircraft that have evolved over time. Instead, a system is needed that will allow voluntary personal risk to be taken in excess of that involved in flying on modern aircraft while fully protecting the safety of third parties (people and property not affiliated with the operator and/or customer).

Legal Factors. Just as there are laws for operating on Earth's land surface and oceans, there will be a need for laws for operating in space and on and around other celestial bodies. The United Nations treaty governing the use of space must be improved and expanded to take into account eventual space operations involving people and accommodating **infrastructure**. From the navigational rules of space lanes to real estate claims for settlement or mining purposes, laws will have to be created by international legal bodies to provide order and justice on the final frontier.

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

Finance and Insurance. Perhaps the most prominent obstacle that must be overcome is the lack of financing available for private space ventures, particularly those involving new **reusable launch vehicles** (RLVs). Several RLV development programs have been stalled because of an inability to find investors. Persuading investors to accept some front-end risk in return for the large rewards that will be realized in the years ahead is the main challenge. Legislation to ease the risk is one potential solution. Innovative methods for raising capital (e.g., tax-exempt bonds) and other ways to lower the risks to acceptable levels will have to come from the investment and insurance communities.

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

Space should be seen as another medium that will be developed for business and recreational purposes, contributing to the welfare and enjoyment of all the world's people. Before long space will become an extension of Earth itself. SEE ALSO Hotels (volume 4); Living in Space (volume 3); Space Tourism, Evolution of (volume 4).

Robert L. Haltermann

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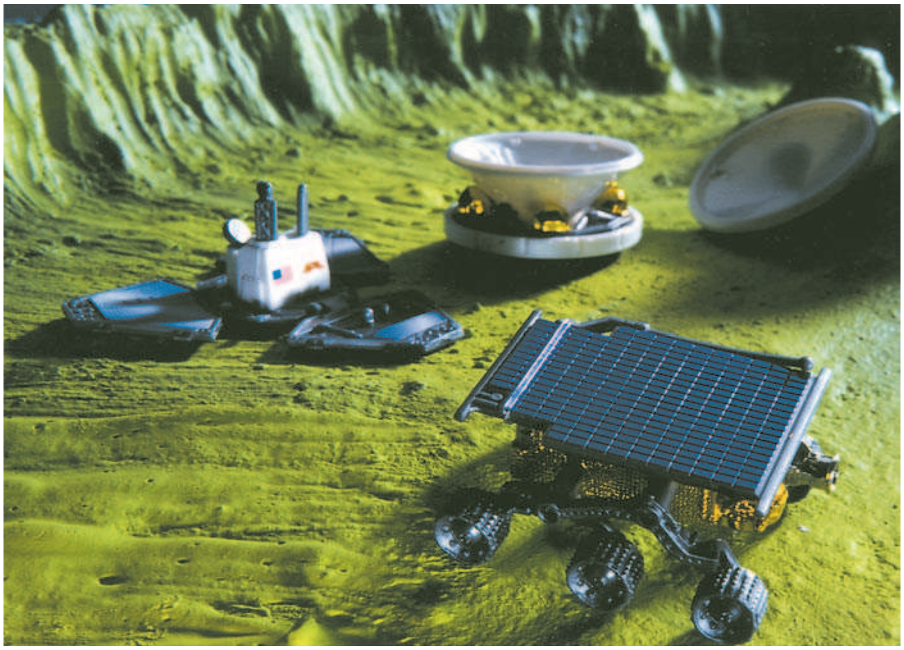
Toys

The term "toy" generally applies to any object used by children in play. However, there is a huge business in creating objects, usually in miniature, designed specifically for children's play. These toys generally model adult culture and society, frequently with great accuracy. In the last half of the twentieth century, model National Aeronautics and Space Administration (NASA) spacecraft, toy ray guns with light and sound action, and spaceships and action figures related to popular films reflected the recent growth of interest in science fiction and space exploration.

There are a wide range of space toys available in the market today. Children have access to transparent model Saturn V rockets, models of the International Space Station, models of the Apollo 15 Lunar Lander with the Lunar Rover, and a complete Cape Canaveral launch pad. The toy manufacturer Brio has a Space Discovery Set suitable for very young children that includes an astronaut, a launch vehicle, and a launch control center with a ground crew member. Lego has three toys in its Life on Mars series: the



Space-related toys, such as this Mattel Hot Wheels JPL Sojourner Mars Rover Action Pack set, can generate profits for toy manufacturers and publicize advancing space technology.

Excavation Searcher, the Mars Solar Explorer, and the Red Planet Protector. Action Products sells the Complete Space Explorer with models of the space shuttle, Apollo Lunar Lander, Skylab, and dozens of small action figures representing astronauts and ground crews.

The Mars Pathfinder mission, one of a series of robotic explorations of other planets, created many business opportunities for toy manufacturers. The Jet Propulsion Laboratory (JPL) and NASA have signed thirty-seven licensing agreements for products related to this mission, including T-shirts, caps, and toys. One of the most interesting and ambitious toys was the Mattel Hot Wheels JPL Sojourner Mars Rover Action Pack set. This set includes toy models of Sojourner, the Pathfinder spacecraft, and a lander. Many of the Sojourner rover's unique attributes are included, such as its six-wheel independent suspension that allows it to navigate rough terrain. According to Joan Horvath, a business alliance manager with JPL's Technology Affiliates Program, these toy models helped educate both kids and parents alike about the Mars Pathfinder mission in the most user-friendly manner possible. Moreover, it made the business community aware of the many different aspects of the JPL's technology transfer programs.

The success of the Mattel Mars Pathfinder set led to another license agreement. JPL and Mattel teamed up for a toy version of NASA's Galileo spacecraft. The Hot Wheels Jupiter/**Europa** Encounter Action Pack includes a highly detailed reproduction of the Galileo spacecraft, the Galileo descent probe, and of one of the ground-based antenna dishes.

Europa one of the large satellites of Jupiter

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Toys in Space

Toys have also ventured into space. Carolyn Sumners of the Houston Museum of Natural Science in Houston, Texas, assembled a small group of toys to be flown on space shuttle mission 51-D in April 1985. During the flight, crew members experimented with the toys, demonstrating the behavior of

SOME BUSINESS FACTS ABOUT TOYS

- In the United States, toy sales amounted to $25 billion dollars in 2001.
- Wal-Mart was the largest retailer, with toy sales of $7,300 million ($7.3 billion).
- Toys 'R Us was a close second with sales of $6,933 million ($6.9 billion).
- Science-related toys were the fastest growing segment of the toy market in the years 1996 through 1999.
- Science-related toy sales amounted to $90 million in 1999.
- Science-related toy sales continue to grow at a rate of 12% a year.
- The Mars Pathfinder Action Pack continues to sell out whenever a shipment is received.
- In contrast to the $90 million science-related toy market, sales of *Star Wars* action figures alone amounted to $500 million in 1999.

objects under conditions of apparent weightlessness. The first "Toys in Space" mission was so successful, a second group of toys was flown on the STS-54 mission in January 1993. During the second Toys in Space mission, astronauts John Casper and Susan Helms demonstrated how the behavior of several simple toys was quite different under **microgravity** conditions.

In June 2001, The Lego company teamed up with Space Media, Inc.™ and RSC Energia to conduct the first experiment on the International Space Station using toys. The Life on Mars: Red Planet Protector was used to measure the mass of an object under zero-gravity conditions. Cosmonauts Talgat Musabayev and Yuri Baturin demonstrated how an object's mass can be determined from oscillation frequency in a weightless environment.

Educational toys related to space exploration can serve the dual roles of providing a good return on investment for toy manufacturers while at the same time providing a rich learning opportunity for children. The vision of Lego, sparking an interest in science and space, can provide a sound basis for socially conscious free enterprise. The cooperative model developed by Mattel and JPL has been mutually beneficial, serving as a strong profit center for Mattel while effectively publicizing NASA and JPL's commitment to technology transfer. SEE ALSO EDUCATION (VOLUME 1); MARS (VOLUME 2); MICROGRAVITY (VOLUME 2); ROBOTIC EXPLORATION OF SPACE (VOLUME 2).

Elliot Richmond

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V

Verne, Jules

French Science Fiction Novelist
1828–1905

Jules Gabriel Verne, one of the founding fathers of science fiction, was born in Nantes, France, in 1828. He was the eldest son of a successful provincial lawyer. At twelve years of age, Verne ran off to be a cabin boy on a merchant ship, thinking he was going to have an adventure. But his father caught up with the ship before it got very far and took Verne home to punish him. Verne promised in the future he would travel only in his imagination.

In 1847 Verne was sent to study law in Paris, and from 1848 until 1863 wrote opera librettos and plays as a hobby. He read incessantly and studied astronomy, geology, and engineering for many hours in Paris libraries. His first play was published in 1850, prompting his decision to discontinue his law studies. Displeased upon hearing this news, his father stopped paying his son's expenses in Paris. This forced Verne to earn money by selling his stories.

In 1862, at the age of thirty-four, Verne sent a series of works called Voyages Extraordinaire to Pierre-Jules Hetzel, a writer and publisher of literature for children and young adults. Verne attained enough success with the first in the series, *Five Weeks in a Balloon*, published in 1863, for the Verne/Hetzel collaboration to continue throughout his entire career. Hetzel published Verne's stories in his periodical, *Magasin d'Education et de Recreation*, and later released them in book form.

Jules Verne, author of *20,000 Leagues under the Sea* (1870), predicted many scientific advancements of the twentieth century and is considered one of the founding fathers of science fiction.

Due to nineteenth-century interest in science and invention, Verne's work was received with enormous popular favor. He forecast with remarkable accuracy many scientific achievements of the twentieth century. He anticipated flights into outer space, automobiles, submarines, helicopters, atomic power, telephones, air conditioning, guided missiles, and motion pictures long before they were developed. In his novels, however, science and technology are not the heroes. Instead, his heroes are admirable men who master science and technology. His object was to write books from which the young could learn.

Among his most popular books are *Journey to the Center of the Earth* (1864), *From the Earth to the Moon* (1865), *20,000 Leagues under the Sea* (1870), *Mysterious Island* (1870), and *Around the World in Eighty Days* (1873). These five novels have remained in almost continuous print for over a century. Verne also produced an illustrated geography of France, and his works have been the source of many films.

Because of the popularity of these and other novels, Verne became a wealthy man. In 1857 he married Honorine de Viane. In 1876 he bought a large yacht and sailed around Europe. This was the extent of his real-life adventuring, leaving the rest for his novels. He maintained a regular writing schedule of at least two volumes a year. Verne published sixty-five novels, thirty plays, librettos, geographies, occasional short stories, and essays.

The last novel he wrote before his death was *The Invasion of the Sea*. He died in the city of Amiens, France, in 1905. SEE ALSO CAREERS IN WRITING, PHOTOGRAPHY, AND FILMMAKING (VOLUME 1); LITERATURE (VOLUME 1).

Vickie Elaine Caffey

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X

X PRIZE

In the early twenty-first century, millions of people fly on airplanes between cities around the world. At any one time, an astounding 10 million people are airborne. But it was not always this way. Only 100 years ago, during the birth of aviation, flying in an airplane was a very expensive, risky, and infrequent activity, much the way spaceflight is in the early twenty-first century.

At the turn of the last century (1904–1930), one of the major activities that made aviation very popular, exciting, and affordable was a series of prizes or competitions. History has shown the amazing power of prizes to accelerate technological development. For example, in 1714, in response to a series of tragic maritime disasters, the British Parliament passed the Longitude Act, which provided a large financial prize for the demonstration of a marine clock that was sufficiently accurate to permit precise determination of a ship's longitude. Within twenty years of the announcement of the Longitude prize, a practical clock was demonstrated and marine navigation was revolutionized.

In the twentieth century the history of aviation contains hundreds of prizes that greatly advanced aircraft technology. One of the most significant prizes in the history of aviation (and the one from which the X PRIZE is modeled) was the Orteig Prize, an award for the first nonstop flight between New York and Paris, which was sponsored by Raymond Orteig, a wealthy hotel owner. Nine teams cumulatively spent $400,000, sixteen times the $25,000 purse, in pursuit of this prize. By offering a prize instead of backing one particular team or technology, Orteig automatically backed the winner. Had Orteig elected to back teams in order of their probability of success, as judged by the conventional wisdom of the day, he would have backed Charles Lindbergh last. Lindbergh achieved success, taking an unconventional single pilot/single engine approach. On May 20, 1927, Lindbergh flew his airplane, the Spirit of St. Louis, nonstop for thirty-three and a half hours across the Atlantic Ocean from New York to Paris, and won the $25,000 Orteig prize.

The X PRIZE is a competition that was created to inspire rocket scientists to build a new generation of spaceships designed to carry the average person into space on a suborbital flight to an altitude of 100 kilometers (62 miles). This flight is very similar to the flight made by astronaut Alan Shepard on May 5, 1961, on the Mercury Redstone rocket from Cape Canaveral, Florida. Shepard, who was the first American in space, did not actually go into orbit, as the space shuttle does, but instead flew a **suborbital trajectory** that lasted about twenty minutes.

suborbital trajectory the trajectory of a rocket or ballistic missile that has insufficient energy to reach orbit

The X PRIZE Foundation, headquartered in St. Louis, Missouri, is offering a $10 million cash prize. To win the prize, vehicles must be privately financed and constructed, and competitors must demonstrate their ability to fly to an altitude of 100 kilometers with three passengers. Furthermore, competitors must prove that their vehicle is reusable by flying it twice within a two-week period. Since the announcement of the X PRIZE, twenty-one teams from five countries have registered to compete.

The suborbital flights of the X PRIZE are just the first step. The competition's goals are to bring about the creation of new generation of spaceships that will serve new markets such as space tourism and point-to-point package delivery (rocket mail). As X PRIZE teams gain experience and improve their technology, their ships will evolve from suborbital to orbital ships in the same fashion that one can draw the lineage from the Wright brothers' Flyer to the DC-3 and eventually to today's 747 aircraft.

The mission of the X PRIZE Foundation is to change the way that people think about space. Rather than viewing spaceflight as the exclusive province of governments, the foundation's goal is to transform spaceflight into an enterprise in which the general public can directly participate, much in the way that people can fly on airplanes today. SEE ALSO Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Shepard, Alan (volume 3); Space Tourism, Evolution of (volume 4); Tourism (volume 1).

Peter H. Diamandis

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Glossary

ablation removal of the outer layers of an object by erosion, melting, or vaporization

abort-to-orbit emergency procedure planned for the space shuttle and other spacecraft if the spacecraft reaches a lower than planned orbit

accretion the growth of a star or planet through the accumulation of material from a companion star or the surrounding interstellar matter

adaptive optics the use of computers to adjust the shape of a telescope's optical system to compensate for gravity or temperature variations

aeroballistic describes the combined aerodynamics and ballistics of an object, such as a spacecraft, in flight

aerobraking the technique of using a planet's atmosphere to slow down an incoming spacecraft; its use requires the spacecraft to have a heat shield, because the friction that slows the craft is turned into intense heat

aerodynamic heating heating of the exterior skin of a spacecraft, aircraft, or other object moving at high speed through the atmosphere

Agena a multipurpose rocket designed to perform ascent, precision orbit injection, and missions from low Earth orbit to interplanetary space; also served as a docking target for the Gemini spacecraft

algae simple photosynthetic organisms, often aquatic

alpha proton X-ray analytical instrument that bombards a sample with alpha particles (consisting of two protons and two neutrons); the X rays are generated through the interaction of the alpha particles and the sample

altimeter an instrument designed to measure altitude above sea level

amplitude the height of a wave or other oscillation; the range or extent of a process or phenomenon

angular momentum the angular equivalent of linear momentum; the product of angular velocity and moment of inertia (moment of inertia = mass $\times$ radius^2)

angular velocity the rotational speed of an object, usually measured in radians per second

anisotropy a quantity that is different when measured in different directions or along different axes

annular ring-like

anomalies phenomena that are different from what is expected

anorthosite a light-colored rock composed mainly of the mineral feldspar (an aluminum silicate); commonly occurs in the crusts of Earth and the Moon

anthropocentrism valuing humans above all else

antimatter matter composed of antiparticles, such as positrons and antiprotons

antipodal at the opposite pole; two points on a planet that are diametrically opposite

aperture an opening, door, or hatch

aphelion the point in an object's orbit that is farthest from the Sun

Apollo American program to land men on the Moon; Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

asthenosphere the weaker portion of a planet's interior just below the rocky crust

astrometry the measurement of the positions of stars on the sky

astronomical unit the average distance between Earth and the Sun (152 million kilometers [93 million miles])

atmospheric probe a separate piece of a spacecraft that is launched from it and separately enters the atmosphere of a planet on a one-way trip, making measurements until it hits a surface, burns up, or otherwise ends its mission

atmospheric refraction the bending of sunlight or other light caused by the varying optical density of the atmosphere

atomic nucleus the protons and neutrons that make up the core of an atom

atrophy condition that involves withering, shrinking, or wasting away

auroras atmospheric phenomena consisting of glowing bands or sheets of light in the sky caused by high-speed charged particles striking atoms in Earth's upper atmosphere

avionics electronic equipment designed for use on aircraft, spacecraft, and missiles

azimuth horizontal angular distance from true north measured clockwise from true north (e.g., if North = 0 degrees; East = 90 degrees; South = 180 degrees; West = 270 degrees)

ballast heavy substance used to increase the stability of a vehicle

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

basalt a dark, volcanic rock with abundant iron and magnesium and relatively low silica common on all of the terrestrial planets

base load the minimum amount of energy needed for a power grid

beacon signal generator a radio transmitter emitting signals for guidance or for showing location

berth space the human accommodations needed by a space station, cargo ship, or other vessel

Big Bang name given by astronomers to the event marking the beginning of the universe when all matter and energy came into being

biocentric notion that all living organisms have intrinsic value

biogenic resulting from the actions of living organisms; or, necessary for life

bioregenerative referring to a life support system in which biological processes are used; physiochemical and/or nonregenerative processes may also be used

biosignatures the unique traces left in the geological record by living organisms

biosphere the interaction of living organisms on a global scale

bipolar outflow jets of material (gas and dust) flowing away from a central object (e.g., a protostar) in opposite directions

bitumen a thick, almost solid form of hydrocarbons, often mixed with other minerals

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

bone mineral density the mass of minerals, mostly calcium, in a given volume of bone

breccia mixed rock composed of fragments of different rock types; formed by the shock and heat of meteorite impacts

bright rays lines of lighter material visible on the surface of a body and caused by relatively recent impacts

brown dwarf star-like object less massive than 0.08 times the mass of the Sun, which cannot undergo thermonuclear process to generate its own luminosity

calderas the bowl-shaped crater at the top of a volcano caused by the collapse of the central part of the volcano

Callisto one of the four large moons of Jupiter; named for one of the Greek nymphs

Caloris basin the largest (1,300 kilometers [806 miles] in diameter) well-preserved impact basin on Mercury viewed by Mariner 10

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

carbon-fiber composites combinations of carbon fibers with other materials such as resins or ceramics; carbon fiber composites are strong and lightweight

carbonaceous meteorites the rarest kind of meteorites, they contain a high percentage of carbon and carbon-rich compounds

carbonate a class of minerals, such as chalk and limestone, formed by carbon dioxide reacting in water

cartographic relating to the making of maps

Cassini mission a robotic spacecraft mission to the planet Saturn scheduled to arrive in July 2004 when the Huygens probe will be dropped into Titan's atmosphere while the Cassini spacecraft studies the planet

catalyst a chemical compound that accelerates a chemical reaction without itself being used up; any process that acts to accelerate change in a system

catalyze to change by the use of a catalyst

cell culture a means of growing mammalian (including human) cells in the research laboratory under defined experimental conditions

cellular array the three-dimensional placement of cells within a tissue

centrifugal directed away from the center through spinning

centrifuge a device that uses centrifugal force caused by spinning to simulate gravity

Cepheid variables a class of variable stars whose luminosity is related to their period. Their periods can range from a few hours to about 100 days and the longer the period, the brighter the star

Čerenkov light light emitted by a charged particle moving through a medium, such as air or water, at a velocity greater than the phase velocity of light in that medium; usually a faint, eerie, bluish, optical glow

chassis frame on which a vehicle is constructed

chondrite meteorites a type of meteorite that contains spherical clumps of loosely consolidated minerals

cinder field an area dominated by volcanic rock, especially the cinders ejected from explosive volcanoes

circadian rhythm activities and bodily functions that recur every twenty-four hours, such as sleeping and eating

Clarke orbit geostationary orbit; named after science fiction writer Arthur C. Clarke, who first realized the usefulness of this type of orbit for communication and weather satellites

coagulate to cause to come together into a coherent mass

comet matrix material the substances that form the nucleus of a comet; dust grains embedded in frozen methane, ammonia, carbon dioxide, and water

cometary outgassing vaporization of the frozen gases that form a comet nucleus as the comet approaches the Sun and warms

communications infrastructure the physical structures that support a network of telephone, Internet, mobile phones, and other communication systems

convection the movement of heated fluid caused by a variation in density; hot fluid rises while cool fluid sinks

convection currents mechanism by which thermal energy moves because its density differs from that of surrounding material. Convection current is the movement pattern of thermal energy transferring within a medium

convective processes processes that are driven by the movement of heated fluids resulting from a variation in density

coronal holes large, dark holes seen when the Sun is viewed in X-ray or ultraviolet wavelengths; solar wind emanates from the coronal holes

coronal mass ejections large quantities of solar plasma and magnetic field launched from the Sun into space

cosmic microwave background ubiquitous, diffuse, uniform, thermal radiation created during the earliest hot phases of the universe

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

cosmocentric ethic an ethical position that establishes the universe as the priority in a value system or appeals to something characteristic of the universe that provides justification of value

cover glass a sheet of glass used to cover the solid state device in a solar cell

crash-landers or hard-lander; a spacecraft that collides with the planet, making no—or little—attempt to slow down; after collision, the spacecraft ceases to function because of the (intentional) catastrophic failure

crawler transporter large, tracked vehicles used to move the assembled Apollo/Saturn from the VAB to the launch pad

cryogenic related to extremely low temperatures; the temperature of liquid nitrogen or lower

cryptocometary another name for carbonaceous asteroids—asteroids that contain a high percentage of carbon compounds mixed with frozen gases

cryptoendolithic microbial microbial ecosystems that live inside sandstone in extreme environments such as Antarctica

crystal lattice the arrangement of atoms inside a crystal

crystallography the study of the internal structure of crystals

dark matter matter that interacts with ordinary matter by gravity but does not emit electromagnetic radiation; its composition is unknown

density-separation jigs a form of gravity separation of materials with different densities that uses a pulsating fluid

desiccation the process of drying up

detruents microorganisms that act as decomposers in a controlled environmental life support system

diffuse spread out; not concentrated

DNA deoxyribonucleic acid; the molecule used by all living things on Earth to transmit genetic information

docking system mechanical and electronic devices that work jointly to bring together and physically link two spacecraft in space

doped semiconductor such as silicon with an addition of small amounts of an impurity such as phosphorous to generate more charge carriers (such as electrons)

dormant comet a comet whose volatile gases have all been vaporized, leaving behind only the heavy materials

downlink the radio dish and receiver through which a satellite or spacecraft transmits information back to Earth

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

dunites rock type composed almost entirely of the mineral olivine, crystallized from magma beneath the Moon's surface

dynamic isotope power the decay of isotopes such as plutonium-238, and polonium-210 produces heat, which can be transformed into electricity by radioisotopic thermoelectric generators

Earth-Moon LaGrange five points in space relative to Earth and the Moon where the gravitational forces on an object balance; two points, 60 degrees from the Moon in orbit, are candidate points for a permanent space settlement due to their gravitational stability

eccentric the term that describes how oval the orbit of a planet is

ecliptic the plane of Earth's orbit

EH condrites a rare form of meteorite containing a high concentration of the mineral enstatite (a type of pyroxene) and over 30 percent iron

ejecta the pieces of material thrown off by a star when it explodes; or, material thrown out of an impact crater during its formation

ejector ramjet engine design that uses a small rocket mounted in front of the ramjet to provide a flow of heated air, allowing the ramjet to provide thrust when stationary

electrodynamic pertaining to the interaction of moving electric charges with magnetic and electric fields

electrolytes a substance that when dissolved in water creates an electrically conducting solution

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

electron a negatively charged subatomic particle

electron volts units of energy equal to the energy gained by an electron when it passes through a potential difference of 1 volt in a vacuum

electrostatic separation separation of substances by the use of electrically charged plates

elliptical having an oval shape

encapsulation enclosing within a capsule

endocrine system in the body that creates and secretes substances called hormones into the blood

equatorial orbit an orbit parallel to a body's geographic equator

equilibruim point the point where forces are in balance

Europa one of the large satellites of Jupiter

eV an electron volt is the energy gained by an electron when moved across a potential of one volt. Ordinary molecules, such as air, have an energy of about $3x10^{-2}$ eV

event horizon the imaginary spherical shell surrounding a black hole that marks the boundary where no light or any other information can escape

excavation a hole formed by mining or digging

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

extrasolar planets planets orbiting stars other than the Sun

extravehicular activity a space walk conducted outside a spacecraft cabin, with the crew member protected from the environment by a pressurized space suit

extremophiles microorganisms that can survive in extreme environments such as high salinity or near boiling water

extruded forced through an opening

failsafe a system designed to be failure resistant through robust construction and redundant functions

fairing a structure designed to provide low aerodynamic drag for an aircraft or spacecraft in flight

fault a fracture in rock in the upper crust of a planet along which there has been movement

feedstock the raw materials introduced into an industrial process from which a finished product is made

feldspathic rock containing a high proportion of the mineral feldspar

fiber-optic cable a thin strand of ultrapure glass that carries information in the form of light, with the light turned on and off rapidly to represent the information sent

fission act of splitting a heavy atomic nucleus into two lighter ones, releasing tremendous energy

flares intense, sudden releases of energy

flybys flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

fracture any break in rock, from small "joints" that divide rocks into planar blocks (such as that seen in road cuts) to vast breaks in the crusts of unspecified movement

freefall the motion of a body acted on by no forces other than gravity, usually in orbit around Earth or another celestial body

free radical a molecule with a high degree of chemical reactivity due to the presence of an unpaired electron

frequencies the number of oscillations or vibrations per second of an electromagnetic wave or any wave

fuel cells cells that react a fuel (such as hydrogen) and an oxidizer (such as oxygen) together; the chemical energy of the initial reactants is released by the fuel cell in the form of electricity

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

fusion fuel fuel suitable for use in a nuclear fusion reactor

G force the force an astronaut or pilot experiences when undergoing large accelerations

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

Galilean satellite one of the four large moons of Jupiter first discovered by Galileo

Galileo mission succesful robot exploration of the outer solar system; this mission used gravity assists from Venus and Earth to reach Jupiter, where it dropped a probe into the atmosphere and studied the planet for nearly seven years

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

Ganymede one of the four large moons of Jupiter; the largest moon in the solar system

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

general relativity a branch of science first described by Albert Einstein showing the relationship between gravity and acceleration

geocentric a model that places Earth at the center of the universe

geodetic survey determination of the exact position of points on Earth's surface and measurement of the size and shape of Earth and of Earth's gravitational and magnetic fields

geomagnetic field Earth's magnetic field; under the influence of solar wind, the magnetic field is compressed in the Sunward direction and stretched out in the downwind direction, creating the magnetosphere, a complex, teardrop-shaped cavity around Earth

geospatial relating to measurement of Earth's surface as well as positions on its surface

geostationary remaining above a fixed point above Earth's equator

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

gimbal motors motors that direct the nozzle of a rocket engine to provide steering

global change a change, such as average ocean temperature, affecting the entire planet

global positioning systems a system of satellites and receivers that provide direct determination of the geographical location of the receiver

globular clusters roughly spherical collections of hundreds of thousands of old stars found in galactic haloes

grand unified theory (GUT) states that, at a high enough energy level (about 10^{25} eV), the electromagnetic force, strong force, and weak force all merge into a single force

gravitational assist the technique of flying by a planet to use its energy to "catapult" a spacecraft on its way—this saves fuel and thus mass and cost of a mission; gravitational assists typically make the total mission duration longer, but they also make things possible that otherwise would not be possible

gravitational contraction the collapse of a cloud of gas and dust due to the mutual gravitational attraction of the parts of the cloud; a possible source of excess heat radiated by some Jovian planets

gravitational lenses two or more images of a distant object formed by the bending of light around an intervening massive object

gravity assist using the gravity of a planet during a close encounter to add energy to the motion of a spacecraft

gravity gradient the difference in the acceleration of gravity at different points on Earth and at different distances from Earth

gravity waves waves that propagate through space and are caused by the movement of large massive bodies, such as black holes and exploding stars

greenhouse effect process by which short wavelength energy (e.g., visible light) penetrates an object's atmosphere and is absorbed by the surface, which reradiates this energy as longer wavelength infrared (thermal) energy; this energy is blocked from escaping to space by molecules (e.g., H_2O and CO_2) in the atmosphere; and as a result, the surface warms

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

hard-lander spacecraft that collides with the planet or satellite, making no attempt to slow its descent; also called crash-landers

heliosphere the volume of space extending outward from the Sun that is dominated by solar wind; it ends where the solar wind transitions into the interstellar medium, somewhere between 40 and 100 astronomical units from the Sun

helium-3 a stable isotope of helium whose nucleus contains two protons and one neutron

hertz unit of frequency equal to one cycle per second

high-power klystron tubes a type of electron tube used to generate high frequency electromagnetic waves

hilly and lineated terrain the broken-up surface of Mercury at the antipode of the Caloris impact basin

hydrazine a dangerous and corrosive compound of nitrogen and hydrogen commonly used in high powered rockets and jet engines

hydroponics growing plants using water and nutrients in solution instead of soil as the root medium

hydrothermal relating to high temperature water

hyperbaric chamber compartment where air pressure can be carefully controlled; used to gradually acclimate divers, astronauts, and others to changes in pressure and air composition

hypergolic fuels and oxidizers that ignite on contact with each other and need no ignition source

hypersonic capable of speeds over five times the speed of sound

hyperspectral imaging technique in remote sensing that uses at least sixteen contiguous bands of high spectral resolution over a region of the electromagnetic spectrum; used in NASA spacecraft Lewis' payload

ilmenite an important ore of titanium

Imbrium Basin impact largest and latest of the giant impact events that formed the mare-filled basins on the lunar near side

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

impact winter the period following a large asteroidal or cometary impact when the Sun is dimmed by stratospheric dust and the climate becomes cold worldwide

impact-melt molten material produced by the shock and heat transfer from an impacting asteroid or meteorite

in situ in the natural or original location

incandescence glowing due to high temperature

indurated rocks rocks that have been hardened by natural processes

information age the era of our time when many businesses and persons are involved in creating, transmitting, sharing, using, and selling information, particularly through the use of computers

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

infrared radiation radiation whose wavelength is slightly longer than the wavelength of light

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

intercrater plains the oldest plains on Mercury that occur in the highlands and that formed during the period of heavy meteoroid bombardment

interferometers devices that use two or more telescopes to observe the same object at the same time in the same wavelength to increase angular resolution

interplanetary trajectories the solar orbits followed by spacecraft moving from one planet in the solar system to another

interstellar between the stars

interstellar medium the gas and dust found in the space between the stars

ion propulsion a propulsion system that uses charged particles accelerated by electric fields to provide thrust

ionization removing one or more electrons from an atom or molecule

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

isotopic ratios the naturally occurring ratios between different isotopes of an element

jettison to eject, throw overboard, or get rid of

Jovian relating to the planet Jupiter

Kevlar® a tough aramid fiber resistant to penetration

kinetic energy the energy an object has due to its motion

KREEP acronym for material rich in potassium (K), rare earth elements (REE), and phosphorus (P)

L-4 the gravitationally stable Lagrange point 60 degrees ahead of the orbiting planet

L-5 the gravitationally stable Lagrange point 60 degrees behind the orbiting planet

Lagrangian point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

laser-pulsing firing periodic pulses from a powerful laser at a surface and measuring the length of time for return in order to determine topography

libration point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

lichen fungus that grows symbiotically with algae

light year the distance that light in a vacuum would travel in one year, or about 9.5 trillion kilometers (5.9 trillion miles)

lithosphere the rocky outer crust of a body

littoral the region along a coast or beach between high and low tides

lobate scarps a long sinuous cliff

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

lunar maria the large, dark, lava-filled impact basins on the Moon thought by early astronomers to resemble seas

Lunar Orbiter a series of five unmanned missions in 1966 and 1967 that photographed much of the Moon at medium to high resolution from orbit

macromolecules large molecules such as proteins or DNA containing thousands or millions of individual atoms

magnetohydrodynamic waves a low frequency oscillation in a plasma in the presence of a magnetic field

magnetometer an instrument used to measure the strength and direction of a magnetic field

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

majority carriers the more abundant charge carriers in semiconductors; the less abundant are called minority carriers; for n-type semiconductors, electrons are the majority carriers

malady a disorder or disease of the body

many-bodied problem in celestial mechanics, the problem of finding solutions to the equations for more than two orbiting bodies

mare dark-colored plains of solidified lava that mainly fill the large impact basins and other low-lying regions on the Moon

Mercury the first American piloted spacecraft, which carried a single astronaut into space; six Mercury missions took place between 1961 and 1963

mesons any of a family of subatomic particle that have masses between electrons and protons and that respond to the strong nuclear force; produced in the upper atmosphere by cosmic rays

meteor the physical manifestation of a meteoroid interacting with Earth's atmosphere; this includes visible light and radio frequency generation, and an ionized trail from which radar signals can be reflected. Also called a "shooting star"

meteorites any part of a meteoroid that survives passage through Earth's atmosphere

meteoroid a piece of interplanetary material smaller than an asteroid or comet

meteorology the study of atmospheric phenomena or weather

meteorology satellites satellites designed to take measurements of the atmosphere for determining weather and climate change

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

micrometeoroid flux the total mass of micrometeoroids falling into an atmosphere or on a surface per unit of time

micrometeoroid any meteoroid ranging in size from a speck of dust to a pebble

microwave link a connection between two radio towers that each transmit and receive microwave (radio) signals as a method of carrying information (similar to radio communications)

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

missing matter the mass of the universe that cannot be accounted for but is necessary to produce a universe whose overall curvature is "flat"

monolithic massive, solid, and uniform; an asteroid that is formed of one kind of material fused or melted into a single mass

multi-bandgap photovoltaic photovoltaic cells designed to respond to several different wavelengths of electromagnetic radiation

multispectral referring to several different parts of the electromagnetic spectrum, such as visible, infrared, and radar

muons the decay product of the mesons produced by cosmic rays; muons are about 100 times more massive than electrons but are still considered leptons that do not respond to the strong nuclear force

near-Earth asteroids asteroids whose orbits cross the orbit of Earth; collisions between Earth and near Earth asteroids happen a few times every million years

nebulae clouds of interstellar gas and/or dust

neutron a subatomic particle with no electrical charge

neutron star the dense core of matter composed almost entirely of neutrons that remain after a supernova explosion has ended the life of a massive star

New Millennium a NASA program to identify, develop and validate key instrument and spacecraft technologies that can lower cost and increase performance of science missions in the twenty-first century

Next Generation Space Telescope the telescope scheduled to be launched in 2009 that will replace the Hubble Space Telescope

nuclear black holes black holes that are in the centers of galaxies; they range in mass from a thousand to a billion times the mass of the Sun

nuclear fusion the combining of low-mass atoms to create heavier ones; the heavier atom's mass is slightly less than the sum of the mass of its constituents, with the remaining mass converted to energy

nucleon a proton or a neutron; one of the two particles found in a nucleus

occultations a phenomena that occurs when one astronomical object passes in front of another

optical interferometry a branch of optical physics that uses the wavelength of visible light to measure very small changes within the environment

optical-interferometry based the use of two or more telescopes observing the same object at the same time at the same visible wavelength to increase angular resolution

optical radar a method of determining the speed of moving bodies by sending a pulse of light and measuring how long it takes for the reflected light to return to the sender

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

orbital dynamics the mathematical study of the nature of the forces governing the movement of one object in the gravitational field of another object

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

orthogonal composed of right angles or relating to right angles

oscillation energy that varies between alternate extremes with a definable period

osteoporosis the loss of bone density; can occur after extended stays in space

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

paleolake depression that shows geologic evidence of having contained a lake at some previous time

Paleozoic relating to the first appearance of animal life on Earth

parabolic trajectory trajectory followed by an object with velocity equal to escape velocity

parking orbit placing a spacecraft temporarily into Earth orbit, with the engines shut down, until it has been checked out or is in the correct location for the main burn that sends it away from Earth

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

payload bay the area in the shuttle or other spacecraft designed to carry cargo

payload fairing structure surrounding a payload; it is designed to reduce drag

payload operations experiments or procedures involving cargo or "payload" carried into orbit

payload specialists scientists or engineers selected by a company or a government employer for their expertise in conducting a specific experiment or commercial venture on a space shuttle mission

perihelion the point in an object's orbit that is closest to the Sun

period of heavy meteoroid the earliest period in solar system history (more than 3.8 billion years ago) when the rate of meteoroid impact was very high compared to the present

perturbations term used in orbital mechanics to refer to changes in orbits due to "perturbing" forces, such as gravity

phased array a radar antenna design that allows rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

phased-array antennas radar antenna designs that allow rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

photolithography printing that uses a photographic process to create the printing plates

photometer instrument to measure intensity of light

photosynthesis a process performed by plants and algae whereby light is transformed into energy and sugars

photovoltaic pertaining to the direct generation of electricity from electromagnetic radiation (light)

photovoltaic arrays sets of solar panels grouped together in big sheets; these arrays collect light from the Sun and use it to make electricity to power the equipment and machines

photovoltaic cells cells consisting of a thin wafer of a semiconductor material that incorporates a p-n junction, which converts incident light into electrical power; a number of photovoltaic cells connected in series makes a solar array

plagioclase most common mineral of the light-colored lunar highlands

planetesimals objects in the early solar system that were the size of large asteroids or small moons, large enough to begin to gravitationally influence each other

pn single junction in a transistor or other solid state device, the boundary between the two different kinds of semiconductor material

point of presence an access point to the Internet with a unique Internet Protocol (IP) address; Internet service providers (ISP) like AOL generally have multiple POPs on the Internet

polar orbits orbits that carry a satellite over the poles of a planet

polarization state degree to which a beam of electromagnetic radiation has all of the vibrations in the same plane or direction

porous allowing the passage of a fluid or gas through holes or passages in the substance

power law energy spectrum spectrum in which the distribution of energies appears to follow a power law

primary the body (planet) about which a satellite orbits

primordial swamp warm, wet conditions postulated to have occurred early in Earth's history as life was beginning to develop

procurement the process of obtaining

progenitor star the star that existed before a dramatic change, such as a supernova, occurred

prograde having the same general sense of motion or rotation as the rest of the solar system, that is, counterclockwise as seen from above Earth's north pole

prominences inactive "clouds" of solar material held above the solar surface by magnetic fields

propagate to cause to move, to multiply, or to extend to a broader area

proton a positively charged subatomic particle

pseudoscience a system of theories that assumes the form of science but fails to give reproducible results under conditions of controlled experiments

pyroclastic pertaining to clastic (broken) rock material expelled from a volcanic vent

pyrotechnics fireworks display; the art of building fireworks

quantum foam the notion that there is a smallest distance scale at which space itself is not a continuous medium, but breaks up into a seething foam of wormholes and tiny black holes far smaller than a proton

quantum gravity an attempt to replace the inherently incompatible theories of quantum physics and Einstein gravity with some deeper theory that would have features of both, but be identical to neither

quantum physics branch of physics that uses quantum mechanics to explain physical systems

quantum vacuum consistent with the Heisenberg uncertainty principle, vacuum is not empty but is filled with zero-point energy and particle-antiparticle pairs constantly being created and then mutually annihilating each other

quasars luminous objects that appear star-like but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

quiescent inactive

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

radar altimetry using radar signals bounced off the surface of a planet to map its variations in elevation

radar images images made with radar illumination instead of visible light that show differences in radar brightness of the surface material or differences in brightness associated with surface slopes

radiation belts two wide bands of charged particles trapped in a planet's magnetic field

radio lobes active galaxies show two regions of radio emission above and below the plane of the galaxy, and are thought to originate from powerful jets being emitted from the accretion disk surrounding the massive black hole at the center of active galaxies

radiogenic isotope techniques use of the ratio between various isotopes produced by radioactive decay to determine age or place of origin of an object in geology, archaeology, and other areas

radioisotope a naturally or artificially produced radioactive isotope of an element

radioisotope thermoelectric device using solid state electronics and the heat produced by radioactive decay to generate electricity

range safety destruct systems system of procedures and equipment designed to safely abort a mission when a spacecraft malfunctions, and destroy the rocket in such a way as to create no risk of injury or property damage

Ranger series of spacecraft sent to the Moon to investigate lunar landing sites; designed to hard-land on the lunar surface after sending back television pictures of the lunar surface; Rangers 7, 8, and 9 (1964–1965) returned data

rarefaction decreased pressure and density in a material caused by the passage of a sound wave

reconnaissance a survey or preliminary exploration of a region of interest

reflex motion the orbital motion of one body, such as a star, in reaction to the gravitational tug of a second orbiting body, such as a planet

regolith upper few meters of a body's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

relative zero velocity two objects having the same speed and direction of movement, usually so that spacecraft can rendezvous

relativistic time dilation effect predicted by the theory of relativity that causes clocks on objects in strong gravitational fields or moving near the speed of light to run slower when viewed by a stationary observer

remote manipulator system a system, such as the external Canada2 arm on the International Space Station, designed to be operated from a remote location inside the space station

remote sensing the act of observing from orbit what may be seen or sensed below on Earth

retrograde having the opposite general sense of motion or rotation as the rest of the solar system, clockwise as seen from above Earth's north pole

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

reusables launches that can be used many times before discarding

rift valley a linear depression in the surface, several hundred to thousand kilometers long, along which part of the surface has been stretched, faulted, and dropped down along many normal faults

rille lava channels in regions of maria, typically beginning at a volcanic vent and extending downslope into a smooth mare surface

rocket vehicle or device that is especially designed to travel through space, and is propelled by one or more engines

"rocky" planets nickname given to inner or solid-surface planets of the solar system, including Mercury, Venus, Mars, and Earth

rover vehicle used to move about on a surface

rutile a red, brown, or black mineral, primarily titanium dioxide, used as a gemstone and also a commercially important ore of titanium

satellite any object launched by a rocket for the purpose of orbiting the Earth or another celestial body

scoria fragments of lava resembling cinders

secondary crater crater formed by the impact of blocks of rock blasted out of the initial crater formed by an asteroid or large meteorite

sedentary lifestyle a lifestyle characterized by little movement or exercise

sedimentation process of depositing sediments, which result in a thick accumulation of rock debris eroded from high areas and deposited in low areas

semiconductor one of the groups of elements with properties intermediate between the metals and nonmetals

semimajor axis one half of the major axis of an ellipse, equal to the average distance of a planet from the Sun

shepherding small satellites exerting their gravitational influence to cause or maintain structure in the rings of the outer planets

shield volcanoes volcanoes that form broad, low-relief cones, characterized by lava that flows freely

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

sine wave a wave whose amplitude smoothly varies with time; a wave form that can be mathematically described by a sine function

smooth plains the youngest plains on Mercury with a relatively low impact crater abundance

soft-landers spacecraft that uses braking by engines or other techniques (e.g., parachutes, airbags) such that its landing is gentle enough that the spacecraft and its instruments are not damaged, and observations at the surface can be made

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

solar corona the thin outer atmosphere of the Sun that gradually transitions into the solar wind

solar flares explosions on the Sun that release bursts of electromagnetic radiation, such as light, ultraviolet waves, and X rays, along with high speed protons and other particles

solar nebula the cloud of gas and dust out of which the solar system formed

solar prominence cool material with temperatures typical of the solar photosphere or chromosphere suspended in the corona above the visible surface layers

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

sounding rocket a vehicle designed to fly straight up and then parachute back to Earth, usually designed to take measurements of the upper atmosphere

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period; to date, only Earth-orbiting space stations have been launched

space-time in relativity, the four-dimensional space through which objects move and in which events happen

spacecraft bus the primary structure and subsystems of a spacecraft

spacewalking moving around outside a spaceship or space station, also known as extravehicular activity

special theory of relativity the fundamental idea of Einstein's theories, which demonstrated that measurements of certain physical quantities such as mass, length, and time depended on the relative motion of the object and observer

specific power amount of electric power generated by a solar cell per unit mass; for example watts per kilogram

spectra representations of the brightness of objects as a function of the wavelength of the emitted radiation

spectral lines the unique pattern of radiation at discrete wavelengths that many materials produce

spectrograph an instrument that can permanently record a spectra

spectrographic studies studies of the nature of matter and composition of substances by examining the light they emit

spectrometers an instrument with a scale for measuring the wavelength of light

spherules tiny glass spheres found in and among lunar rocks

spot beam technology narrow, pencil-like satellite beam that focuses highly radiated energy on a limited area of Earth's surface (about 100 to 500 miles in diameter) using steerable or directed antennas

stratigraphy the study of rock layers known as strata, especially the age and distribution of various kinds of sedimentary rocks

stratosphere a middle portion of a planet's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

subduction the process by which one edge of a crustal plate is forced to move under another plate

sublimate to pass directly from a solid phase to a gas phase

suborbital trajectory the trajectory of a rocket or ballistic missile that has insufficient energy to reach orbit

subsolar point the point on a planet that receives direct rays from the Sun

substrate the surface, such as glass, metallic foil, or plastic sheet, on which a thin film of photovoltaic material is deposited

sunspots dark, cooler areas on the solar surface consisting of transient, concentrated magnetic fields

supercarbonaceous term given to P- and D-type meteorites that are richer in carbon than any other meteorites and are thought to come from the primitive asteroids in the outer part of the asteroid belt

supernova an explosion ending the life of a massive star

supernovae ejecta the mix of gas enriched by heavy metals that is launched into space by a supernova explosion

superstring theory the best candidate for a "theory of everything" unifying quantum mechanics and gravity, proposes that all particles are oscillations in tiny loops of matter only 10^{-35} meters long and moving in a space of ten dimensions

superstrings supersymmetric strings are tiny, one dimensional objects that are about 10^{-33} cm long, in a 10-dimensional spacetime. Their different vibration modes and shapes account for the elementary particles we see in our 4-dimensional spacetime

Surveyor a series of spacecraft designed to soft-land robotic laboratories to analyze and photograph the lunar surface; Surveyors 1, 3, and 5–7 landed between May 1966 and January 1968

synchrotron radiation the radiation from electrons moving at almost the speed of light inside giant magnetic accelerators of particles, called synchrotrons, either on Earth or in space

synthesis the act of combining different things so as to form new and different products or ideas

technology transfer the acquisition by one country or firm of the capability to develop a particular technology through its interactions with the existing technological capability of another country or firm, rather than through its own research efforts

tectonism process of deformation in a planetary surface as a result of geological forces acting on the crust; includes faulting, folding, uplift, and downwarping of the surface and crust

telescience the act of operation and monitoring of research equipment located in space by a scientist or engineer from their offices or laboratories on Earth

terrestrial planet a small rocky planet with high density orbiting close to the Sun; Mercury, Venus, Earth, and Mars

thermodynamically referring to the behavior of energy

thermostabilized designed to maintain a constant temperature

thrust fault a fault where the block on one side of the fault plane has been thrust up and over the opposite block by horizontal compressive forces

toxicological related to the study of the nature and effects on humans of poisons and the treatment of victims of poisoning

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

transonic barrier the aerodynamic behavior of an aircraft moving near the speed of sound changes dramatically and, for early pioneers of transonic flight, dangerously, leading some to hypothesize there was a "sound barrier" where drag became infinite

transpiration process whereby water evaporates from the surface of leaves, allowing the plant to lose heat and to draw water up through the roots

transponder bandwidth-specific transmitter-receiver units

troctolite rock type composed of the minerals plagioclase and olivine, crystallized from magma

tunnelborer a mining machine designed to dig a tunnel using rotating cutting disks

Tycho event the impact of a large meteoroid into the lunar surface as recently as 100 million years ago, leaving a distinct set of bright rays across the lunar surface including a ray through the Apollo 17 landing site

ultramafic lavas dark, heavy lavas with a high percentage of magnesium and iron; usually found as boulders mixed in other lava rocks

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

ultraviolet radiation electromagnetic radiation with a shorter wavelength and higher energy than light

uncompressed density the lower density a planet would have if it did not have the force of gravity compressing it

Universal time current time in Greenwich, England, which is recognized as the standard time that Earth's time zones are based

vacuum an environment where air and all other molecules and atoms of matter have been removed

vacuum conditions the almost complete lack of atmosphere found on the surface of the Moon and in space

Van Allen radiation belts two belts of high energy charged particles captured from the solar wind by Earth's magnetic field

variable star a star whose light output varies over time

vector sum sum of two vector quantities taking both size and direction into consideration

velocity speed and direction of a moving object; a vector quantity

virtual-reality simulations a simulation used in training by pilots and astronauts to safely reproduce various conditions that can occur on board a real aircraft or spacecraft

visible spectrum the part of the electromagnetic spectrum with wavelengths between 400 nanometers and 700 nanometers; the part of the electromagnetic spectrum to which human eyes are sensitive

volatile ices (e.g., H_2O and CO_2) that are solids inside a comet nucleus but turn into gases when heated by sunlight

volatile materials materials that easily pass into the vapor phase when heated

wavelength the distance from crest to crest on a wave at an instant in time

X ray form of high-energy radiation just beyond the ultraviolet portion of the spectrum

X-ray diffraction analysis a method to determine the three-dimensional structure of molecules

Volume 1 Index

*Page numbers in **boldface type** indicate article titles; those in italic type indicate illustrations. A cumulative index, which combines the terms in all volumes of* Space Sciences, *can be found in volume 4 of this series.*

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space sciences

space sciences

VOLUME 2

Planetary Science and Astronomy

Pat Dasch, Editor in Chief

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Preface

Astronomers have studied the heavens for more than two millennia, but in the twentieth century, humankind ventured off planet Earth into the dark vacuum void of space, forever changing our perspective of our home planet and on our relationship to the universe in which we reside.

Our explorations of space—the final frontier in our niche in this solar system—first with satellites, then robotic probes, and finally with humans, have given rise to an extensive space industry that has a major influence on the economy and on our lives. In 1998, U.S. space exports (launch services, satellites, space-based communications services, and the like) totaled $64 billion. As we entered the new millennium, space exports were the second largest dollar earner after agriculture. The aerospace industry directly employs some 860,000 Americans, with many more involved in subcontracting companies and academic research.

Beginnings

The Chinese are credited with developing the rudiments of rocketry—they launched rockets as missiles against invading Mongols in 1232. In the nineteenth century William Congrieve developed a rocket in Britain based on designs conceived in India in the eighteenth century. Congrieve extended the range of the Indian rockets, adapting them specifically for use by armies. Congrieve's rockets were used in 1806 in the Napoleonic Wars.

The Birth of Modern Space Exploration

The basis of modern spaceflight and exploration came with the writings of Konstantin Tsiolkovsky (1857–1935), a Russian mathematics teacher. He described multi-stage rockets, winged craft like the space shuttle developed in the 1970s, space stations like Mir and the International Space Station, and interplanetary missions of discovery.

During the same period, space travel captured the imagination of fiction writers. Jules Verne wrote several novels with spaceflight themes. His book, *From the Earth to the Moon* (1865), describes manned flight to the Moon, including a launch site in Florida and a spaceship named Columbia—the name chosen for the Apollo 11 spaceship that made the first lunar landing in July 1969 and the first space shuttle, which flew in April 1981. In the twentieth century, Arthur C. Clarke predicted the role of communications satellites and extended our vision of human space exploration while

television series such as *Star Trek* and *Dr. Who* challenged the imagination and embedded the idea of space travel in our culture.

The first successful test of the V-2 rocket developed by Wernher von Braun and his team at Peenemünde, Germany, in October 1942 has been described as the "birth of the Space Age." After World War II some of the Peenemünde team under von Braun came to the United States, where they worked at the White Sands Missile Range in New Mexico, while others went to Russia. This sowed the seeds of the space race of the 1960s. Each team worked to develop advanced rockets, with Russia developing the R-7, while a series of rockets with names like Thor, Redstone, and Titan were produced in the United States.

When the Russians lofted Sputnik, the first artificial satellite, on October 4, 1957, the race was on. The flights of Yuri Gagarin, Alan Shepard, and John Glenn followed, culminating in the race for the Moon and the Apollo Program of the 1960s and early 1970s.

The Emergence of a Space Industry

The enormous national commitment to the Apollo Program marked a new phase in our space endeavors. The need for innovation and technological advance stimulated the academic and engineering communities and led to the growth of a vast network of contract supporters of the aerospace initiative and the birth of a vibrant space industry. At the same time, planetary science emerged as a new geological specialization.

Following the Apollo Program, the U.S. space agency's mission remained poorly defined through the end of the twentieth century, grasping at major programs such as development of the space shuttle and the International Space Station, in part, some argue, to provide jobs for the very large workforce spawned by the Apollo Program. The 1980s saw the beginnings of what would become a robust commercial space industry, largely independent of government programs, providing communications and information technology via space-based satellites. During the 1990s many thought that commercialization was the way of the future for space ventures. Commercially coordinated robotic planetary exploration missions were conceived with suggestions that NASA purchase the data, and Dennis Tito, the first paying space tourist in 2001, raised hopes of access to space for all.

The terrorist attacks on the United States on September 11, 2001 and the U.S. recession led to a re-evaluation of the entrepreneurial optimism of the 1990s. Many private commercial space ventures were placed on hold or went out of business. Commentators suggested that the true dawning of the commercial space age would be delayed by up to a decade. But, at the same time, the U.S. space agency emerged with a more clearly defined mandate than it had had since the Apollo Program, with a role of driving technological innovation—with an early emphasis on reducing the cost of getting to orbit—and leading world class space-related scientific projects. And military orders, to fill the needs of the new world order, compensated to a point for the downturn in the commercial space communications sector.

It is against this background of an industry in a state of flux, a discipline on the cusp of a new age of innovation, that this encyclopedia has been prepared.

Organization of the Material

The 341 entries in *Space Sciences* have been organized in four volumes, focusing on the business of space exploration, planetary science and astronomy, human space exploration, and the outlook for the future exploration of space. Each entry has been newly commissioned for this work. Our contributors are drawn from academia, industry, government, professional space institutes and associations, and nonprofit organizations. Many of the contributors are world authorities on their subject, providing up-to-the-minute information in a straightforward style accessible to high school students and university undergraduates.

One of the outstanding advantages of books on space is the wonderful imagery of exploration and achievement. These volumes are richly illustrated, and sidebars provide capsules of additional information on topics of particular interest. Entries are followed by a list of related entries, as well as a reading list for students seeking more information.

Acknowledgements

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Pat Dasch
Editor in Chief

For Your Reference

The following section provides information that is applicable to a number of articles in this reference work. Included in the following pages is a chart providing comparative solar system planet data, as well as measurement, abbreviation, and conversion tables.

SOLAR SYSTEM PLANET DATA

	Mercury	Venus[2]	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Mean distance from the Sun (AU): [1]	0.387	0.723	1	1.524	5.202	9.555	19.218	30.109	39.439
Siderial period of orbit (years):	0.24	0.62	1	1.88	11.86	29.46	84.01	164.79	247.68
Mean orbital velocity (km/sec):	47.89	35.04	29.79	24.14	13.06	9.64	6.81	5.43	4.74
Orbital essentricity:	0.206	0.007	0.017	0.093	0.048	0.056	0.047	0.009	0.246
Inclination to ecliptic (degrees):	7.00	3.40	0	1.85	1.30	2.49	0.77	1.77	17.17
Equatorial radius (km):	2439	6052	6378	3397	71492	60268	25559	24764	1140
Polar radius (km):	same	same	6357	3380	66854	54360	24973	24340	same
Mass of planet (Earth = 1):[3]	0.06	0.82	1	0.11	317.89	95.18	14.54	17.15	0.002
Mean density (gm/cm ^{3}):	5.44	5.25	5.52	3.94	1.33	0.69	1.27	1.64	2.0
Body rotation period (hours):	1408	5832.R	23.93	24.62	9.92	10.66	17.24	16.11	153.3
Tilt of equator to orbit (degrees):	0	2.12	23.45	23.98	3.08	26.73	97.92	28.8	96

[1]AU indicates one astronomical unit, defined as the mean distance between Earth and the Sun (~1.495 x 10^8 km).
[2]R indicates planet rotation is retrograde (i.e., opposite to the planet's orbit).
[3]Earth's mass is approximately 5.976 x 10^{26} grams.

SI BASE AND SUPPLEMENTARY UNIT NAMES AND SYMBOLS

Physical Quality	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
Plane angle	radian	rad
Solid angle	steradian	sr

Temperature

Scientists commonly use the Celsius system. Although not recommended for scientific and technical use, earth scientists also use the familiar Fahrenheit temperature scale (°F). 1°F = 1.8°C or K. The triple point of H_2O, where gas, liquid, and solid water coexist, is 32°F.

- To change from Fahrenheit (F) to Celsius (C):
  °C = (°F-32)/(1.8)
- To change from Celsius (C) to Fahrenheit (F):
  °F = (°C x 1.8) + 32
- To change from Celsius (C) to Kelvin (K):
  K = °C + 273.15
- To change from Fahrenheit (F) to Kelvin (K):
  K = (°F-32)/(1.8) + 273.15

UNITS DERIVED FROM SI, WITH SPECIAL NAMES AND SYMBOLS

Derived Quantity	Name of SI Unit	Symbol for SI Unit	Expression in Terms of SI Base Units
Frequency	hertz	Hz	s-1
Force	newton	N	m kg s-2
Pressure, stress	Pascal	Pa	N m-2 =m-1 kg s-2
Energy, work, heat	Joule	J	N m =m2 kg s-2
Power, radiant flux	watt	W	J s-1 =m2 kg s-3
Electric charge	coulomb	C	A s
Electric potential, electromotive force	volt	V	J C-1 =m-2 kg s-3 A-1
Electric resistance	ohm	_	V A-1 =m2 kg s-3 A-2
Celsius temperature	degree Celsius	C	K
Luminous flux	lumen	lm	cd sr
Illuminance	lux	lx	cd sr m-2

UNITS USED WITH SI, WITH NAME, SYMBOL, AND VALUES IN SI UNITS

The following units, not part of the SI, will continue to be used in appropriate contexts (e.g., angtsrom):

Physical Quantity	Name of Unit	Symbol for Unit	Value in SI Units
Time	minute	min	60 s
	hour	h	3,600 s
	day	d	86,400 s
Plane angle	degree	°	(π/180) rad
	minute	'	(π/10,800) rad
	second	"	(π/648,000) rad
Length	angstrom	Å	10^{-10} m
Volume	liter	l, L	1 dm^3 = 10^{-3} m^3
Mass	ton	t	1 mg = 10^3 kg
	unified atomic mass unit	u (=m_a(^{12}C)/12)	≈1.66054 x 10^{-27} kg
Pressure	bar	bar	10^5 Pa = 10^5 N m^{-2}
Energy	electronvolt	eV (= e X V)	≈1.60218 x 10^{-19} J

CONVERSIONS FOR STANDARD, DERIVED, AND CUSTOMARY MEASUREMENTS

Length

1 angstrom (Å)	0.1 nanometer (exactly) 0.000000004 inch
1 centimeter (cm)	0.3937 inches
1 foot (ft)	0.3048 meter (exactly)
1 inch (in)	2.54 centimeters (exactly)
1 kilometer (km)	0.621 mile
1 meter (m)	39.37 inches 1.094 yards
1 mile (mi)	5,280 feet (exactly) 1.609 kilometers
1 astronomical unit (AU)	1.495979×10^{13} cm
1 parsec (pc)	206,264.806 AU 3.085678×10^{18} cm 3.261633 light-years
1 light-year	9.460530×10^{17} cm

Area

1 acre	43,560 square feet (exactly) 0.405 hectare
1 hectare	2.471 acres
1 square centimeter (cm^2)	0.155 square inch
1 square foot (ft^2)	929.030 square centimeters
1 square inch (in^2)	6.4516 square centimeters (exactly)
1 square kilometer (km^2)	247.104 acres 0.386 square mile
1 square meter (m^2)	1.196 square yards 10.764 square feet
1 square mile (mi^2)	258.999 hectares

MEASUREMENTS AND ABBREVIATIONS

Volume

1 barrel (bbl)*, liquid	31 to 42 gallons
1 cubic centimeter (cm^3)	0.061 cubic inch
1 cubic foot (ft^3)	7.481 gallons 28.316 cubic decimeters
1 cubic inch (in^3)	0.554 fluid ounce
1 dram, fluid (or liquid)	$\frac{1}{8}$ fluid ounce (exactly) 0.226 cubic inch 3.697 milliliters
1 gallon (gal) (U.S.)	231 cubic inches (exactly) 3.785 liters 128 U.S. fluid ounces (exactly)
1 gallon (gal) (British Imperial)	277.42 cubic inches 1.201 U.S. gallons 4.546 liters
1 liter	1 cubic decimeter (exactly) 1.057 liquid quarts 0.908 dry quart 61.025 cubic inches
1 ounce, fluid (or liquid)	1.805 cubic inches 29.573 mililiters
1 ounce, fluid (fl oz) (British)	0.961 U.S. fluid ounce 1.734 cubic inches 28.412 milliliters
1 quart (qt), dry (U.S.)	67.201 cubic inches 1.101 liters
1 quart (qt), liquid (U.S.)	57.75 cubic inches (exactly) 0.946 liter

* There are a variety of "barrels" established by law or usage. For example, U.S. federal taxes on fermented liquors are based on a barrel of 31 gallons (141 liters); many state laws fix the "barrel for liquids" as 31½ gallons (119.2 liters); one state fixes a 36-gallon (160.5 liters) barrel for cistern measurment; federal law recognizes a 40-gallon (178 liters) barrel for "proof spirts"; by custom, 42 gallons (159 liters) comprise a barrel of crude oil or petroleum products for statistical purposes, and this equivalent is recognized "for liquids" by four states.

Units of mass

1 carat (ct)	200 milligrams (exactly) 3.086 grains
1 grain	64.79891 milligrams (exactly)
1 gram (g)	15.432 grains 0.035 ounce
1 kilogram (kg)	2.205 pounds
1 microgram (μg)	0.000001 gram (exactly)
1 milligram (mg)	0.015 grain
1 ounce (oz)	437.5 grains (exactly) 28.350 grams
1 pound (lb)	7,000 grains (exactly) 453.59237 grams (exactly)
1 ton, gross or long	2,240 pounds (exactly) 1.12 net tons (exactly) 1.016 metric tons
1 ton, metric (t)	2,204.623 pounds 0.984 gross ton 1.102 net tons
1 ton, net or short	2,000 pounds (exactly) 0.893 gross ton 0.907 metric ton

Pressure

1 kilogram/square centimeter (kg/cm^2)	0.96784 atmosphere (atm) 14.2233 pounds/square inch (lb/in^2) 0.98067 bar
1 bar	0.98692 atmosphere (atm) 1.02 kilograms/square centimeter (kg/cm^2)

Milestones in Space History

c. 850	The Chinese invent a form of gunpowder for rocket propulsion.
1242	Englishman Roger Bacon develops gunpowder.
1379	Rockets are used as weapons in the Siege of Chioggia, Italy.
1804	William Congrieve develops ship-fired rockets.
1903	Konstantin Tsiolkovsky publishes *Research into Interplanetary Science by Means of Rocket Power*, a treatise on space travel.
1909	Robert H. Goddard develops designs for liquid-fueled rockets.
1917	Smithsonian Institute issues grant to Goddard for rocket research.
1918	Goddard publishes the monograph *Method of Attaining Extreme Altitudes.*
1921	Soviet Union establishes a state laboratory for solid rocket research.
1922	Hermann Oberth publishes *Die Rakete zu den Planetenräumen*, a work on rocket travel through space.
1923	Tsiolkovsky publishes work postulating multi-staged rockets.
1924	Walter Hohmann publishes work on rocket flight and orbital motion.
1927	The German Society for Space Travel holds its first meeting.
	Max Valier proposes rocket-powered aircraft adapted from Junkers G23.
1928	Oberth designs liquid rocket for the film *Woman in the Moon.*
1929	Goddard launches rocket carrying barometer.
1930	Soviet rocket designer Valentin Glusko designs U.S.S.R. liquid rocket engine.

1931	Eugene Sänger test fires liquid rocket engines in Vienna.
1932	German Rocket Society fires first rocket in test flight.
1933	Goddard receives grant from Guggenheim Foundation for rocket studies.
1934	Wernher von Braun, member of the German Rocket Society, test fires water-cooled rocket.
1935	Goddard fires advanced liquid rocket that reaches 700 miles per hour.
1936	Glushko publishes work on liquid rocket engines.
1937	The Rocket Research Project of the California Institute of Technology begins research program on rocket designs.
1938	von Braun's rocket researchers open center at Pennemünde.
1939	Sänger and Irene Brendt refine rocket designs and propose advanced winged suborbital bomber.
1940	Goddard develops centrifugal pumps for rocket engines.
1941	Germans test rocket-powered interceptor aircraft Me 163.
1942	V-2 rocket fired from Pennemünde enters space during ballistic flight.
1943	First operational V-2 launch.
1944	V-2 rocket launched to strike London.
1945	Arthur C. Clarke proposes geostationary satellites.
1946	Soviet Union tests version of German V-2 rocket.
1947	United States test fires Corporal missile from White Sands, New Mexico.
	X-1 research rocket aircraft flies past the speed of sound.
1948	United States reveals development plan for Earth satellite adapted from RAND.
1949	Chinese rocket scientist Hsueh-Sen proposes hypersonic aircraft.
1950	United States fires Viking 4 rocket to record 106 miles from USS Norton Sound.
1951	Bell Aircraft Corporation proposes winged suborbital rocket-plane.
1952	Wernher von Braun proposes wheeled Earth-orbiting space station.
1953	U.S. Navy D-558II sets world altitude record of 15 miles above Earth.
1954	Soviet Union begins design of RD-107, RD-108 ballistic missile engines.
1955	Soviet Union launches dogs aboard research rocket on suborbital flight.

1956	United States announces plan to launch Earth satellite as part of Geophysical Year program.
1957	U.S. Army Ballistic Missile Agency is formed.
	Soviet Union test fires R-7 ballistic missile.
	Soviet Union launches the world's first Earth satellite, Sputnik-1, aboard R-7.
	United States launches 3-stage Jupiter C on test flight.
	United States attempts Vanguard 1 satellite launch; rocket explodes.
1958	United States orbits Explorer-1 Earth satellite aboard Jupiter-C rocket.
	United States establishes the National Aeronautics and Space Administration (NASA) as civilian space research organization.
	NASA establishes Project Mercury manned space project.
	United States orbits Atlas rocket with Project Score.
1959	Soviet Union sends Luna 1 towards Moon; misses by 3100 miles.
	NASA announces the selection of seven astronauts for Earth space missions.
	Soviet Union launches Luna 2, which strikes the Moon.
1960	United States launches Echo satellite balloon.
	United States launches Discoverer 14 into orbit, capsule caught in midair.
	Soviet Union launches two dogs into Earth orbit.
	Mercury-Redstone rocket test fired in suborbital flight test.
1961	Soviet Union tests Vostok capsule in Earth orbit with dummy passenger.
	Soviet Union launches Yuri Gagarin aboard Vostok-1; he becomes the first human in space.
	United States launches Alan B. Shepard on suborbital flight.
	United States proposes goal of landing humans on the Moon before 1970.
	Soviet Union launches Gherman Titov into Earth orbital flight for one day.
	United States launches Virgil I. "Gus" Grissom on suborbital flight.
	United States launches first Saturn 1 rocket in suborbital test.

1962	United States launches John H. Glenn into 3-orbit flight.
	United States launches Ranger to impact Moon; craft fails.
	First United States/United Kingdom international satellite launch; Ariel 1 enters orbit.
	X-15 research aircraft sets new altitude record of 246,700 feet.
	United States launches Scott Carpenter into 3-orbit flight.
	United States orbits Telstar 1 communications satellite.
	Soviet Union launches Vostok 3 and 4 into Earth orbital flight.
	United States launches Mariner II toward Venus flyby.
	United States launches Walter Schirra into 6-orbit flight.
	Soviet Union launches Mars 1 flight; craft fails.
1963	United States launches Gordon Cooper into 22-orbit flight.
	Soviet Union launches Vostok 5 into 119-hour orbital flight.
	United States test fires advanced solid rockets for Titan 3C.
	First Apollo Project test in Little Joe II launch.
	Soviet Union orbits Vostok 6, which carries Valentina Tereshkova, the first woman into space.
	Soviet Union tests advanced version of R-7 called Soyuz launcher.
1964	United States conducts first Saturn 1 launch with live second stage; enters orbit.
	U.S. Ranger 6 mission launched towards Moon; craft fails.
	Soviet Union launches Zond 1 to Venus; craft fails.
	United States launches Ranger 7 on successful Moon impact.
	United States launches Syncom 3 communications satellite.
	Soviet Union launches Voshkod 1 carrying three cosmonauts.
	United States launches Mariner 4 on Martian flyby mission.
1965	Soviet Union launches Voshkod 2; first space walk.
	United States launches Gemini 3 on 3-orbit piloted test flight.
	United States launches Early Bird 1 communications satellite.
	United States launches Gemini 4 on 4-day flight; first U.S. space walk.

	United States launches Gemini 5 on 8-day flight.
	United States launches Titan 3C on maiden flight.
	Europe launches Asterix 1 satellite into orbit.
	United States Gemini 6/7 conduct first space rendezvous.
1966	Soviet Union launches Luna 9, which soft lands on Moon.
	United States Gemini 8 conducts first space docking; flight aborted.
	United States launches Surveyor 1 to Moon soft landing.
	United States tests Atlas Centaur advanced launch vehicle.
	Gemini 9 flight encounters space walk troubles.
	Gemini 10 flight conducts double rendezvous.
	United States launches Lunar Orbiter 1 to orbit Moon.
	Gemini 11 tests advanced space walks.
	United States launches Saturn IB on unpiloted test flight.
	Soviet Union tests advanced Proton launch vehicle.
	United States launches Gemini 12 to conclude two-man missions.
1967	Apollo 1 astronauts killed in launch pad fire.
	Soviet Soyuz 1 flight fails; cosmonaut killed.
	Britain launches Ariel 3 communications satellite.
	United States conducts test flight of M2F2 lifting body research craft.
	United States sends Surveyor 3 to dig lunar soils.
	Soviet Union orbits anti-satellite system.
	United States conducts first flight of Saturn V rocket (Apollo 4).
1968	Yuri Gagarin killed in plane crash.
	Soviet Union docks Cosmos 212 and 213 automatically in orbit.
	United States conducts Apollo 6 Saturn V test flight; partial success.
	Nuclear rocket engine tested in Nevada.
	United States launches Apollo 7 in three-person orbital test flight.
	Soviet Union launches Soyuz 3 on three-day piloted flight.
	United States sends Apollo 8 into lunar orbit; first human flight to Moon.
1969	Soviet Union launches Soyuz 4 and 5 into orbit; craft dock.
	Largest tactical communications satellite launched.

	United States flies Apollo 9 on test of lunar landing craft in Earth orbit.
	United States flies Apollo 10 to Moon in dress rehearsal of landing attempt.
	United States cancels military space station program.
	United States flies Apollo 11 to first landing on the Moon.
	United States cancels production of Saturn V in budget cut.
	Soviet lunar rocket N-1 fails in launch explosion.
	United States sends Mariner 6 on Mars flyby.
	United States flies Apollo 12 on second lunar landing mission.
	Soviet Union flies Soyuz 6 and 7 missions.
	United States launches Skynet military satellites for Britain.
1970	China orbits first satellite.
	Japan orbits domestic satellite.
	United States Apollo 13 mission suffers explosion; crew returns safely.
	Soviet Union launches Venera 7 for landing on Venus.
	United States launches military early warning satellite.
	Soviet Union launches Luna 17 to Moon.
	United States announces modifications to Apollo spacecraft.
1971	United States flies Apollo 14 to Moon landing.
	Soviet Union launches Salyut 1 space station into orbit.
	First crew to Salyut station, Soyuz 11, perishes.
	Soviet Union launches Mars 3 to make landing on the red planet.
	United States flies Apollo 15 to Moon with roving vehicle aboard.
1972	United States and the Soviet Union sign space cooperation agreement.
	United States launches Pioneer 10 to Jupiter flyby.
	Soviet Union launches Venera 8 to soft land on Venus.
	United States launches Apollo 16 to moon.
	India and Soviet Union sign agreement for launch of Indian satellite.
	United States initiates space shuttle project.
	United States flies Apollo 17, last lunar landing mission.

1973	United States launches Skylab space station.
	United States launches first crew to Skylab station.
	Soviet Union launches Soyuz 12 mission.
	United States launches second crew to Skylab space station.
1974	United States launches ATS research satellite.
	Soviet Union launches Salyut 3 on unpiloted test flight.
	Soviet Union launches Soyuz 12, 13, and 14 flights.
	Soviet Union launches Salyut 4 space station.
1975	Soviet Union launches Soyuz 17 to dock with Salyut 4 station.
	Soviet Union launches Venera 9 to soft land on Venus.
	United States and Soviet Union conduct Apollo-Soyuz Test Project joint flight.
	China orbits large military satellite.
	United States sends Viking 1 and 2 towards landing on Martian surface.
	Soviet Union launches unpiloted Soyuz 20.
1976	Soviet Union launches Salyut 5 space station.
	First space shuttle rolls out; Enterprise prototype.
	Soviet Union docks Soyuz 21 to station.
	China begins tests of advanced ballistic missile.
1977	Soyuz 24 docks with station.
	United States conducts atmospheric test flights of shuttle Enterprise.
	United States launches Voyager 1 and 2 on deep space missions.
	Soviet Union launches Salyut 6 space station.
	Soviet Soyuz 25 fails to dock with station.
	Soyuz 26 is launched and docks with station.
1978	Soyuz 27 is launched and docks with Salyut 6 station.
	Soyuz 28 docks with Soyuz 27/Salyut complex.
	United States launches Pioneer/Venus 1 mission.
	Soyuz 29 docks with station.
	Soviet Union launches Progress unpiloted tankers to station.
	Soyuz 30 docks with station.
	United States launches Pioneer/Venus 2.
	Soyuz 31 docks with station.

1979	Soyuz 32 docks with Salyut station.
	Voyager 1 flies past Jupiter.
	Soyuz 33 fails to dock with station.
	Voyager 2 flies past Jupiter.
1980	First Ariane rocket launches from French Guiana; fails.
	Soviet Union begins new Soyuz T piloted missions.
	STS-1 first shuttle mission moves to launching pad.
1981	Soviet Union orbits advanced Salyut stations.
	STS-1 launched on first space shuttle mission.
	United States launches STS-2 on second shuttle flight; mission curtailed.
1982	United States launches STS-5 first operational shuttle flight.
1983	United States launches Challenger, second orbital shuttle, on STS-6.
	United States launches Sally Ride, the first American woman in space, on STS-7.
	United States launches Guion Bluford, the first African-American astronaut, on STS-8.
	United States launches first Spacelab mission aboard STS-9.
1984	Soviet Union tests advanced orbital station designs.
	Shuttle Discovery makes first flights.
	United States proposes permanent space station as goal.
1985	Space shuttle Atlantis enters service.
	United States announces policy for commercial rocket sales.
	United States flies U.S. Senator aboard space shuttle Challenger.
1986	Soviet Union launches and occupies advanced Mir space station.
	Challenger—on its tenth mission, STS-51-L—is destroyed in a launching accident.
	United States restricts payloads on future shuttle missions.
	United States orders replacement shuttle for Challenger.
1987	Soviet Union flies advanced Soyuz T-2 designs.
	United States' Delta, Atlas, and Titan rockets grounded in launch failures.
	Soviet Union launches Energyia advanced heavy lift rocket.

1988	Soviet Union orbits unpiloted shuttle Buran.
	United States launches space shuttle Discovery on STS-26 flight.
	United States launches STS-27 military shuttle flight.
1989	United States launches STS-29 flight.
	United States launches Magellan probe from shuttle.
1990	Shuttle fleet grounded for hydrogen leaks.
	United States launches Hubble Space Telescope.
1992	Replacement shuttle Endeavour enters service.
	United States probe Mars Observer fails.
1993	United States and Russia announce space station partnership.
1994	United States shuttles begin visits to Russian space station Mir.
1995	Europe launches first Ariane 5 advanced booster; flight fails.
1996	United States announces X-33 project to replace shuttles.
1997	Mars Pathfinder lands on Mars.
1998	First elements of International Space Station launched.
1999	First Ocean space launch of Zenit rocket in Sea Launch program.
2000	Twin United States Mars missions fail.
2001	United States cancels shuttle replacements X-33 and X-34 because of space cutbacks.
	United States orbits Mars Odyssey probe around Mars.
2002	First launches of United States advanced Delta IV and Atlas V commercial rockets.

Frank Sietzen, Jr.

Human Achievements in Space

The road to space has been neither steady nor easy, but the journey has cast humans into a new role in history. Here are some of the milestones and achievements.

Oct. 4, 1957 The Soviet Union launches the first artificial satellite, a 184-pound spacecraft named Sputnik.

Nov. 3, 1957 The Soviets continue pushing the space frontier with the launch of a dog named Laika into orbit aboard Sputnik 2. The dog lives for seven days, an indication that perhaps people may also be able to survive in space.

Jan. 31, 1958 The United States launches Explorer 1, the first U.S. satellite, and discovers that Earth is surrounded by radiation belts. James Van Allen, who instrumented the satellite, is credited with the discovery.

Apr. 12, 1961 Yuri Gagarin becomes the first person in space. He is launched by the Soviet Union aboard a Vostok rocket for a two-hour orbital flight around the planet.

May 5, 1961 Astronaut Alan Shepard becomes the first American in space. Shepard demonstrates that individuals can control a vehicle during weightlessness and high gravitational forces. During his 15-minute suborbital flight, Shepard reaches speeds of 5,100 mph.

May 24, 1961 Stung by the series of Soviet firsts in space, President John F. Kennedy announces a bold plan to land men on the Moon and bring them safely back to Earth before the end of the decade.

Feb. 20, 1962 John Glenn becomes the first American in orbit. He flies around the planet for nearly five hours in his Mercury capsule, Friendship 7.

June 16, 1963 The Soviets launch the first woman, Valentina Tereshkova, into space. She circles Earth in her Vostok spacecraft for three days.

Nov. 28, 1964 NASA launches Mariner 4 spacecraft for a flyby of Mars.

Mar. 18, 1965 Cosmonaut Alexei Leonov performs the world's first space walk outside his Voskhod 2 spacecraft. The outing lasts 10 minutes.

Mar. 23, 1965 Astronauts Virgil I. "Gus" Grissom and John Young blast off on the first Gemini mission and demonstrate for the first time how to maneuver from one orbit to another.

June 3, 1965 Astronaut Edward White becomes the first American to walk in space during a 21-minute outing outside his Gemini spacecraft.

Mar. 16, 1966 Gemini astronauts Neil Armstrong and David Scott dock their spacecraft with an unmanned target vehicle to complete the first joining of two spacecraft in orbit. A stuck thruster forces an early end to the experiment, and the crew makes America's first emergency landing from space.

Jan. 27, 1967 The Apollo 1 crew is killed when a fire breaks out in their command module during a prelaunch test. The fatalities devastate the American space community, but a subsequent spacecraft redesign helps the United States achieve its goal of sending men to the Moon.

Apr. 24, 1967 Tragedy also strikes the Soviet space program, with the death of cosmonaut Vladimir Komarov. His new Soyuz spacecraft gets tangled with parachute lines during reentry and crashes to Earth.

Dec. 21, 1968 Apollo 8, the first manned mission to the Moon, blasts off from Cape Canaveral, Florida. Frank Borman, Jim Lovell and Bill Anders orbit the Moon ten times, coming to within 70 miles of the lunar surface.

July 20, 1969 Humans walk on another world for the first time when astronauts Neil Armstrong and Edwin "Buzz" Aldrin climb out of their spaceship and set foot on the Moon.

Apr. 13, 1970 The Apollo 13 mission to the Moon is aborted when an oxygen tank explosion cripples the spacecraft. NASA's most serious inflight emergency ends four days later when the astronauts, ill and freezing, splash down in the Pacific Ocean.

June 6, 1971 Cosmonauts blast off for the first mission in the world's first space station, the Soviet Union's Salyut 1. The crew spends twenty-two days aboard the outpost. During reentry, however, a faulty valve leaks air from the Soyuz capsule, and the crew is killed.

Jan. 5, 1972 President Nixon announces plans to build "an entirely new type of space transportation system," pumping life into NASA's dream to build a reusable, multi-purpose space shuttle.

Dec. 7, 1972 The seventh and final mission to the Moon is launched, as public interest and political support for the Apollo program dims.

May 14, 1973 NASA launches the first U.S. space station, Skylab 1, into orbit. Three crews live on the station between May 1973 and February 1974. NASA hopes to have the shuttle fly-

ing in time to reboost and resupply Skylab, but the outpost falls from orbit on July 11, 1979.

July 17, 1975 In a momentary break from Cold War tensions, the United States and Soviet Union conduct the first linking of American and Russian spaceships in orbit. The Apollo-Soyuz mission is a harbinger of the cooperative space programs that develop between the world's two space powers twenty years later.

Apr. 12, 1981 Space shuttle Columbia blasts off with a two-man crew for the first test-flight of NASA's new reusable spaceship. After two days in orbit, the shuttle lands at Edwards Air Force Base in California.

June 18, 1983 For the first time, a space shuttle crew includes a woman. Astronaut Sally Ride becomes America's first woman in orbit.

Oct. 30, 1983 NASA's increasingly diverse astronaut corps includes an African-American for the first time. Guion Bluford, an aerospace engineer, is one of the five crewmen assigned to the STS-8 mission.

Nov. 28, 1983 NASA flies its first Spacelab mission and its first European astronaut, Ulf Merbold.

Feb. 7, 1984 Shuttle astronauts Bruce McCandless and Robert Stewart take the first untethered space walks, using a jet backpack to fly up to 320 feet from the orbiter.

Apr. 9–11, 1984 First retrieval and repair of an orbital satellite.

Jan. 28, 1986 Space shuttle Challenger explodes 73 seconds after launch, killing its seven-member crew. Aboard the shuttle was Teacher-in-Space finalist Christa McAuliffe, who was to conduct lessons from orbit. NASA grounds the shuttle fleet for two and a half years.

Feb. 20. 1986 The Soviets launch the core module of their new space station, Mir, into orbit. Mir is the first outpost designed as a module system to be expanded in orbit. Expected lifetime of the station is five years.

May 15, 1987 Soviets launch a new heavy-lift booster from the Baikonur Cosmodrome in Kazakhstan.

Oct. 1, 1987 Mir cosmonaut Yuri Romanenko breaks the record for the longest space mission, surpassing the 236-day flight by Salyut cosmonauts set in 1984.

Sept. 29, 1988 NASA launches the space shuttle Discovery on the first crewed U.S. mission since the 1986 Challenger explosion. The shuttle carries a replacement communications satellite for the one lost onboard Challenger.

May 4, 1989 Astronauts dispatch a planetary probe from the shuttle for the first time. The Magellan radar mapper is bound for Venus.

Nov. 15, 1989 The Soviets launch their space shuttle Buran, which means snowstorm, on its debut flight. There is no crew onboard, and unlike the U.S. shuttle, no engines to help place it into orbit. Lofted into orbit by twin Energia heavy-lift boosters, Buran circles Earth twice and lands. Buran never flies again.

Apr. 24, 1990 NASA launches the long-awaited Hubble Space Telescope, the cornerstone of the agency's "Great Observatory" program, aboard space shuttle Discovery. Shortly after placing the telescope in orbit, astronomers discover that the telescope's prime mirror is misshapen.

Dec. 2, 1993 Space shuttle Endeavour takes off for one of NASA's most critical shuttle missions: repairing the Hubble Space Telescope. During an unprecedented five space walks, astronauts install corrective optics. The mission is a complete success.

Feb. 3, 1994 A Russian cosmonaut, Sergei Krikalev, flies aboard a U.S. spaceship for the first time.

Mar. 16, 1995 NASA astronaut Norman Thagard begins a three and a half month mission on Mir—the first American to train and fly on a Russian spaceship. He is the first of seven Americans to live on Mir.

Mar. 22, 1995 Cosmonaut Valeri Polyakov sets a new space endurance record of 437 days, 18 hours.

June 29, 1995 Space shuttle Atlantis docks for the first time at the Russian space station Mir.

Mar. 24, 1996 Shannon Lucid begins her stay aboard space aboard Mir, which lasts 188 days—a U.S. record for spaceflight endurance at that time.

Feb. 24, 1997 An oxygen canister on Mir bursts into flames, cutting off the route to the station's emergency escape vehicles. Six crewmembers are onboard, including U.S. astronaut Jerry Linenger.

June 27, 1997 During a practice of a new docking technique, Mir commander Vasily Tsibliyev loses control of an unpiloted cargo ship and it plows into the station. The Spektr module is punctured, The crew hurriedly seals off the compartment to save the ship.

Oct. 29, 1998 Senator John Glenn, one of the original Mercury astronauts, returns to space aboard the shuttle.

Nov. 20, 1998 A Russian Proton rocket hurls the first piece of the International Space Station into orbit.

Aug. 27, 1999 Cosmonauts Viktor Afanasyev, Sergei Avdeyev, and Jean-Pierre Haignere leave Mir. The station is unoccupied for the first time in almost a decade.

Oct. 31, 2000 The first joint American-Russian crew is launched to the International Space Station. Commander Bill Shepherd requests the radio call sign "Alpha" for the station and the name sticks.

Mar. 23, 2001 The *Mir* space station drops out of orbit and burns up in Earth's atmosphere.

Apr. 28, 2001 Russia launches the world's first space tourist for a week-long stay at the International Space Station. NASA objects to the flight, but is powerless to stop it.

Irene Brown

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Age of the Universe

A

The idea that the universe had a beginning is common to various religions and mythologies. However, astronomical evidence that the universe truly has a finite age did not appear until early in the twentieth century. The first clue that the universe has a finite age came at the end of World War I, when astronomer Vesto Slipher noted that a mysterious class of objects, collectively called spiral **nebula**, were all receding from Earth. He discovered that their light was stretched or reddened by their apparent motion away from Earth—the same way an ambulance siren's pitch drops when it speeds away from a stationary observer.

nebula clouds of interstellar gas and/or dust

Hubble's Contribution

In the early 1920s American astronomer Edwin P. Hubble was able to measure the distances to these receding objects by using a special class of milepost marker stars called Cepheid variables. Hubble realized that these spiral nebulae were so far away they were actually galaxies—separate cities of stars—far beyond our own Milky Way.

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

By 1929, Hubble had made the momentous discovery that the farther away a **galaxy** is, the faster it is receding from Earth. This led him to conclude that galaxies are apparently moving away because space itself is expanding uniformly in all directions. Hubble reasoned that the galaxies must inevitably have been closer to each other in the distant past. Indeed, at some point they all must have occupied the same space. This idea led theoreticians to conceive of the notion of the Big Bang, the theory that the universe ballooned from an initially hot and dense state.

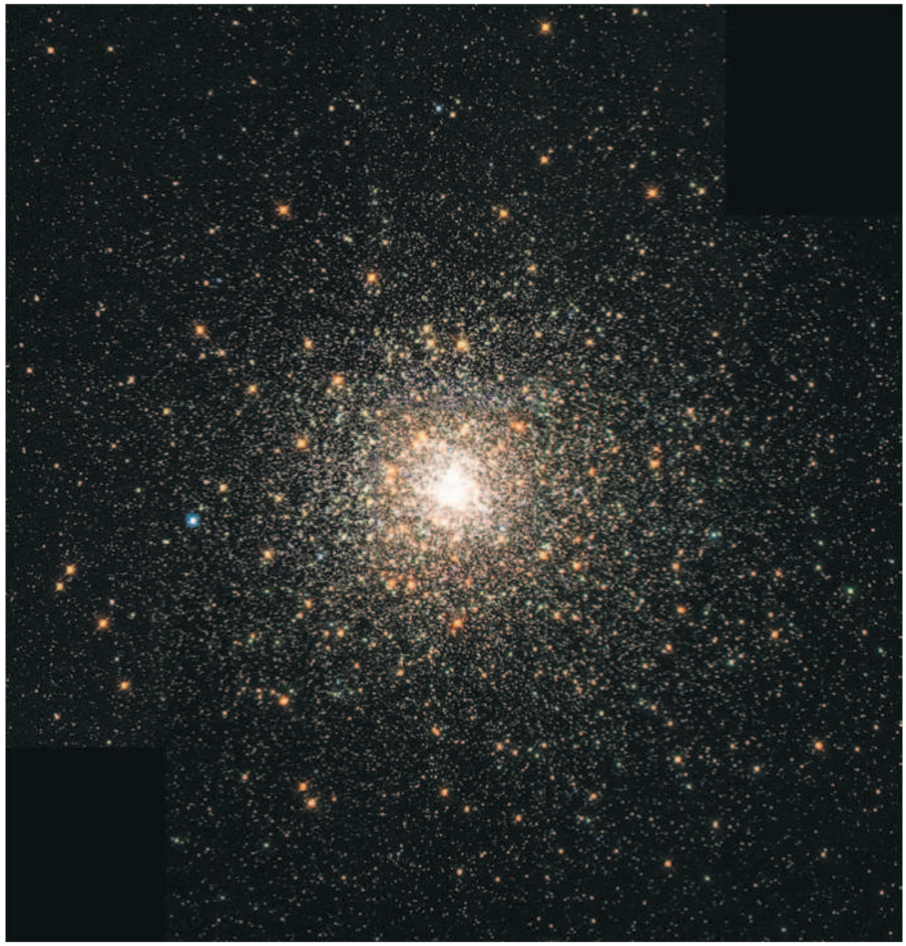
Hubble realized that if he could measure the universe's speed of expansion, he could easily calculate the universe's true age. Assuming the universe's expansion rate has not changed much over time, he calculated an age of about 2 billion years. One problem with this estimate, however, was that it was younger than geologists' best estimate for the age of Earth at the time.

Astronomers since then have sought to refine the expansion rate—and the estimate for the universe's age—by more precisely measuring distances to galaxies. Based on uncertainties over the true distances of galaxies, estimates for the universe's age have varied from 10 billion to 20 billion years old.

EINSTEIN'S VIEW

Despite his genius for envisioning the farthest reaches of space and time, even the great theoretician Albert Einstein could not imagine that the universe had a beginning. When, using his general theory of relativity, he predicted that the universe should be collapsing under the pull of gravity among galaxies, Einstein arbitrarily altered his equations to maintain an eternal, static universe.

Astronomers were able to date all of the stars in globular star cluster M80 (as seen through the Hubble Space Telescope) at 15 billion years.



More Recent Estimates

A primary task of the Hubble Space Telescope (HST), launched in 1990, was to break this impasse by observing Cepheid variable stars in galaxies much farther away than can be seen from ground-based telescopes. The HST allowed astronomers to measure precisely the universe's expansion rate and calculate an age of approximately 11 to 12 billion years.

Estimating the age is now complicated, however, by recent observations that show the universe expanded at a slower rate in the past. This is due to some mysterious repulsive force, first envisioned by physicist Albert Einstein as part of his so-called fudge factor in keeping the universe balanced. The presence of such a repulsive force pushing galaxies apart means that the universe is more likely to be 13 to 15 billion years old.

Using Stars to Estimate Age. The universe's age can also be estimated independently by observing the oldest stars. Astronomers know that stars must have started forming quickly after the universe expanded and cooled enough for gas to **coagulate** into stars. So the oldest star must be close to the true age of the universe itself. The oldest stars, which lie inside **globular clusters** that orbit our galaxy, are estimated to be at least 12 billion years old. These estimates are difficult because they rely on complex models and calculations about how a star burns its nuclear fuel and ages.

coagulate to cause to come together into a coherent mass

globular clusters roughly spherical collections of hundreds of thousands of old stars found in galactic haloes

A simpler cosmic clock is a class of star called white dwarfs, which are the burned-out remnants of Sun-like stars. Like dying cinders, it takes a long time for dwarfs to cool to absolute zero—longer than the present age of the universe itself. So the coolest, dimmest dwarfs represent the remnants of the oldest stars. Because they are so dim, these dwarfs are hard to find. Astronomers are using the HST to pinpoint the very oldest white dwarfs in globular clusters.

The HST has uncovered the very faintest and coolest dwarfs in the Milky Way galaxy, with ages of 12.6 billion years, thus giving an age estimate for the universe of 13 to 14 billion years. This is a very successful and entirely independent confirmation of previous age estimates of the universe.

Astronomers now know the age of the universe to within a good degree of accuracy. This is quite an achievement considering that less than a century ago, astronomers did not even realize the universe had a beginning. SEE ALSO Cosmology (volume 2); Hubble, Edwin P. (volume 2); Stars (volume 2).

Ray Villard

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Asteroids

Asteroids are small bodies in space—the numerous leftover **planetesimals** from which the planets were made nearly 4.6 billion years ago. Most are in the "main belt," which is a doughnut-like volume of space between Mars and Jupiter (about 2.1 to 3.2 astronomical units [AU] from the Sun; one AU is equal to the mean distance between Earth and the Sun). The Trojans are two groups of asteroids around 60 degrees ahead of (and behind) Jupiter in its **orbit** (5.2 AU from the Sun). Asteroids range in location from within Earth's orbit to the outer solar system, where the distinction between asteroids and comets blurs.

planetesimals objects in the early solar system that were the size of large asteroids or small moons, large enough to begin to gravitationally influence each other

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

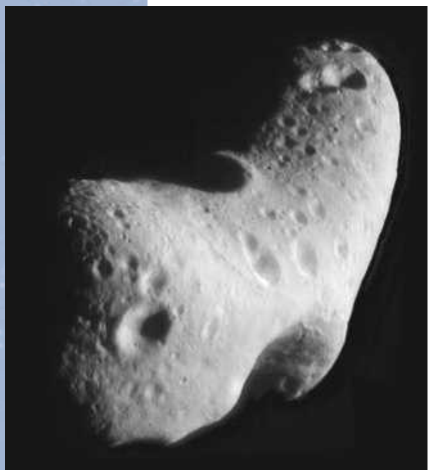
Some asteroids orbit at a solar distance where their year is matched to Jupiter's year. For example, the Hilda asteroids circle the Sun three times for every two revolutions of Jupiter. Other Jupiter-asteroid relationships are unstable, so asteroids are missing from those locations. For example, gaps occur in the main belt where asteroids orbit the Sun twice and three times each **Jovian** year. These gaps are called Kirkwood gaps. Any asteroids originally formed in such locations have been kicked out of the asteroid belt by Jupiter's strong gravitational forces, so no asteroids remain there.

Jovian relating to the planet Jupiter

Many asteroids are members of groups with very similar orbital shapes, tilts, and solar distances. These so-called families were formed when asteroids smashed into each other at interasteroidal velocities of 5 kilometers per second (3 miles per second). Fragments from such explosive disruptions became separate asteroids.

Asteroid Sizes, Shapes, and Compositions

Ceres, the first asteroid to be discovered (on January 1, 1801), remains the largest asteroid found to date; it is about 1,000 kilometers (620 miles) in diameter. Dozens of asteroids range from 200 to 300 kilometers (124 to 186 miles) in diameter, thousands are the size of a small city, and hundreds of billions are house-sized. Indeed, asteroids grade into the rocks that occasionally burn through our atmosphere as fireballs and the even smaller grains of sand that produce meteors ("shooting stars") in a clear, dark sky. Collected remnants are called meteorites. All are debris from the cratering and catastrophic disruptions of inter-asteroidal collisions.



Eros is a 34-kilometer-long, Earth-approaching asteroid.

Asteroids are small and distant, so even in telescopes they are only faint points of light gradually moving against the backdrop of the stars. Astronomers use telescopes to measure asteroid motions, brightnesses, and the spectral colors of sunlight reflected from their surfaces. Asteroid brightnesses change every few hours as they spin, first brightening when they are broadside to us and fading when end-on. From these data, astronomers infer that most asteroids have irregular, nonspherical shapes and spin every few minutes (for some very small asteroids) to less often than once a month.

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

wavelength the distance from crest to crest on a wave at an instant in time

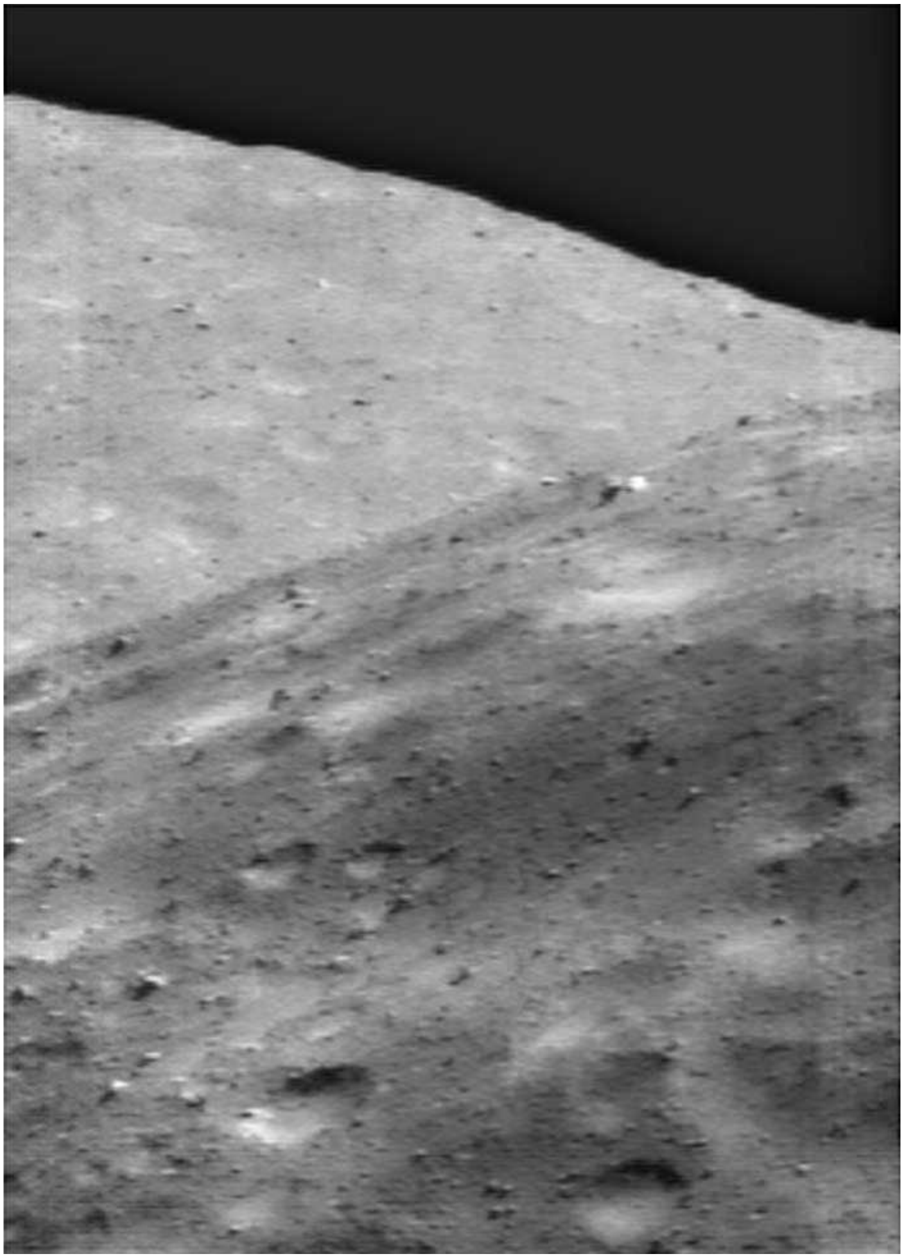
carbonaceous meteorites the rarest kind of meteorites, they contain a high percentage of carbon and carbon-rich compounds

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Different **minerals** reflect sunlight (at **ultraviolet**, visible, and **infrared wavelengths**) in different ways. So the spectra of asteroids enable astronomers to infer what they are made of. Many are made of primitive materials, such as rocky minerals and flecks of metal, from which it is believed the planets were made. Such is the case with the ordinary chondrites, the most common meteorites in museums. Most asteroids are exceedingly dark in color, and are apparently rich in carbon and other black compounds, including the uncommon **carbonaceous meteorites**. Such fragile, C-type materials are abundant in space but often disintegrate when passing through Earth's atmosphere. C-type asteroids may even contain water ice deep below their surfaces.

While most asteroids survived fairly unchanged from the earliest epochs of solar system history, others were heated and melted. The metal flecks sank to form iron cores (like nickel-iron meteorites), while lighter rocks floated upwards and flowed out across their surfaces, like lavas do on Earth. Vesta, one of the largest asteroids, appears to be covered with lava; certain lava-like meteorites probably came from Vesta. Metallic asteroids are rare but are readily recognized by Earth-based **radar** observations because metal reflects radar pulses well.

New techniques in astronomy, such as radar delay–Doppler mapping and adaptive optics (which unblurs the twinkling of visible light induced by Earth's atmosphere), have revealed a variety of asteroid shapes and configurations. One asteroid, named Antiope, is a double body: Two separate bodies, each 80 kilometers (50 miles) across and separated by 160 kilometers (100 miles), orbit about each other every sixteen hours. Other asteroids have satellites (e.g., moonlets) and still others have very odd shapes (e.g., dumbbells).

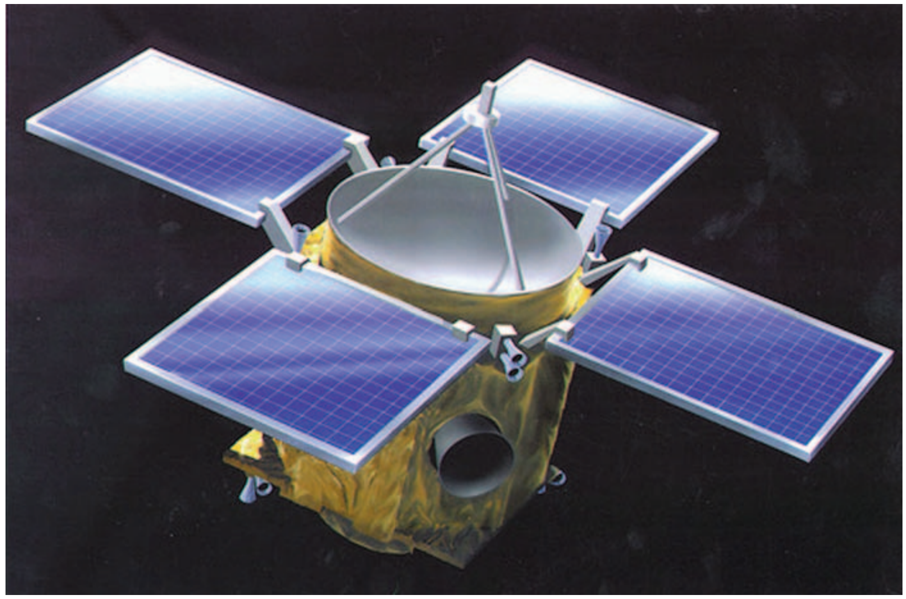


The surface of the asteroid Eros looks similar to a desert on Earth. In reality, the environment of an asteroid is highly dissimilar to Earth's, with low gravity, no atmosphere, and a rotation period of a little more than five-and-one-quarter hours.

Spacecraft Studies of Asteroids

The best (though most expensive) way to study an asteroid, of course, is to send a spacecraft. Three main-belt asteroids—Gaspra, Ida, and Mathilde—were visited in the 1990s by spacecraft en route to other targets. But even during the few minutes available for close-up observations during such high-speed encounters, scientists obtained images a hundred times sharper than the best possible images from Earth.

The most thorough study of an asteroid was of Eros by the Near Earth Asteroid Rendezvous spacecraft (which was renamed NEAR Shoemaker, after American astronomer Eugene Shoemaker, who first thought of the enterprise). Eros is a 34-kilometer-long (21-mile-long), Earth-approaching asteroid. NEAR Shoemaker orbited Eros until February 12, 2001, when it



The Near Earth Asteroid Rendezvous (NEAR) spacecraft, renamed NEAR Shoemaker after scientist Eugene Shoemaker, was the first of NASA's Discovery Program spacecrafts, providing small-scale, low-cost planetary missions.

was landed on the asteroid's surface. Its instruments were designed specifically for asteroid studies. It revealed Eros to be an oddly shaped, heavily cratered object, with ridges and grooves, and covered by a million boulders, each larger than a house. Eros is made of minerals much like the ordinary **chondrite meteorites**.

chondrite meteorite a type of meteorite that contains spherical clumps of loosely consolidated minerals

Near Earth Asteroids

A few asteroids escape from the main belt through Kirkwood gaps and move around the Sun on elongated orbits that can cross the orbits of Mars and Earth. If an asteroid comes within 0.3 AU of Earth, it is called a near Earth asteroid (NEA). More than half of the estimated 1,000 NEAs larger than 1 kilometer (0.6 mile) in diameter have been discovered. Orbits of NEAs are not stable, and within a few million years they collide with the Sun, crash into a planet, or are ejected from the solar system.

The Threat of Impacts. If a 2-kilometer (1.2-mile) NEA struck Earth, it would explode as 100,000 megatons of TNT, more than the world's nuclear weapons arsenal. It would contaminate the **stratosphere** with so much Sun-darkening dust that humans would lose an entire growing season worldwide, resulting in mass starvation and threatening civilization as we know it. Such a collision happens about once every million years, so there is one chance in 10,000 of one occurring during the twenty-first century. A 10- or 15-kilometer (6- or 9-mile) asteroid, like the one that caused the extinction of the dinosaurs 65 million years ago, hits every 50 or 100 million years with a force of 100 million megatons.

stratosphere a middle portion of Earth's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

Though the chances of dying by asteroid impact are similar to the chances of dying in an air crash, society has done little to address the impact hazard. Modest telescopic searches for threatening objects are underway in several countries. Given months to a few years warning, ground zero could be evacuated and food could be saved to endure an **impact winter**. If given many years, or decades, of warning, high-tech space missions could

impact winter the period following a large asteroidal or cometary impact when the Sun is dimmed by stratospheric dust and the climate becomes cold worldwide be launched in an attempt to study and then divert the oncoming body. SEE ALSO Asteroid Mining (volume 4); Impacts (volume 4); Close Encounters (volume 2); Galilei, Galileo (volume 2); Meteorites (volume 2); Planetesimals (volume 2); Shoemaker, Eugene (volume 2); Small Bodies (volume 2).

Clark R. Chapman

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Astrobiology *See Astrobiology (Volume 4).*

Astronomer

An astronomer is an individual who studies the universe primarily using telescopes. Astronomers rely on both observations of celestial objects, including planets, stars, and galaxies, and physical theories to better understand how these objects formed and work. Although professional astronomers conduct most astronomy research today, amateur sky watchers continue to play a key role.

Astronomy has been practiced since the beginning of recorded history. Many ancient civilizations employed people with some knowledge of the night sky and the motions of the Sun and Moon, although in many cases the identities of these ancient astronomers have long since been lost. At that time the work of astronomers had both practical importance, in the form of keeping track of days, seasons, and years, as well as religious implications. Astronomers did not emerge as true scientists until the Renaissance, when new observations and theories by astronomers such as Nicholas Copernicus (1473–1543) of Poland and Galileo Galilei (1564–1642) of Italy challenged the beliefs of the church. Since then astronomers have gradually emerged as scientists in the same class as physicists and chemists, employed primarily by universities and government research institutions.

Two Types of Astronomers

In the early twenty-first century, astronomers can be grouped into two different types, observational and theoretical. Observational astronomers use telescopes, on Earth and in space, to study objects ranging from planets and moons to distant galaxies. They analyze images, spectra, and other data in an effort to gain new knowledge about the objects under examination.

Astronomers use many different tools, including telescopes, satellites, computers, and radio telescope dishes, to gather and study information on the universe.

Theoretical astronomers, on the other hand, may never venture near a telescope. They work with computers, or even just pencil and paper, to develop models and theories to explain astronomical phenomena. In many respects observational astronomers are closer to the classical image of an astronomer, whereas theoretical astronomers are more strongly rooted in the worlds of physics and mathematics. The two groups do work closely together: Observational astronomers provide data to help theoretical astronomers develop and refine models, and in turn seek observational evidence for the theoreticians' work.

The Difference Between Astronomy and Astrology

Astronomers are often confused with astrologers, although the two are very different. Astrologers attempt to divine information about the future through the locations of the Sun and planets in the sky. Astrology is opposed by nearly all astronomers, who not only reject the notion that the positions of celestial objects govern the future but also note that many of the data and definitions used by astrologers are inaccurate. Astronomy and astrology, however, were once more closely tied together: In medieval times, many astronomers relied on astrology as a primary means of making a living.

Not all astronomers are paid to do their work. There are a large number of amateur astronomers who pursue astronomy as a hobby rather than as a full-time job. They play a useful role in astronomical research, because they can observe the full sky far better than professional astronomers, who focus on small regions of the sky at a particular time. Amateur astronomers have made many asteroid, comet, and **supernova** discoveries. Automated sky surveys by professional astronomers, though, have began to make more of the discoveries that were once made almost exclusively by amateur astronomers. SEE ALSO Astronomy, History of (volume 2); Astronomy, Kinds of (volume 2); Careers in Astronomy (volume 2).

supernova an explosion ending the life of a massive star

Jeff Foust

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Astronomy, History of

In ancient times, people watched the sky and used its changing patterns throughout the year to regulate their planting and hunting. The Sun seemed to move against the background of stars. A few bright objects (Mercury, Venus, Mars, Jupiter, and Saturn) wandered against the same background. Greek philosopher Aristotle (384–322 B.C.E.) tried to make sense of all this by proposing a system of the universe with Earth in the center (known as a geocentric system). Revolving around Earth were the Sun, the five known planets, and the Moon. This system satisfied the Greek desire for uniformity with its perfectly circular orbits as well as everyone's common sense of watching sunrise and sunset.

Greek astronomer and mathematician Ptolemy refined Aristotle's theory in 140 C.E. by adding more circles to obtain better predictions. For over a thousand years people used his scheme to predict the motions of the planets. Polish astronomer Nicholas Copernicus (1473–1543) was dissatisfied with its increasingly inaccurate predictions. He looked for a method that would be both accurate and mathematically simpler in structure. Although he did not achieve great accuracy, he was able to produce a beautiful scheme with the Sun in the center of the universe (known as a heliocentric system). His system improved on Ptolemy's plan by determining with fair accuracy the relative distance of all the planets from the Sun. However, it still used circles. The plan became a matter of religious controversy because some people did not want to displace humankind from the important spot as the center of the universe.

In 1609, German astronomer Johannes Kepler (1571–1630) showed with careful mathematical calculations that the orbits were not circles but ellipses. (An ellipse is a mathematically determined oval.) Also in 1609, Italian mathematician and astronomer Galileo Galilei (1564–1642) first used a telescope to observe celestial objects. He discovered moons orbiting Jupiter, phases of Venus, sunspots, and features on the Moon that made it seem more like a planet. None of these discoveries proved that the Copernican heliocentric theory was correct, but they offered evidence that Aristotle was wrong. For example, the phases of Venus indicated that Venus orbited the Sun (but did not prove that Earth did also). The discovery of sunspots and lunar surface features proved that the Sun and Moon were not perfect unblemished spheres. Galileo also did experiments to explore gravity and motion. English physicist and mathematician Isaac Newton (1642–1727) articulated the laws of gravity and motion. He also used a prism to split light into its component colors (spectroscopy).

In 1860 Italian astronomer Angelo Secchi (1818–1878) first classified stellar spectra. In the twentieth century, astronomers used spectra to find tem-

fusion releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

peratures and line-of-sight motions of stars and galaxies. Stellar temperature and distance, when combined with the theory of how stars are powered by **fusion**, provide the basis for the current theory of stellar evolution. American astronomer Edwin P. Hubble (1889–1953) discovered that galaxies are moving away from each other as the universe expands. These motions of galaxies and changes of their component stars and gas over time indicate the evolution of the universe. It has thus become clear that although we can map our location with respect to the galaxies, we live in the midst of an expanding universe for which no center can be measured. SEE ALSO Age of the Universe (volume 2); Cassini, Giovanni (volume 2); Copernicus, Nicholas (volume 2); Cosmology (volume 2); Einstein, Albert (volume 2); Exploration Programs (volume 2); Galaxies (volume 2); Galilei, Galileo (volume 2); Gravity (volume 2); Herschel Family (volume 2); Hubble Constant (volume 2); Hubble, Edwin P. (volume 2); Huygens, Christiaan (volume 2); Kepler, Johannes (volume 2); Kuiper, Gerard Peter (volume 2); Newton, Isaac (volume 2); Planetary Exploration, Future of (volume 2); Sagan, Carl (volume 2); Shapley, Harlow (volume 2); Shoemaker, Eugene (volume 2); Stars (volume 2); Tombaugh, Clyde (volume 2).

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Astronomy, Kinds of

wavelength the distance from crest to crest on a wave at an instant in time

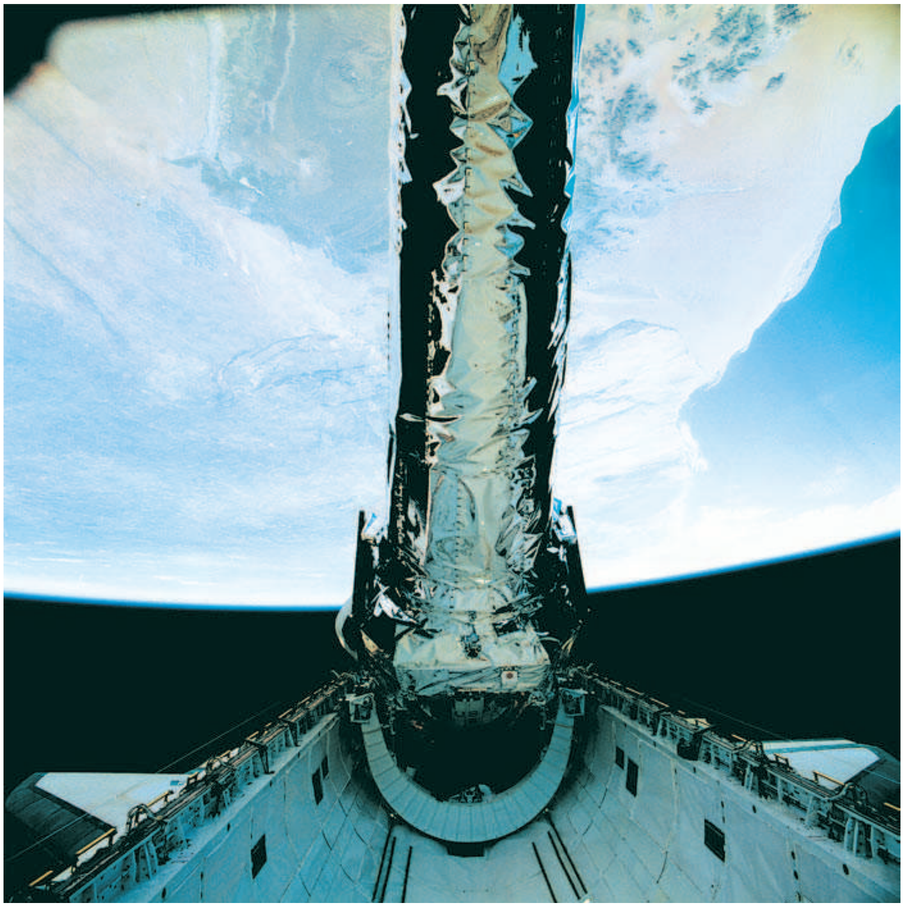
Astronomers study light, and almost everything we know about the universe has been figured out through the study of light gathered by telescopes on Earth, in Earth's atmosphere, and in space. This light comes in many different **wavelengths** (including visible colors), the sum of which comprises what is known as the electromagnetic spectrum. Unfortunately, Earth's atmosphere blocks almost all wavelengths in the electromagnetic spectrum. Only the visible and radio "windows" are accessible from the ground, and they thus have the longest observational "history." These early restrictions on the observational astronomer also gave rise to classifying "kinds" of astronomy based on their respective electromagnetic portion, such as the term "radio astronomy."

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

Over the past few decades, parts of the **infrared** and submillimeter have become accessible to astronomers from the ground, but the telescopes needed for such studies have to be placed in high-altitude locations (greater than 3,050 meters [10,000 feet]) or at the South Pole where water absorption is minimal. Other options have included balloon experiments, airborne telescopes, and short-lived rocket experiments.

X ray a form of high-energy radiation just beyond the ultraviolet portion of the spectrum

Presently, the field of astronomy is enriched immensely by the accessibility of several high-caliber airborne telescopes (e.g., Kuiper Airborne Observatory [KAO], Stratospheric Observatory For Infrared Astronomy [SOFIA]) and space telescopes, all of which are opening up other, previously blocked windows of the electromagnetic spectrum (such as gamma ray,



The Chandra X-Ray Observatory, pictured just prior to release from space shuttle Columbia's payload bay, has detected new classes of black holes and is giving astronomers new information about exploding stars.

X ray, **ultraviolet**, far infrared, millimeter, and microwave). Additionally, modern astronomers often need to piece together information from different parts of the electromagnetic spectrum to build up a picture of the physics/chemistry of their object(s) of interest. The table on page 12 summarizes some of the links between wavelength, objects/physics of interest, and current/planned observing platforms. It provides a flavor of how the field of astronomy today varies across wavelength, and hence, by the energy of the object sampled.

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

The field of astronomy is also quite vast in terms of the physical nature, location, and frequency of object types to study. The field can be broken down into four categories:

1. Solar and **extrasolar planets** and planet formation, star formation, and the **interstellar** medium;
2. Stars (including the Sun) and stellar evolution;
3. Galaxies (including the Milky Way) and stellar systems (clusters, superclusters, large scale structure, **dark matter**); and
4. Cosmology and fundamental physics.

extrasolar planets planets orbiting stars other than the Sun

interstellar between the stars

dark matter matter that interacts with ordinary matter by gravity but does not emit electromagnetic radiation; its composition is unknown

The Study of Planets, Star Formation, and the Interstellar Medium

One of the most important developments in the first category over the past few years has been the detection of several planets orbiting other stars along

Approximate Wavelengths (m)	Wavelengths Other Units	Photon Energies Greater Than	Frequency	Name for Spectral Brand	Produced by Temperatures in Region of (K)	Examples of Astrophysical Objects of Interest	Examples of Present/ Planned Telescopes to Use for Observations
10^{-13} 10^{-12} 10^{-11}		80.6MeV 80.6MeV 0.8MeV		Gamma-ray	10^8	Cosmic rays, gamma-ray bursters, nuclear processes	**Space only:** CGRO (1991–2000), INTEGRAL (2002–), GLAST (2005–)
10^{-10} 10^{-9}	1Å, 0.1nm 10Å, 1nm	80.6keV 8.06keV		Hard X-ray	10^7	Accretion disks in binaries, black holes, hot gas in galaxy clusters, Seyfert galaxies	**Space only:** ROSAT (1990–1999), ASCA (1993–), Chandra (1999–), XMM (2000–)
10^{-8}	100Å, 10nm	0.806keV		Soft X-ray	10^6	Supernovae remnants, neutron stars, X-ray stars, superbubbles	
10^{-7}	1000Å, 100nm	80eV		XUV/EUV Far UV	10^5	White dwarfs, flare stars, O stars, plasmas	**Space only:** EUVE (1992–), FUSE (1999–)
2×10^{-7}	200nm			Ultraviolet	10^5	Hot/young stars, Orion-like star nurseries, interstellar gas, helium from the big bang, solar corona, Ly alpha forest sources	**Space only:** HST (1990–), Astro-½ (1990, 1995), SOHO (1996–)
4×10^{-7}	400nm			Violet Visible	10^4	B stars, spiral galaxies, nebulae, Cepheids, QSOs	**Ground:** Keck, Gemini (1999–), Magellan (1999–), Subaru (1999–) VLT (1999–), MMT (2000–),
7×10^{-7}	700nm			Red	10^4	K, M stars, globular clusters, galaxy mass	**Space:** HST
$8–50 \times 10^{-7}$	0.8-5µm			Near-infrared	10^3	Circumstellar dust shells comets, asteroids, high z galaxies, brown dwarfs	**Ground:** CHFT, CTIO, IRTF, Keck Magellan, Subaru, UKIRT, VLT **Space:** ISO (1995–98), SIRTF (2002–)
$5–30 \times 10^{-6}$	5–30µm			Mid–infrared		Cool interstellar dust, PAHs, organic molecules, planetary nebulae, molecular hydrogen	**Ground:** IR optimized telescopes: IRTF, UKIRT, Gemini **Airborne:** SOFIA (2005–) **Space:** ISO (1995–1998), SIRTF (2002–)
$3–20 \times 10^{-5}$	30–200µm			Far-infrared		Ultraluminous/starburst galaxies, debris disks, Kuiper Belt Objects	**Airborne:** SOFIA **Space:** ISO, SIRTF
$3.5–10 \times 10^{-4}$	350mm–1mm			Sub-millimeter	100	High z galaxies/proto-galaxies; molecular clouds; interstellar dust	**Ground:** HHT, JCMT, SMA (1999–) **Space:** SWAS (1998–), FIRST (2008–)
10^{-3}	1 mm		300,000MHz, 300GHz	Millimeter		Molecules in dark dense interstellar clouds (CO)	**Gound:** IRAM, ALMA
10^{-2}	1 cm		30,000MHz, 30GHz	Microwave	10	Cosmic microwave background	**Space:** COBE (1989–), MAP (2001–)
10^{-1}	10cm		3000MHz, 3GHz		1	Galaxy studies, Hydrogen clouds (21cm), masers	**Ground:** Arecibo, VLA, VLBA, MERLIN **Space:** VSOP (1997–)
1	1 m		300MHz	Radio	<1	Quasars, radio galaxies, hot gasses in nebulae	
10	10 m		30MHz			Synchroton radiation (electronics spiraling in magnetic fields) from supernovae remnants, magnetic lobes of radio galaxies	
10^2	100m		3MHz				
10^3	1 km			Long wave		No data yet. We could explore cosmic ray origins, pulsars, super-novae remnants, and look for coherent emission.	No missions planned, space only due to opaqueness of Earth's ionosphere. Lunar telescope(s) perhaps.
10^4	10km and greater		<30kHz	Very long wave/very low frequency			

SOURCE: Different "kinds" of astronomy separated by wavelength. Adapted and expanded from J. K. Davies, *Astronomy from Space*, 1997, Table 1.1, p.2.

with the detections, through deep infrared sky surveys, of substellar objects (**brown dwarfs**), whose spectral characteristics have been found to be similar to that of giant planets. Additionally, through superb Hubble Space Telescope (HST) imaging with its infrared camera and through infrared instruments on large ground-based telescopes, astronomers have started to directly observe the protostellar disks out of which planets are forming.

brown dwarfs star-like objects less massive than 0.08 times the mass of the Sun, which cannot undergo thermonuclear process to generate their own luminosity

Astronomers have learned that the formation of stars and protostellar disks start in the interstellar medium, the vast "vacuum" of gas and dust between the stars, but astronomers are only just learning what the structure of the interstellar medium really is and how it affects and is affected by stellar birth (dust-enshrouded stars) and death (planetary nebulae and **supernovae**). Another step forward is to understand star formation in other galaxies, for astronomers readily see active star formation in the arms of spiral galaxies and in the collisions of galaxies.

supernova an explosion ending the life of a massive star

The Study of Stars and Stellar Evolution

The study of stars and their evolution is perhaps one of the oldest subfields of astronomy, and has benefited greatly from observational evidence dating back over hundreds of years. This is the core of astronomy because stars are truly the fundamental blocks of the universe, creating and destroying chemical elements, acting as light posts in galaxies, and giving insights into understanding mysterious phenomena, such as **black holes** and gamma-ray bursts. Understanding such exotic and high-energy events is critical to the advancement of astronomy and fundamental physics, where such "events" occur in conditions impossible to create on Earth. Astronomers are even continuing to learn new things about the nearest star, the Sun, through, for example, recent amazing images (e.g., solar storm activity) from the Solar and Heliospheric Observatory (SOHO) satellite.

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

The Study of Galaxies and Stellar Systems

Just as stars are the building blocks of galaxies, galaxies are the building blocks of the universe. The study of their types, sizes, distribution, and interactions with neighbors is essential to understanding the nature and future of the universe. The study of the earliest galaxies (galaxy "seeds") is the main motivating factor behind building larger ground-based telescopes and more sensitive infrared space telescopes, such as the Space InfraRed Telescope Facility (SIRTF) and the **Next Generation Space Telescope** (NGST). Astronomers know from the deepest HST images that the early universe was composed of many irregular, active, star-formation-rich galaxies. Astronomers do not know, however, how such a chaotic early universe evolved to what is seen in our local group, whose component galaxies are quite different.

Next Generation Space Telescope the telescope scheduled to be launched in 2009 that will replace the Hubble Space Telescope

Among the many mysteries in the universe is the dark matter in galaxies and clusters. We know little about its amount (speculated to be roughly 10 to 100 times greater than the observed mass), structure, location, and makeup, despite evidence from beautiful HST pictures of **gravitational lenses**, and observations of hot gases in galaxy clusters measured by sensitive X-ray telescopes (e.g., German Röntgensatellit (ROSAT), Japanese Advanced Satellite for Cosmology and Astrophysics (ASCA), American Chandra).

gravitational lenses two or more images of a distant object formed by the bending of light around an intervening massive object

quasars luminous objects that appear starlike but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

Another very active field is the study of elusive **quasars**, observed out to a distance when the universe was less than 10 percent of its present age. Recent far infrared and X-ray data have revealed a large population of these objects, indicating that many of them might be heavily obscured by dust and therefore not seen by earlier visible light surveys. Astronomers know very little about the power mechanisms of these objects, and this field is a very active area for today's radio, X-ray, and gamma-ray astronomers.

The Study of Cosmology and Fundamental Physics

The area of cosmology and fundamental physics is perhaps the most elusive and yet also the most important field in astronomy because it encompasses the other three categories. Cosmology literally means "the study of the beginning of the universe." Cosmologists, however, strive to answer questions not only about the universe's origin but also about its evolution, contents, and future.

cosmic microwave background ubiquitous, diffuse, uniform, thermal radiation created during the earliest hot phases of the universe

many-bodied problem in celestial mechanics, the problem of finding solutions to the equations for more than two orbiting bodies

It is now widely believed that the universe started with a "big bang," with the most conclusive evidence being precise measurements of variations in the big bang signature 2.7K **cosmic microwave background** by the Cosmic Background Explorer satellite in 1997. Other recent advances in this subfield have come through all-sky infrared surveys, which have mapped out the distribution of galaxies across the sky; additional observational evidence that has led to more accurate estimates of the rate of expansion of the universe and its deceleration parameter; and increased computing power for numerical simulations that attempt to solve the ever-present **many-bodied problem**.

spectrometer an instrument with a scale for measuring the wavelength of light

Astronomers can comprehend the universe only through what they can see (limited by the sensitivities of the instruments used), what they can infer from observational data and numerical simulations, and what is supported by theory. As time has progressed, so too has the toolkit of the astronomer, from easier access to satellites, large ground-based telescopes, arrays of telescopes around the world working as one, increased computing power, and more sensitive cameras and **spectrometers**. As long as there is a way to improve detection techniques and strategies, astronomers will never run out of new discoveries or rediscoveries among the many "kinds" of astronomy. SEE ALSO Hubble Space Telescope (volume 2); Observatories, Ground (volume 2); Observatories, Space-Based (volume 2).

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Black Holes

B

Black holes are objects for which the gravitational attraction is so strong that nothing, not even light, can escape from it. They exist in the universe in large numbers.

Albert Einstein's theory of **general relativity** explains the properties of black holes.✶ The material inside a black hole is concentrated into a singularity: a single point of infinitely high density where space and time are infinitely distorted. Distant objects can escape from a black hole's gravitational pull, but objects inside the so-called **event horizon** inevitably fall toward the center (such objects would have to move faster than light to escape, which is impossible according to the laws of physics). The size of the event horizon and the distortions of the space and time surrounding it are determined by the mass and spin (rate of rotation) of the black hole. Space and time distortions cause unusual effects; for example, a clock falling into a black hole will be perceived by a distant observer to become redder and to run slower.

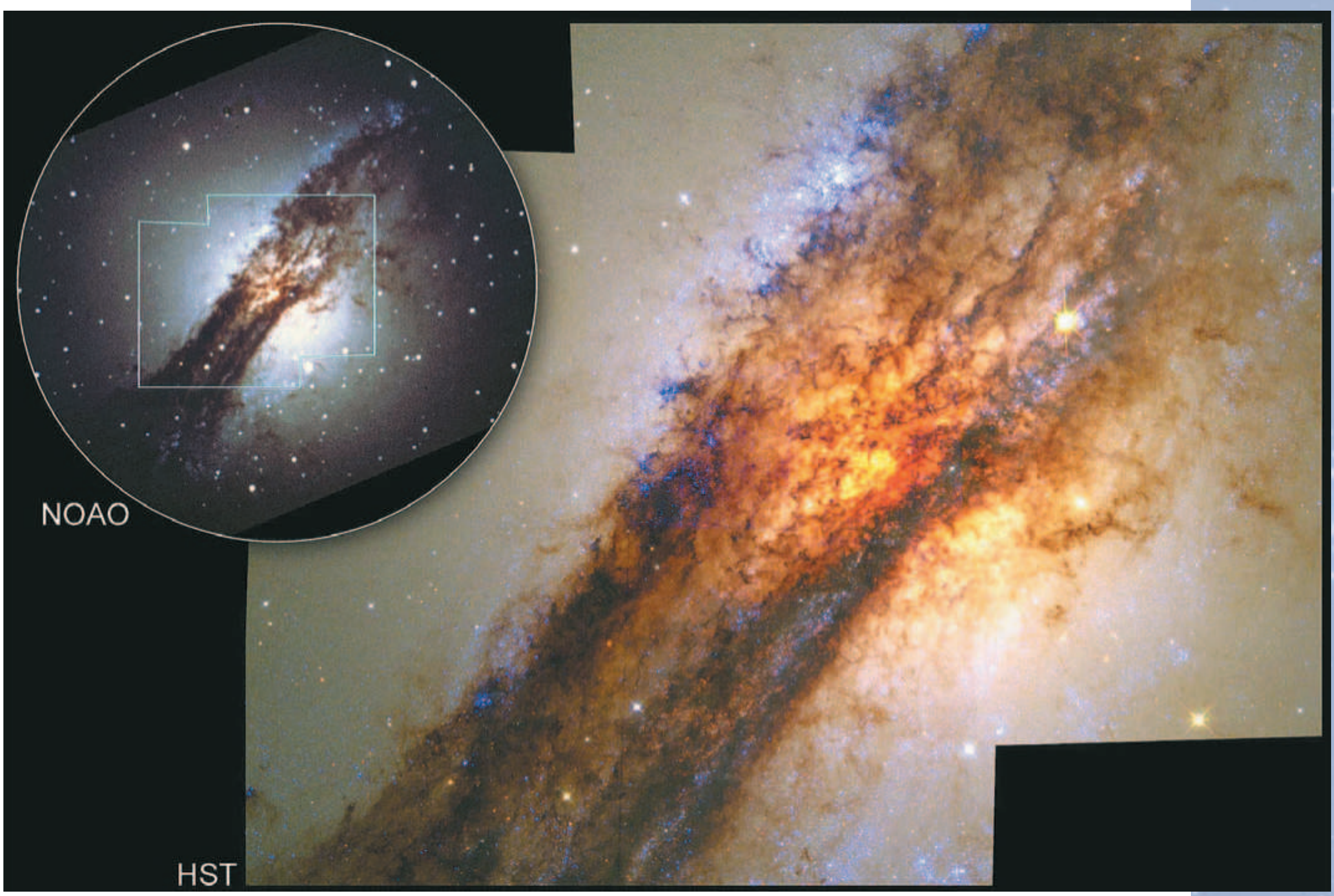
Two types of black holes are found in the universe: stellar-mass black holes and supermassive black holes. They are characterized by different masses and formation mechanisms.

A stellar-mass black hole forms when a heavy star collapses under its own weight in a supernova explosion. This happens after the nuclear fuel,

general relativity a scientific theory first described by Albert Einstein showing the relationship between gravity and acceleration

✶**Einstein was a renowned theoretical physicist, whose theory of special relativity produced what is arguably the most well-known equation in science: $E=mc^2$.**

event horizon the imaginary spherical shell surrounding a black hole that marks the boundary where no light or any other information can escape



Through the Hubble Space Telescope, scientists were able to observe a massive black hole hidden at the center of a giant galaxy.

which makes the star shine for millions of years, is exhausted. The resulting black hole is a little heavier than the Sun and has an event horizon a few miles across (for comparison, to turn Earth into a black hole it would have to be squeezed into the size of a marble). The existence of such black holes has been inferred in cases where the black hole pulls gas of a companion star that orbits around it. The gas heats up as it falls towards the black hole and then produces **X rays** that can be observed with Earth-orbiting satellites.

X rays a form of high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

Supermassive black holes are found in the centers of galaxies that contain billions of stars. They may exist in most galaxies and probably formed at the same time as the galaxies themselves. They are millions or billions times as heavy as the Sun, as determined from the motions of stars and gas surrounding them. Spectacular activity can occur when gas falls onto the black hole (as observed in a few percent of all galaxies). Material is ejected in jets that emit radio waves, and the heated gas produces X-ray emission. Observations of such X rays may soon provide insight into the spin of black holes.

There are enough black holes in the universe that there should occasionally be collisions between them. Such violent events send ripples through the **space-time** fabric of the universe. Scientists are hoping to soon detect such "gravitational waves" for the first time.

space-time in relativity, the four-dimensional space through which objects move and in which events happen

English physicist Steven Hawking showed in 1974 that every black hole spontaneously and continuously loses a tiny fraction of its mass because of radiation. This Hawking radiation, however, is negligible for the known black holes in the universe and will not be detectable in the foreseeable future. SEE ALSO Einstein, Albert (Volume 2); Gravity (Volume 2); Stars (Volume 2); Supernova (Volume 2).

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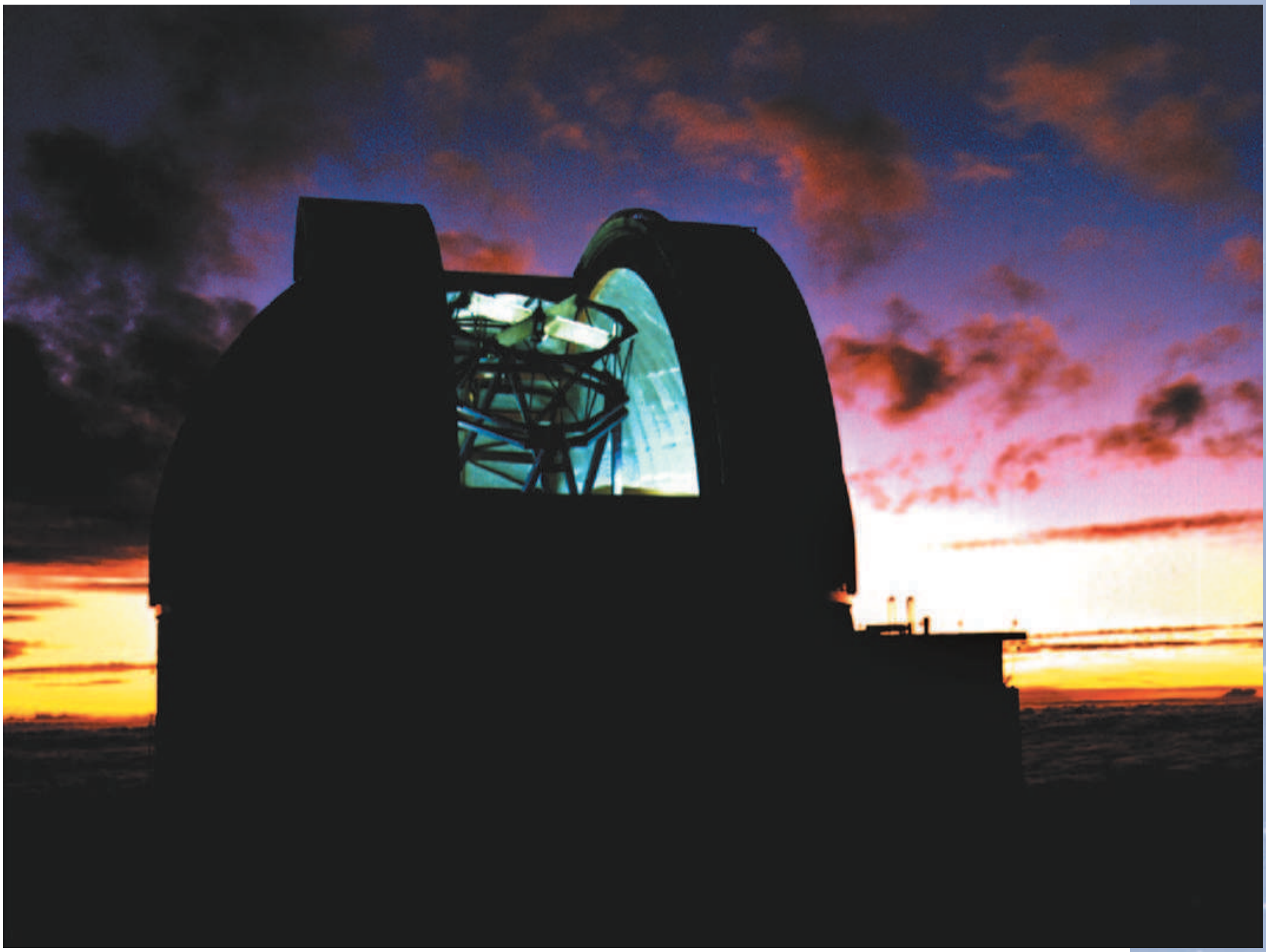
Careers in Astronomy

During just the last few years of the twentieth century, astronomers began to find planets orbiting other stars. They also made detailed measurements of the remnant radiation left over from the **Big Bang** and identified the first appearance of structure in the universe, the structure that eventually led to the formation of stars and galaxies. Some astronomers even found tantalizing evidence that suggests that the expansion of the universe may be speeding up, perhaps because of previously unrecognized properties of space itself. These important findings and many others lead to a particularly exciting time to consider a career in astronomy or space science.

Big Bang name given by astronomers to the event marking the beginning of the universe, when all matter and energy came into being

When considering such a career it is important to realize that nowadays most astronomy is *not* classical astronomy—observing or photographing astronomical objects. Instead it involves the use of physics, mathematics, or geology to understand these objects. Many "astronomy" departments at col-



The open dome of the United Kingdom Infrared Telescope. Internships at universities and national observatories are invaluable for individuals studying for a career in astronomy.

leges and universities are, in fact, called departments of astrophysics or planetary science. A significant fraction of the Ph.D. candidates in astrophysics hold an undergraduate degree in physics or mathematics. Many Ph.D. candidates in physics departments choose thesis topics that involve astrophysics, because some of the most interesting topics in modern physics are topics in this field. In this article, "astronomy" should be understood to encompass astrophysics or one of the other fields mentioned above.

Education and Training

Students interested in a career in astronomy must be prepared to work hard for a number of years during their training. The average Ph.D. takes approximately seven years to earn, and a Ph.D. is required for those interested in doing research. During their education, students pursuing doctoral degrees in astronomy take approximately twenty physics courses and a similar number of courses in mathematics. Those who enjoy science and problem solving will enjoy much of this, although it is challenging work. As early as possible, it is important for students to gain research experience. Most scientists find research much more interesting than class work. Nowadays many national observatories and universities offer research experience for undergraduates, an opportunity that should be taken advantage of when one is still in college. This kind of "internship" is the best way for students to determine whether they will really enjoy a career in astronomy.

Those aiming to become faculty members will probably hold one or more two- to three-year postdoctoral positions before they can hope to earn a tenure-track appointment. Be forewarned that less than half of those who seek a tenured faculty position actually earn one. Nevertheless, the problem-solving and analytical skills learned during training for an astronomy Ph.D. are good preparation for a number of possible jobs, not just as a professor of astronomy. Indeed, people with doctorates in astronomy have applied their problem-solving and computer skills in a variety of jobs, including computer consulting and business. Those who prepare for a career in astronomy with a flexible attitude about the job that they will eventually take are less likely to be disappointed than those who have very fixed career goals.

Where Astronomers Work

The largest employers of astronomers are colleges, universities, and the government. Large government employers included the National Aeronautics and Space Administration (NASA) and the national observatories (such as the National Optical Astronomy Observatories, with branches in Arizona, New Mexico, and Chile; the National Radio Astronomy Observatory; and the Space Telescope Science Institute). With the proliferation of national facilities and the communications network provided by the Internet, it is possible to do first-rate astronomy work at many universities and colleges, even some of the smaller ones. Many of these schools emphasize the quality of their teachers, and those interested in being hired by such a school should acquire good communications skills as well as scientific and technical training.

More and more astronomy is being done using observations made from space missions, and NASA is playing an increasingly large role in astronomy. Highlights of planned NASA missions include: the exploration of Saturn and Mars; the use of large telescopes to observe the **infrared** from space and from a 747 aircraft; and the development of a number of **interferometers** that will search for planets orbiting other stars and will eventually produce images of those planets. These kinds of missions are always done in large teams, so good teamwork and communications skills as well as good scientific and technical skills are desirable when working for NASA. For those interested in engineering—in building and testing instruments—there are also many interesting opportunities working on space missions such as these. As the equipment used in astronomy becomes more complex, the field will require more and more people skilled in engineering, interferometry, and similar techniques. It is possible that there could be a shortage of people with these skills who want to work in astronomy and space science.

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

interferometers devices that use two or more telescopes to observe the same object at the same time in the same wavelength to increase angular resolution

Another aspect of astronomy is closely related to mathematics and computer science. Much of the theoretical work in astronomy now involves sophisticated modeling using most powerful computers. Students interested in computer-based analysis might consider applying their skills to astronomy. Theoretical astronomers build computer models of the Sun and stars, of supernovas, of high-temperature explosions that produce **X rays**, of in-

X rays a form of high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum teracting galaxies, and even of the formation of the first structure in the entire universe. Many current and planned investigations, such as the Sloan Digital Sky Survey, will observe and record hundreds of millions of objects. Astronomers are just beginning to plan for a National Virtual Observatory, which would develop new ways to analyze the large data sets that will soon be gathered.

Career Options for Those with Bachelor's and Master's Degrees

Career options for those with a bachelor's or a master's degree in astronomy are more limited than individuals who have a doctoral degree. All of the NASA missions and some of the observatories described in this entry hire research assistants or data assistants to help with operations and data analysis. People in such positions may work on very interesting science but they do not usually have the opportunity to choose their own projects or areas of investigation.

Because astronomy is such a popular subject, there are a number of opportunities for presenting astronomy to the public. Planetariums hire astronomers to work as educators, and most NASA missions hire people to provide educational services and public outreach. The standards for these positions are highly variable, and they often do not require a Ph.D.

One of the most important jobs available to someone with training in astronomy is teaching physics (and sometimes astronomy) at the high school level. Considerably less than half the people who teach physics in high school have been trained in the field, and this is one of the contributing factors to the poor science knowledge of American students. Anyone who pursues the astronomy studies described above, even through the first year or two of graduate school, would have more physics background than the typical high school physics teacher, and this could provide the background needed for teaching.

Opportunities for Women and Minorities

It is important to note that opportunities for women in astronomy have been increasing and may continue to do so. Approximately 25 percent of the Ph.Ds now granted in astronomy go to women. This is twice the percentage of Ph.Ds granted to women in physics. Studies also show, however, that women continue to drop out at higher rates than men at each career step. One reason for this at the beginning of a career is that it is harder for women to find role models, mentoring, and encouragement in a field where most of the professors are male. It is therefore very important for women interested in a career in astronomy to make contact with a woman already in the field and ask for some guidance. Organizations such as the American Astronomical Society can provide further information.

The number of minority students in astronomy is currently very small. Out of the total of 150 astronomy Ph.Ds that are awarded in United States annually, only a very small percentage of these are received by African-American and Hispanic students. Students with a minority background who are interested in the exciting field of astronomy would also profit by finding a mentor. In fact, most successful scientists, no matter what their background, took advantage of guidance or mentoring from someone in the field during their training. SEE ALSO Astronomer (volume 2); Astronomy, History of (volume 2); Astronomy, Kinds of (volume 2); Galilei, Galileo (volume 2); Hubble Space Telescope (volume 2); Observatories, Ground-Based (volume 2); Observatories, Space-Based (volume 2).

Douglas Duncan

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Careers in Space Science

Considering possible career options in space science can be as full of variety and inviting choices as selecting from an elegant buffet or wandering through the stalls of an exotic overseas bazaar. Space science now encompasses practically all areas of science, and space research draws on an even broader collection of skills and specialties beyond the pure sciences.

One way to think about careers in space science is to notice that there are two main areas. First, there are specialties in which scientists place their tools in space so that they can see aspects of nature that cannot be examined from the ground. These approaches, which might be called "science *from* space," include research in astronomy and research that looks back at Earth from space. In the second category are researchers who take advantage of unique aspects of operating in an orbital laboratory or on another planet to do experiments or exploration that would not be possible otherwise. They conduct "science *in* space" by making space, itself, their laboratory.

Science from Space

Astronomers build or use telescopes that are launched into space to study the universe by measuring the **infrared**, X-ray, and gamma-ray light that cannot be detected below Earth's atmosphere. They also make observations in the **visible spectrum** but with much greater clarity than astronomers often can from the ground. These space astronomy studies examine the Sun, nearby stars, more distant galaxies, and even objects at the very edges of the universe.

Science from space can involve looking in as well as looking out. Information about our own planet, Earth, can often be obtained best by getting a genuinely global view from space. Such research includes studies in climatology, atmospheric science, **meteorology**, geology and geophysics, ecology, and oceanography, just to name a few. Looking at Earth from space is a good example of how space science can span a full range of goals. Those goals can include exploring very basic questions about how nature operates, gathering information that has important and immediate value to help so-

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

visible spectrum the part of the electromagnetic spectrum with wavelengths between 400 nanometers and 700 nanometers; the part of the electromagnetic spectrum to which human eyes are sensitive

meteorology the study of atmospheric phenomena or weather

Two astronomers review images of the collision between Comet Shoemaker-Levy 9 and Jupiter.

ciety deal with natural hazards, or the management of natural resources, agriculture, forestry, or environmental problems.

Science in Space

Science *in* space takes advantage of being in the immediate presence of the objects of study, or of some unique properties of spaceflight, such as the existence of very low gravity (so-called microgravity) or a nearly perfect **vacuum**. In the former case, space scientists study the properties of the space environment itself, including the hot gas that flows out from the Sun to fill the solar system and the high-energy atomic particles that create **radiation belts** around many planets. Those belts can pose a hazard to astronauts or to any robotic spacecraft that fly through them. Planetary scientists explore other objects in the own solar system. They use orbiting telescopes, spacecraft that are sent to orbit other planets, robots that land and move around on the surface of another planet, and spacecraft that retrieve samples of planetary material and bring them back to Earth for analysis. These scientists also study the natural satellites of other planets as well as asteroids and comets.

vacuum a space where air and all other molecules and atoms of matter have been removed

radiation belts two wide bands of charged particles trapped in a planet's magnetic field

The microgravity environment of spaceflight creates opportunities for in-space laboratories that span a wide range of scientific topics. These include biomedical studies of how weightlessness affects human performance and how to minimize those effects on astronauts. It also includes more basic studies in biology that examine the role of gravity in the development and functionality of plants and animals. Researchers in the physical sciences find space laboratories to be equally useful because they offer a unique setting for experiments in materials science, studies of combustion and the behavior of fluids, and a number of other areas of both basic and applied physics and chemistry.

Many areas of space science are now reaching across the traditional specialties of science and emerging as new multidisciplinary fields. Two notable examples are studies of global change and the field of astrobiology. In studying global change, scientists combine expertise from many Earth science specialties (e.g., oceanography, hydrology, atmospheric science, ecology) and use the vantage point of space to monitor how Earth is changing and to predict and understand the consequences of those changes. Astrobiology is a relatively new field in which researchers seek to understand how life formed in the universe and how it has evolved. Astrobiologists also want to discover whether there was or is now life beyond Earth, and to learn from those studies about the possibilities for life beyond Earth in the future. As a result of the breadth of such profound scientific questions, astrobiologists draw heavily on expertise in biology, chemistry, astronomy, and planetary science.

In all fields of space science, those who conduct research may find themselves involved in many phases of the work. That is, they may help design the experiments, the instruments, and even the spacecraft that carry them. They help build and test the instruments to be launched into space and then help operate them, and they are often involved in analyzing and interpreting the measurements that are returned to Earth. In a small number of cases a few lucky researchers get to go with their experiments into space as scientist astronauts.

Careers Outside Pure Science

Space science offers career opportunities that extend beyond pure scientific fields. Space science depends not only on scientists but also equally heavily on engineers, mathematicians, information technology experts, and other technical specialists who help make the research possible. In fact these members of a space research team often outnumber the scientists on the project. They work side by side with the scientists to build and operate experiments and to prepare data or samples that are returned from the experiments for analysis.

Finally, where do people in space science work? That is also a question with many answers. Most space scientists are on university staffs and faculties, but they also reside in industry laboratories, government laboratories such as the National Aeronautics and Space Administration's field centers, and in laboratories of nonprofit organizations. Regardless of where they work, people who earn their living in space science have a common bond. They share in the excitement and fascination that comes from pursuing some of the most challenging questions in contemporary science, and they know that they are helping to open new frontiers in exploration and to bring the benefits of science back to Earth. SEE ALSO Astrobiology (Volume 4); Environmental Changes (Volume 4); Life in the Universe, Search for (Volume 2); Microgravity (Volume 2).

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NASA Spacelink. "Careers." <http://spacelink.nasa.gov/Instructional.Materials/Curriculum.Support/Careers/>.

Cassini, Giovanni Domenico

Italian Astronomer
1625–1712

Born in Perinaldo, Italy, Giovanni✶ Domenico Cassini (1625–1712) was an astronomer best known for his discoveries connected with the planet Saturn. At the age of twenty-five, Cassini was named chair of astronomy at the University of Bologna and held that position for nineteen years. He determined the rotation rates of Jupiter in 1665, of Mars in 1666, and of Venus (erroneously) in 1667. In 1668, Cassini computed tables that predicted the motion of Jupiter's four known moons. This led directly to Danish astronomer Ole (or Olaus) Römer's determination of the speed of light in 1675.

✶**Giovanni Domenico Cassini is sometimes known as "Gian Cassini."**

In 1669, King Louis XIV of France invited Cassini to Paris to direct the city's observatory. At the Paris Observatory, Cassini, now using Jean Dominique as his first name, continued his astronomical observations, at times using the extremely long "aerial telescopes" developed by Dutch astronomer Christiaan Huygens.

In Paris, Cassini discovered the second satellite of Saturn, Iapetus, in 1671 and correctly explained its brightness variations. He found another satellite of Saturn, Rhea, in 1672. In 1675 Cassini observed a band on Saturn and found that its ring had a division, now named the Cassini Division. Cassini discovered two more of Saturn's satellites, Tethys and Dione, in 1684.

Among his other projects, Cassini used innovative methods to make the best measure—at the time—of the astronomical unit (the average distance between Earth and the Sun). Cassini also studied **atmospheric refraction** and conducted a **geodetic survey**.

atmospheric refraction the bending of sunlight or other light caused by the varying optical density of the atmosphere

geodetic survey determination of the exact position of points on Earth's surface and measurement of the size and shape of Earth and of Earth's gravitational and magnetic fields

Cassini is the namesake of a joint program of the National Aeronautics and Space Administration, the European Space Agency, and the Italian Space Agency to study the Saturn system beginning in 2004. SEE ALSO HUYGENS, CHRISTIAAN (VOLUME 2); JUPITER (VOLUME 2); SATURN (VOLUME 2); SMALL BODIES (VOLUME 2).

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Close Encounters

Most asteroids follow fairly regular paths in **orbits** between Mars and Jupiter. A small fraction, about one in a thousand, have evolved from their regular orbits by slow gravitational effects of the planets, mainly Jupiter, to

orbits the circular or elliptical paths of objects around a much larger object, governed by the gravitational field of the larger object

Cosmic impacts can cause major damage to Earth's surface and ecosystem. This meteorite crater is located near Winslow, Arizona.

elliptical having an oval shape

travel in more **elliptical** orbits that cross the paths of other planets, including Earth. The first of these discovered was Eros, found in 1898, which crosses the orbit of Mars but not Earth. The first space mission dedicated primarily to visiting an asteroid was the Near Earth Asteroid Rendezvous (NEAR) mission (later renamed NEAR Shoemaker in honor of American astronomer Eugene Shoemaker), which orbited Eros for a year in 2000–2001, before touching down on its surface on February 12, 2001.

Even in 1694, when Edmund Halley discovered that the orbit of the comet that bears his name crosses Earth's orbit, he suggested the possibility of a collision with Earth by a comet, and he rightly suggested that such an event would have a catastrophic effect on Earth and its inhabitants. In 1932, two more asteroids were discovered, named Amor and Apollo, which pass close enough to Earth to suggest the possibility of eventual collision with the planet.

astronomical units one AU is the average distance between Earth and the Sun (152 million kilometers [93 million miles])

Today scientists refer to asteroids that can come closer than 1.3 **astronomical units** (AU) to the Sun (0.3 AU to Earth) as near Earth asteroids (NEAs), or collectively along with comets that come that close, near Earth objects (NEOs). By January 2002, 1,682 NEAs had been discovered, 572 of which were estimated to be 1 kilometer (0.6 mile) or larger in diameter. Scientists estimate that the total number of NEAs larger than 1 kilometer in diameter is about 1,000, so somewhat more than half of them had been found by January 2002. The largest asteroid in an orbit actually crossing Earth's orbit is around 10 kilometers (6 miles) in diameter. Scientists do not believe that there are any undiscovered objects larger than 4 or 5 kilometers (2.5 or 3 miles) in diameter.

The Frequency and Energy of Impacts

Given that these cosmic bullets are flying around Earth, the expected frequency of impacts on Earth can be estimated. Any one NEA has a likelihood of hitting Earth in about 500 million years. Since there are about 1,000 NEAs larger than 1 kilometer, one impact about every 500,000 years can be expected. The energy of such an impact can also be estimated. A piece of rock 1 kilometer in diameter, traveling at 20 kilometers per second (12.4 miles per second) on impact, should release an energy equivalent to almost 100,000 megatons of TNT, or about the total energy of all the nuclear weapons in the world. Such a blast should make a crater nearly 20 kilometers (12.4 miles) in diameter.

Past Collisions

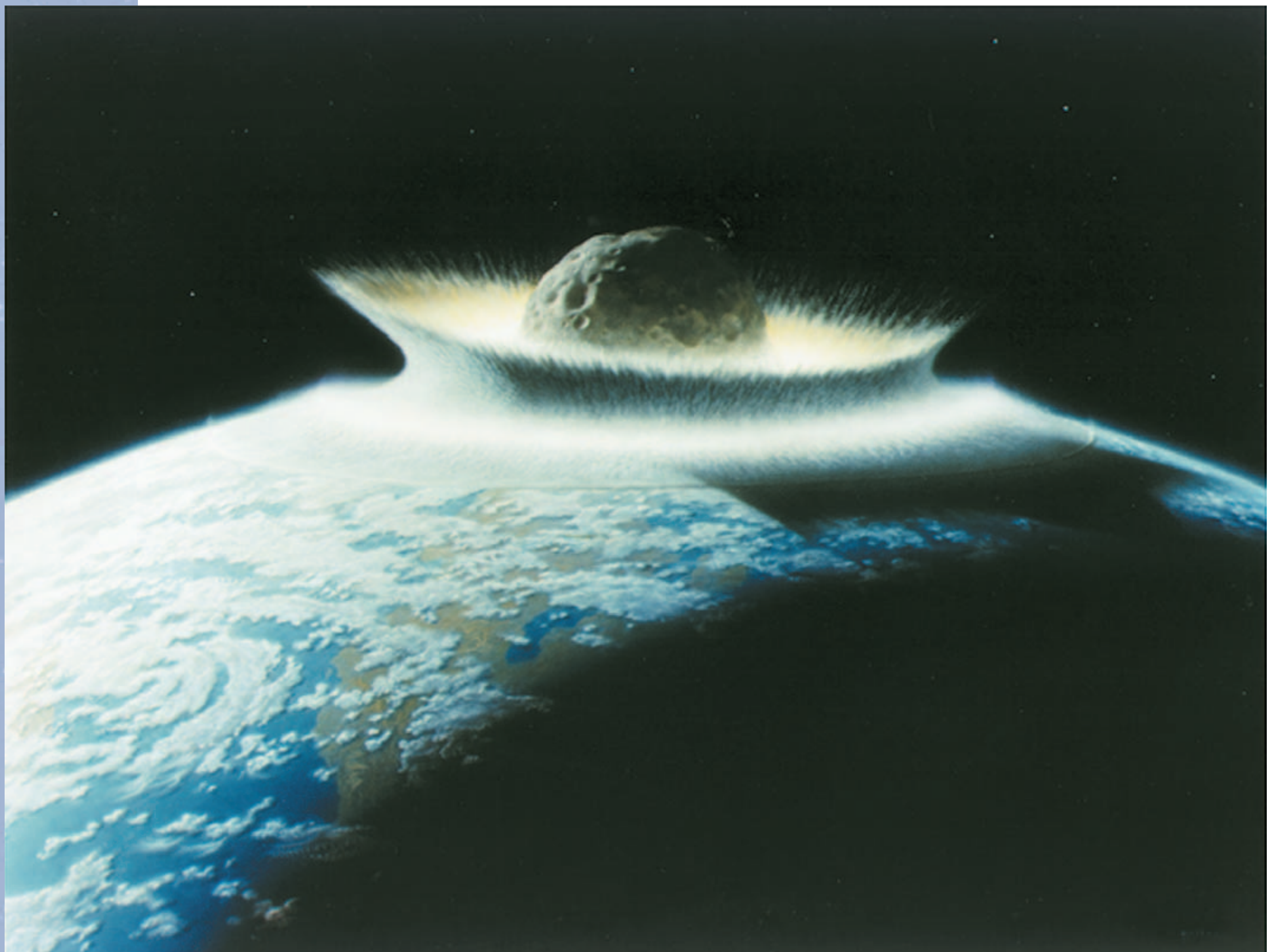
Evidence abounds of past collisions, on Earth as well as on the surfaces of almost all other solid-surface bodies in the solar system. Impact craters up to hundreds of kilometers across are clearly visible on the face of the Moon and have been found and counted on Mercury, Venus, Mars, planetary satellites, and even the asteroids themselves.

In 1980, the father and son team of Louis and Walter Alvarez, along with two other colleagues, offered a revolutionary explanation for the extinction of the dinosaurs, as well as most other species inhabiting Earth at that time (65 million years ago). They found the rare element iridium in the thin clay layer that caps the rocks of the Cretaceous era. The element was present in concentrations far too high for a terrestrial explanation, but just about right for the debris left from a cosmic impact by an asteroid or comet about 10 kilometers (6 miles) in diameter. This hypothesis, which was first met with widespread skepticism, has gained strength with many subsequent supporting discoveries, including the identification of the "smoking gun"—the remains of the crater at the tip of the Yucatan Peninsula in Mexico. Known as the Chicxulub Crater, it is buried in sediments and invisible from the surface, except for a ring of sinkholes outlining the original rim, approximately 200 kilometers (125 miles) in diameter. Impact cratering is now recognized as an important geological process, which can even affect the evolution of life on Earth.

Potential Effects of a Collision

The world received a "wake-up call" in July 1994 when the pieces of the comet Shoemaker-Levy 9 slammed into the planet Jupiter, leaving giant dark spots in the clouds, easily visible from Earth through a small telescope. Some of the spots were as large as the entire Earth. Based on these observations and computer models of the expected effects of a cosmic impact on Earth, it is estimated that an asteroid 1 to 2 kilometers (0.6 to 1.2 miles) in diameter would form an impact crater more than 20 kilometers (12.4 miles) in diameter. In addition, it would throw enough dust into the upper atmosphere to block out the Sun for about a year, producing a global "impact winter."

Such a climatic catastrophe could lead to global crop failures and the starvation of perhaps a quarter of the world's population. The individual numbers boggle the mind: more than a billion deaths, but only once in 500,000 years. Yet the quotient is quite understandable: an average of some thousands of deaths per year, or in the same range as the death toll from commercial airline accidents, floods, earthquakes, volcanic eruptions, and



Scientists estimate that an asteroid 1 to 2 kilometers in diameter hitting Earth's surface could create a crater about 20 kilometers in diameter. Such an impact could cause an "impact winter," with catastrophic results.

other such disasters that are taken very seriously. Because the frequency of occurrence is so low—indeed there has never been a catastrophic asteroid impact in recorded history—humans have paid less attention to this risk than to the others mentioned. But the consequences are as terrible as the intervals are long, so the importance is about the same as the other natural hazards, with one significant difference. This hazard alone (with the possible exception of a very massive volcanic eruption) has the potential to end human civilization globally.

Preparations for and Responses to Potential Collisions

What can, or should, be done? As a first step, it makes sense to simply look and find all the asteroids and Earth-approaching comets out there and see if one has our name on it. Beginning in the late 1990s, several governments and agencies embarked on what has been loosely called the Spaceguard Survey.✶ The goal of this survey is to find at least 90 percent of all NEAs larger than 1 kilometer (0.6 mile) in diameter, the lower size limit for objects that could cause a global catastrophe. By the year 2001, the project was about half complete, and it is likely to be finished by 2010. With continued effort, ever-smaller asteroids can be found and cataloged, providing assur-

✶The term 'Spaceguard Survey" is borrowed from Arthur C. Clarke's science fiction novel, *Rendezvous with Rama* (1973), detailing the story of a huge and mysterious object that appears in the solar system.

ance that nothing is coming Earth's way in the foreseeable future (i.e., about the next fifty years).

But if we find that something is coming, what can we do? With many years warning, only a small push of a few centimeters per second would divert an asteroid from a collision course to a near miss. Even without knowing quite how to do it, it is easy to estimate that the energy needed is within the range available from nuclear weapons, and the rocket technology to deliver a bomb to an asteroid is available. Whether such a system should be developed in advance of any specific threat is a more difficult question and one that will need to be carefully addressed by both scientists and policymakers. SEE ALSO Asteroids (Volume 2); Comets (Volume 2); Impacts (Volume 4).

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Comets

A bright comet is a spectacular astronomical event. Throughout history, comets have left a strong impression on those who have witnessed their appearances. The name comes from the Greek *kometes*, meaning "the long-haired one." Ancient Greeks thought comets to be atmospheric phenomena, part of the "imperfect" changeable Earth, not of the "perfect" immutable heavens. Today we know they are "icy conglomerates," as proposed in 1950 by Fred Whipple—that is, chunks of ice and dust left over from the formation of the solar system some 4.6 billion years ago.

Comets are among the most primitive bodies in the solar system. Because of their orbits and small sizes, comets have undergone relatively little processing, unlike larger bodies, such as the Moon and Earth, which have been modified considerably since they formed. The chemical composition of comets contains a wealth of information about their origin and evolution as well as the origin and evolution of the solar system. Hence, comets are often called cosmic fossils.

When a comet is far from the Sun, it is an inert icy body. As it approaches the Sun, heat causes ices in the nucleus to **sublimate**, creating a cloud of gas and dust known as the coma. Sunlight and **solar wind** will push the coma gas and dust away from the Sun creating two tails. The dust tail is generally curved and appears yellowish because the dust particles are scattering sunlight. The gas (or ion) tail is generally straight and it appears blue

sublimate to pass directly from a solid phase to a gas phase

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

Edmund Halley was an eighteenth-century British astronomer who first calculated the orbit of comets. The most famous comet, Halley, is named after him.

meteor the physical manifestation of a meteoroid interacting with Earth's atmosphere; this includes visible light and radio frequency generation, and an ionized trail from which radar signals can be reflected

astronomical units one AU is the average distance between Earth and the Sun (152 million kilometers [93 million miles])

ecliptic the plane of Earth's orbit

because its light is dominated by emission from carbon monoxide ions. The appearance of comets in photographs can give the erroneous impression that they streak through the night sky like a **meteor** or a shooting star. In fact, comets move slowly from night to night with respect to the stars and can sometimes be visible for many weeks, as was the case with comet Hale-Bopp in 1997 and with comet Halley during its 1985–1986 appearance.

Comet Halley is not the brightest comet, but it is the most famous, mainly because it is the brightest of the predictable comets. It was named after Edmund Halley, an eighteenth-century British astronomer who was the first to calculate the orbits of comets. Comet Halley's orbit has an average period of seventy-six years. Its closest approach to the Sun (perihelion) is between the orbits of Venus and Mercury (0.59 **astronomical units**), and its aphelion (farthest distance from the Sun) is at 35 AU, beyond Neptune's orbit. The orbit has an inclination of 162 degrees with respect to the **ecliptic**. This means that comet Halley orbits the Sun clockwise when seen from the north, whereas Earth orbits the Sun counterclockwise.

The study of comets is a very active field of science. In 1986 a flotilla of spacecraft were used to study comet Halley. In the first decade of the twenty-first century, several spacecraft are scheduled to be launched to encounter and study a number of comets. In addition to space-based studies, ground-based observations of comets have yielded a wealth of information.

The Comet's Nucleus

All of the activity in a comet originates in its nucleus, which is composed of roughly equal amounts of ices and dust. Water ice is the most abundant of the ices, comprising about 80 percent of the total. So far, only the nuclei of comets Halley and Borrelly have been imaged in detail. Comet Halley turned out to be larger, darker, and less spherical than expected by most astronomers. The images of comet Borrelly's nucleus obtained in September 2001 by NASA's Deep Space 1 spacecraft show considerable similarity with those of comet Halley. Halley's nucleus is peanut-shaped, approximately 18 kilometers (11 miles) long and 8 kilometers (5 miles) wide. The reflectivity (or albedo) is 4 percent, which is as dark as coal. The size, albedo, and approximate shape of several other cometary nuclei have been determined. Comet Halley's nucleus seems to be typical among comets with relatively short orbital periods, and there are much larger nuclei such as that of comet Hale-Bopp. So far, the cometary nuclei studied in detail appear to have most of their surface covered by an inert mantle or crust. The active (exposed ice) fraction of their surface is small; in comet Halley, this fraction is somewhere between 15 and 30 percent.

The development of a crust can suppress the activity of cometary nuclei and give them an asteroidal appearance. The best example to date is comet Wilson-Harrington, which was discovered in 1949 and was lost until it was rediscovered as an inert object and given the asteroid number 4015. The behavior of this object has added credence to the long-held expectation that some Earth-crossing asteroids are extinct or dormant comet nuclei.

The Composition of Comets

The composition of cometary nuclei is primarily inferred from studies of the coma components, namely gas, plasma (ions), and dust. So far, twenty-

Comet Hale-Bopp (seen in the center) was visible from Earth for several weeks in 1997. Comets travel at a relatively slow rate although they give the appearance of streaking through the sky.

four different molecules have been identified in comets, ten of which were discovered in comet Hale-Bopp. The molecules observed in comets and their relative abundances are very similar to those observed in dense **interstellar** molecular cloud cores, which is the environment where star formation occurs. Thus, it appears that comets underwent little processing in the **solar nebula** and they preserve a good record of its original composition.

interstellar between the stars

solar nebula the cloud of gas and dust out of which the solar system formed

Information on the composition of cometary dust particles was scarce before 1986. Studies of the dust in comet Halley and other comets confirmed that some of the grains are silicates, more specifically crystalline olivine $(Mg, Fe)_2 SiO_4$ and pyroxene $(Mg,Fe,Ca) SiO_3$. Another major component of the dust in comet Halley was organic dust. These small solid particles were discovered by the visiting spacecraft and were called "CHON" because they were composed almost exclusively of the elements carbon, hydrogen, oxygen, and nitrogen.

COMET-PLANET COLLISIONS

Many comets are in Earth-crossing orbits and collisions do occur between comets and planets. A spectacular example of such a collision was the impact of comet Shoemaker-Levy 9 with Jupiter in July 1994. It is now well established that an impact with an asteroid or comet created a large crater at the edge of the Yucatan Peninsula 65 million years ago. Known as the Chicxulub impact, this event almost certainly caused the extinction of the dinosaurs. Efforts are underway to study the population of potential hazards from both comets and asteroids in sufficient detail to predict and prevent future large impacts.

The Origins of Comets

Dutch astronomer Jan Hendrik Oort noted in 1950 that the source of new comets was a shell located between 20,000 and 100,000 AU from the Sun. The existence of the Oort cloud is now widely accepted. Astronomers believe that comets in the Oort cloud formed near Uranus and Neptune and were gravitationally scattered by these two planets into their current location. In addition to the Oort cloud, there is another reservoir that was proposed in 1951 by Dutch-born American astronomer Gerard Peter Kuiper as a ring of icy bodies beyond Pluto's orbit. This Kuiper belt is considered to be the main source of Jupiter-family comets, which are those with low-inclination and short-period orbits. SEE ALSO Close Encounters (volume 2); Comet Capture (volume 4); Impacts (volume 4); Kuiper Belt (volume 2); Kuiper, Gerard Peter (volume 2); Oort Cloud (volume 2).

Humberto Campins

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Copernicus, Nicholas

Polish Astronomer
1473–1543

Nicholas Copernicus was the first to argue the theory that the Sun, not Earth, is the center of the solar system.

Nicholas Copernicus was a Polish astronomer who changed humankind's view of the universe. Greek astronomers, particularly Ptolemy, had argued that Earth was the center of the universe with the Sun, Moon, planets, and stars orbiting around it. This geocentric (Earth-centered) model, however, could not easily explain retrograde motion, the apparent backwards movement that planets exhibit at some points in their paths across the sky. Ptolemy and others had proposed a complicated system of superimposed circles to explain retrograde motion under the geocentric model. Copernicus realized that if all the planets, including Earth, orbited the Sun, then retrograde motion resulted from the changing of perspective as Earth and the other planets moved in their orbits.

Copernicus published his heliocentric (Sun-centered) theory in the book *De revolutionibus orbium coelesticum* (On the revolutions of the celestial orbs). The Catholic Church, however, had accepted the geocentric model as an accurate description of the universe, and anyone arguing against this model faced severe repercussions. At the time, Copernicus was gravely ill, so he asked Andreas Osiander to oversee the book's publication. Osiander, concerned about the Church's reaction, wrote an unsigned preface to the book stating that the model was simply a mathematical tool, not a true depiction of the universe. Copernicus received the first copy of his book on his deathbed and never read the preface. The telescopic discoveries of Italian mathematician and astronomer Galileo Galilei (1564–1642) and the mathematical description of planetary orbits by German astronomer Johannes Kepler (1571–1630) led to the acceptance of Copernicus's heliocentric model. SEE ALSO Astronomy, History of (volume 2); Galilei, Galileo (volume 2); Kepler, Johannes (volume 2).

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Cosmic Rays

Cosmic rays are, in fact, not rays, but high energy subatomic particles of cosmic origin that continually bombard Earth. The measurements scientists make of them, both on the ground and from probes in space, are the only direct measurements that are made of matter originating outside the solar system.

Among the cosmic rays are electrons, protons, and the complete nuclei of all the elements. Their energies range from below the rest mass of an electron, easily attainable in terrestrial accelerators, up to energies 10^{11} times the rest mass of a proton. Matter with such energies is moving at speeds so close to the speed of light that there is an enormous **relativistic time dilation**, so that in its proper frame only 10^{-11} of the time has elapsed that an observer on Earth would have measured. An early verification of German-born American physicist Albert Einstein's **special theory of relativity** came from explaining how unstable **mesons** produced by cosmic rays impinging on the upper atmosphere (whose lifetime was less than the time it took for them to reach the detectors on Earth) managed to survive without decaying. According to special relativity, these high energy mesons would not have had enough time in their own reference frame to decay.

Although cosmic rays have been known for more than a century, neither their precise origin nor their source of energy is known. Austrian-born American physicist Viktor Hess demonstrated their cosmic origin in 1912, using balloon flights to show that the penetrating, ubiquitous, ionizing radiation increases in intensity with altitude. It was not until the 1930s, with increased understanding of nuclear physics, that the "radiation" was recognized to be charged particles.

The low energy particles measured—below 10^{10} **eV**—are dominated by the effects of our environment in the solar system and the unpredictability of space weather. Incoming galactic cosmic rays are scattered on magnetic irregularities in the solar wind, resulting in "solar modulation" of the galactic cosmic ray spectrum. At low energies, many of the particles themselves originate in solar flares, or are accelerated by shocks in the solar wind.

At mid-energies, 10^{10} to 10^{15} eV, the particles measured are galactic, show a smooth **power law energy spectrum**, and show a composition of nuclei roughly consistent with **supernovae ejecta**, modified by their subsequent diffusion through the galaxy. Bulk acceleration in the supernova blast wave, and diffusive acceleration in shocks in the remnant can probably account for particles up to 10^{14} eV. They diffuse throughout the **interstellar medium**, but remain trapped within the galaxy for several million years by the magnetic field and scattering by **magnetohydrodynamic waves**.

Particles have been detected with energies up to about 10^{21} eV. There is no generally accepted mechanism for accelerating them above about 10^{15} eV. One speculation is that collapsing **superstrings** could produce particles with the **grand unified theory** (GUT) energy of 10^{25} eV; the particles then decay and lose energy. Above 10^{19} eV neither the spectrum nor the composition are well-known because the events are rare and the detection methods indirect.

In 1938 French physicist Pierre Auger discovered extensive air showers. When a single high energy particle impinges on the atmosphere, it generates a cascade that can contain 10^9 particles. Information about the primary

relativistic time dilation effect predicted by the theory of relativity that causes clocks on objects in strong gravitational fields or moving near the speed of light to run slower when viewed by a stationary observer

special theory of relativity the fundamental idea of Einstein's theories, which demonstrated that measurements of certain physical quantities such as mass, length, and time depended on the relative motion of the object and observer

mesons any of a family of subatomic particle that have masses between electrons and protons and that respond to the strong nuclear force; produced in the upper atmosphere by cosmic rays

eV an electron volt is the energy gained by an electron when moved across a potential of one volt. Ordinary molecules, such as air, have an energy of about $3x10^{-2}$ eV

power law energy spectrum spectrum in which the distribution of energies appears to follow a power law

supernovae ejecta the mix of gas enriched by heavy metals that is launched into space by a supernova explosion

interstellar medium the gas and dust found in the space between the stars

magnetohydrodynamic waves a low frequency oscillation in a plasma in the presence of a magnetic field

superstrings supersymmetric strings are tiny, one dimensional objects that are about 10^{-33} cm long, in a 10-dimensional spacetime. Their different vibration modes and shapes account for the elementary particles we see in out 4-dimensional spacetime

grand unified theory states that, at a high enough energy level (about 10^{25} eV), the electromagnetic force, strong force, and weak force all merge into a single force

muons the decay product of the mesons produced by cosmic rays; muons are about 100 times more massive than electrons but are still considered leptons that do not respond to the strong nuclear force

Čerenkov light light emitted by a charged particle moving through a medium, such as air or water, at a velocity greater than the phase velocity of light in that medium; usually a faint, eerie, bluish, optical glow

anisotropy a quantity that is different when measured in different directions or along different axes

cosmic microwave background ubiquitous, diffuse, uniform, thermal radiation created during the earliest hot phases of the universe

nucleus can be deduced from the lateral distribution of the **muons** and electrons that reach the ground, and from the pulse of **Čerenkov light** emitted as the shower descends through the atmosphere. If the spectrum, composition, and **anisotropy** above $5x10^{19}$ eV, where there should be a cutoff in the spectrum because of interactions on the 2.7°K **cosmic microwave background** photons, can be measured, and these are consistent, these cosmic rays will identify sites where some of the most exotic and energetic events in the universe occur.

Cosmic rays represent a significant component in the energy balance of our galaxy. The energy density in cosmic rays in the galactic disk is comparable to that found in starlight and in the galactic magnetic field, and therefore must play an important, if so far poorly understood, role in the cycle of star formation. By maintaining a residual ionization in the cores of dense molecular clouds, star formation is inhibited because the magnetic field cannot diffuse out. On the other hand, cosmic rays streaming along the magnetic field in the diffuse interstellar medium could provoke cloud condensation through MHD instabilities. SEE ALSO Galaxies (volume 2); Solar Particle Radiation (volume 2); Solar Wind (volume 2); Space Environment, Nature of the (volume 2); Stars (volume 2); Sun (volume 2); Supernova (volume 2); Weather, Space (volume 2).

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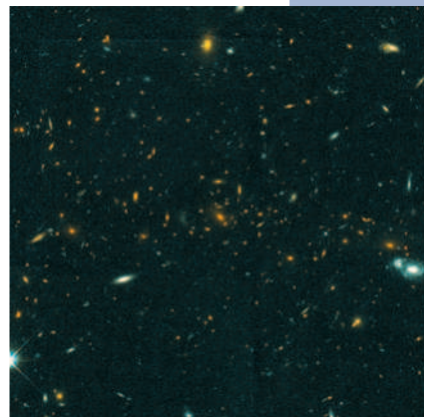
Cosmology

Cosmology is the study of the origin and evolution of the universe. In the last half of the twentieth century, astronomers made enormous progress in understanding cosmology. The discovery that the universe apparently began at a specific point in time and has continued to evolve ever since is one of the most revolutionary discoveries in science.

The History of the Universe: In the Beginning

The universe began in what astronomers dubbed the "Big Bang"—an initial event, after which the universe began to expand. Current estimates place the Big Bang at about 13 to 15 $\times$ 10^9 years ago. During the first seconds after the Big Bang, the universe was extremely hot and dense. The physics needed to understand the universe in these early stages is very speculative because it is impossible to recreate these conditions in an experiment today to check the predictions of the theory. Before 10^{-44} seconds after the Big Bang, the four fundamental forces of nature—gravity, the electromagnetic force, and the strong and weak nuclear forces—were unified into a single force. At 10^{-44} seconds, gravity separated from the others; at 10^{-34} seconds, the strong force became separated; and at 10^{-11} seconds, the weak force separated from the electromagnetic force.

During this period the universe began a sudden burst of exponential expansion—faster than the speed of light. This expansion is called "inflation" and explains why the universe we observe is so uniform. Temperatures were so hot (10^{27} K) before inflation that the familiar particles that make up atoms today (**protons** and **neutrons**) were not stable—the universe was a hot soup of quarks (particles that are hypothesized to make up baryons), leptons (**electrons** and neutrinos), photons, and other exotic particles.



As the universe expands, overdense regions in space collapse, and the resulting protogalactic fragments merge to form galaxies.

The History of the Universe: Formation of the Elements, Stars, and Galaxies, and the Cosmic Microwave Background

As the universe expanded after inflation it continued to cool. For the first three minutes conditions everywhere were similar to those at the center of stars today, and **fusion** of protons into deuterium, helium, and lithium took place. Most of the helium we see today in stars is believed to have been produced during these early minutes. The universe was an extremely opaque plasma, and photons dominated the mass density and dynamical evolution of the universe. When the universe cooled sufficiently to allow the free electrons to recombine with the hydrogen and helium nuclei, suddenly the opacity dropped, and the photons were free to stream through space unimpeded. These photons are seen today as the cosmic microwave background, a bath of light that is seen in all directions today. The experimental detection of the cosmic microwave background was one of the great triumphs of the Big Bang theory. Recombination and the subsequent production of the cosmic microwave background occurred about 180,000 years after the Big Bang.

protons positively charged subatomic particles

neutrons subatomic particles with no electrical charge

electrons negatively charged subatomic particles

fusion releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

At this point the matter distribution of the universe was still fairly uniform, with only small density fluctuations from place to place. As the universe expanded, the slightly overdense regions began to collapse. Sheets and filaments in the gas formed, which drained into dense clumps where star formation began. Eventually, these protogalactic fragments merged and galaxies and **quasars** formed. The universe began to look like it does today.

quasars luminous objects that appear starlike but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

The Future of the Universe: Einstein's Biggest Blunder or Most Amazing Prediction?

Cosmologists predict the future of the universe as well as study its past. Whether the universe will expand forever or eventually slow down, turn around, and recollapse depends on how fast the galaxies are moving apart today and how much gravity there is to counter the expansion—quantities that in principle can be measured.

German-born American physicist Albert Einstein (1879–1955) described the modern theory of gravity, general relativity. He used the idea that space could be curved to reformulate English physicist and mathematician Isaac Newton's (1642–1727) theory of gravity. In general relativity, the mass of an object curves the space around it, and parallel lines no longer go on forever without intersecting. In many textbooks the curvature

BLACK HOLES AND HAWKING RADIATION

Hawking radiation: A particle-antiparticle pair can be created spontaneously near a black hole. If one member of the pair falls into the event horizon, its partner can escape, carrying away energy, called Hawking radiation, from the black hole. This radiation is named after English theoretical physicist Stephen Hawking, who first hypothesized that this could be an important way that black holes evaporate.

A noted cosmologist, Hawking is working on the basic laws that govern the universe. This creative visionary was born in January 1942, and now studies a variety of issues related to the Big Bang and black holes. His seminal work, *A Brief History of Time* (1988), was a popular best-seller. Despite his disability because of an incurable disease, amyotrophic lateral sclerosis (ALS), the wheelchair-bound Hawking continues active research into theoretical physics, mixed with a fast-paced agenda of travel and public lectures. Communicating via computer system and a speech synthesizer, Hawking is still active in his quest to decipher the nature of space and time.

neutron stars the dense cores of matter composed almost entirely of neutrons that remain after a supernova explosion has ended the lives of massive stars

of space is represented by a sphere or a saddle shape—but in reality, space is three-dimensional, and the "curvature" is not in a particular direction. Einstein wrote down what are called "field equations" that described how the curvature of space can be calculated from mass and energy. When he solved the equations he realized that even if the universe is infinite, isotropic (the same in all directions), and homogeneous (the same density everywhere), it would not be static. Depending on the geometry, it would expand or contract. American astronomer Edwin P. Hubble (1889–1953) had not yet discovered that the universe expands, so in 1917 Einstein added a "parameter" lambda, called the cosmological constant, to the field equations. Later, when Hubble showed that the universe is expanding, and that there was no need to add a cosmological constant to the field equations, Einstein called the cosmological constant "the biggest blunder of my life."

Were Einstein alive to day, he would be amazed to learn about recent observations that suggest that the cosmological constant is not zero and that the expansion is accelerating. In this case, the curvature of space is not so easily related to the dynamical evolution of the universe. At the beginning of the twenty-first century, theorists had not come up with a theory for the origin of a non-zero lambda that has testable predictions. Certainly, more observations are called for to confirm or refute this result.

Nonetheless, the conditions in the universe in the distant future can be described, given the physics that is understood today. If the universe is *closed*, then the Hubble expansion will eventually stop, and the universe will then collapse. If the density of the universe is, for the sake of argument, about twice the critical density for closing the universe, then the expansion stops about 50 billion years after the Big Bang. At about 85 billion years after the Big Bang, the density of the universe will again be about what it is today. At this point, the nearby galaxies will appear to move toward us, more distant galaxies will be standing still, and the very distant galaxies will be moving away. Eventually, the galaxies will all touch, and the universe will continue to contract and heat. Soon the stars will be cooler than the universe as a whole, so radiation will not be able to flow out of them, and they will explode. As a result, 100 billion years after the Big Bang will come the big crunch. At this point the universe may become a black hole—or it may bounce, and cycle again.

If the universe is *open* or *flat*, the Hubble expansion goes on forever. Physical processes that take such a long time that they are irrelevant in today's universe will eventually have time to occur. After 1 trillion (10^{12}) years, star formation will have used up all the available gas, and no new stars will form. Stellar remnants such as white dwarfs, **neutron stars**, and black holes will remain. After 10^{18} years, galaxies will evaporate—their stars will disperse into space. After 10^{40} years, protons and neutrons will decay into positrons and electrons. After that, only black holes will exist. The black holes will eventually evaporate by Hawking radiation. At 10^{100} years after the Big Bang, all of the black holes, even the supermassive ones in quasars, will be gone. The universe will be very black and cold indeed.

Conclusion

The questions asked by cosmologists are some of the most simple and yet most profound questions intelligent creatures can ask. What is the origin of this beautiful and complex universe we live in, and what is its ultimate fate? Amazing progress was made over the last hundred years in cosmology, but clearly many important parts of the story are yet to be discovered. SEE ALSO Age of the Universe (volume 2); Einstein, Albert (volume 2); Galaxies (volume 2); Hubble Constant (volume 2); Hubble, Edwin P. (volume 2); Shapley, Harlow (volume 2); What Is Space? (volume 2).

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BEFORE THE BIG BANG

What came before the Big Bang? Cosmologists have no shortage of answers to this question, but we may never know from direct observation what the true story is. Perhaps space-time had such a peculiar topology that it curved around on itself—and so asking what came before the Big Bang might be like asking what is south of the South Pole.

Earth

Imagine that you are describing planet Earth to someone who has never seen it. How would you describe its appearance? What would you say about it? What things about Earth are typical of all planets? What things are unique?

To describe Earth, you might say that it is the third planet from the Sun in this solar system, and that it is 12,756 kilometers (7,909 miles) in diameter. Someone else might say that Earth is a fragile-looking blue, brown, and white sphere. A third person might say that Earth is the only planet in our system, as far as we know, with life. All of these descriptions are true; they are very different, however, from the descriptions of Earth that someone living in the 1950s or earlier would have given. Before we began to travel into space and to send spacecraft to observe other planets, we did not realize how different, or how similar, our planet was from other planets. And we were so busy examining the details and small regional differences of our world that we did not think about the planet as a whole.

Planet Earth

Our knowledge of Earth has been fundamentally changed by the knowledge we have gained about the other planets in the solar system. We have come to realize that, in some ways, Earth is very similar to its nearest neighbors in space. Like all of the other planets in our system, Earth orbits around our star (the Sun). It is the largest of the inner planets, just slightly larger than Venus; and it experiences seasons (as does Mars) due to the tilt of its rotation axis.

Like many other planets in our system, Earth has a natural satellite. We call our single satellite the "Moon" and have used that term to describe all of the other moons in our system, although Earth and its Moon are unusually closer in size than is common. One of the ways in which Earth is similar to its nearest neighbors is that all of the **"rocky" planets** have been

"rocky" planets nickname given to inner or solid-surface planets of the solar system, including Mercury, Venus, Mars, Earth, and the Moon

Faults, such as the San Andreas Fault in California, are indications that Earth is still geologically active.

tectonism process of deformation in a planetary surface as a result of geological forces acting on the crust; includes faulting, folding, uplift, and down-warping of the surface and crust

affected by four fundamental geological processes: volcanism, **tectonism**, erosion, and impact cratering.

The surface of our planet is a battleground between the processes of volcanism and tectonism that create landforms and the process of erosion that attempts to wear away these landforms. Geologically speaking, Earth is a "water-damaged" planet, because water is the dominant agent of erosion on the surface of our world. On planets with little or no atmosphere, erosion of the surface may occur due to other processes, such as impact cratering. On the rocky planets the dominant mechanism of erosion may differ, and the styles or details of the volcanic or tectonic landscape may differ, but the fundamental geological processes remain the same.

Approximately 50 percent of Earth's surface at any one time is cloud covered. Clouds play an important role in global temperature balance.

Of the four fundamental processes, the one that may be unexpected is impact cratering. In fact, prior to our exploration of the Moon, impact cratering was not considered important to Earth. Those few impact craters identified on Earth were treated as curiosities. Now, after studying the other planets, we realize that impact cratering is an important and continuing process on all planets, including Earth. Impacts from **meteorites**, comets, and occasionally large asteroids have occurred throughout the history of Earth and have been erased by Earth's dynamic and continuing geology. The formation of an impact crater can significantly affect the geology, atmosphere, and even the biology of our world. For example, scientists believe that an impact that occurred about 65 million years ago on the margin of the Yucatan Peninsula was a possible cause of the extinction of the dinosaurs and many other species.

WHAT IS VOLCANISM?

Volcanism is a geological term used to describe the complete range of volcanic eruptions, volcanic landforms, and volcanic materials. Volcanism is driven by the internal heat of a planet and provides evidence of the way in which heat is released from that planet. The type and abundance of volcanoes on the surface of a planet can provide evidence about the level of geologic activity of the planet.

meteorite any part of a meteoroid that survives passage through Earth's atmosphere

A Uniquely Different Planet

Although Earth is in some ways a typical rocky planet, several of its most interesting features appear to be unique. For example, a global map of Earth with the ocean water removed shows a very different planet from our neighboring rocky planets. The patterns made by continents, oceans, aligned volcanoes, and linear mountains are the result of the process geologists call plate tectonics.

We know from the study of earthquake waves moving through Earth that our planet is made up of three main layers: the crust, mantle, and core.

WHAT IS TECTONISM?

Tectonism is a geological term used to describe major structural features and the processes that create them, including compressional or tensional movements on a planetary surface that produce faults, mountains, ridges, or scarps. Tectonic or structural movements are driven by the internal heat of a planet, and those movements on Earth produce earthquakes. Faults, ridges, or mountains on a planetary surface imply that the planet was or is still geologically active.

convection the movement of heated fluid caused by a variation in density

The upper layer of Earth (consisting of the crust and the upper mantle) is broken into rigid plates that move and interact in various ways. Where plates are moving together or one plate is moving beneath another, mountains such as the Himalayas or explosive volcanoes such as the Cascades are formed. Where plates are moving apart, such as along the mid-oceanic ridges, new crust is formed by the slow eruption of lava. Where two plates slide along each other, such as the San Andreas Fault zone in California, major earthquakes occur. The movement of the plates is caused by the **convection** of the mantle beneath them; that convection is driven by the planet's internal heat, derived from radioactive decay of certain elements. Similarly, rotation and convection in the fluid metallic outer core is responsible for Earth's uniquely strong magnetic field. Plate tectonics can be thought of as a giant recycling mechanism for Earth's crust.

The concept of plate tectonics is a relatively new idea, and it is central to our understanding of Earth's dynamic geology. Nevertheless, planetary geologists have found no clear evidence of past or present Earth-style plate tectonics on any of the other rocky planets; Earth seems to be unique in this regard.

Earth is also unique in that no other planet in the solar system currently has the proper temperature and atmospheric pressure to maintain liquid water on its surface. Water exists on Earth as gas (water vapor), liquid, and solid (ice), and all three forms are stable at Earth's surface temperature and pressure. Water may be the single most important criteria for life as it has developed on Earth. And the presence of life, in turn, has changed and affected the composition of the atmosphere and the surface of Earth. For example, the rock type limestone would not be possible without marine life, and limestone formation may have significantly altered the distribution of carbon dioxide on Earth.

Mars and Venus also have atmospheres, but they are primarily composed of carbon dioxide. Earth's atmosphere is approximately 76 percent nitrogen and 20 percent oxygen with traces of water vapor, carbon dioxide, and ozone. Although water is not a major component by percent, it is a very important part of Earth's atmosphere. Earth's surface water and atmosphere are linked to form a single system. Water evaporates from the oceans, moves through the atmosphere as vapor or cloud droplets, precipitates onto the surface as rain or snow, and returns to the oceans by way of rivers. Clouds cover approximately 50 percent of Earth's surface at any one time, and they play an important role in maintaining the balance of atmospheric and surface temperatures on our planet.

basalt a dark, volcanic rock with abundant iron and magnesium and relatively low silica; common on all of the terrestrial planets

Our atmosphere and water work together to form a general category of rocks on Earth that is not known to exist on any neighboring planets. On Earth's surface, sedimentary rocks, such as quartz-rich sandstone or marine limestone, are very common; they cover approximately 70 percent of the surface of our planet in a very thin veneer. Although Mars may surprise us, initial studies of our nearest neighbors indicate that the volcanic rock **basalt** is the basic building block of planetary crust (including most of Earth's subsurface crust) and the most common rock type on the surface of the other rocky planets. Once again, Earth is unique. And as we explore other planets around other suns, typical Earth sandstone might be as exotic and rare as gold. SEE ALSO Close Encounters (volume 2); Earth—Why Leave?

(VOLUME 4); MARS (VOLUME 2); MOON (VOLUME 2); NASA (VOLUME 3); SOLAR WIND (VOLUME 2).

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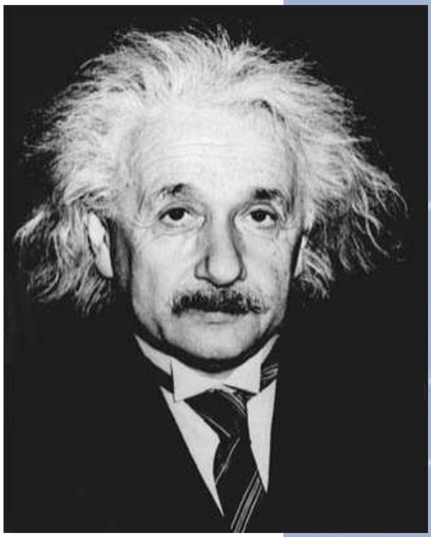
Einstein, Albert

German-born, Swiss-educated Physicist
1879–1955

Albert Einstein was a scientist who revolutionized physics in the early twentieth century with his theories of relativity. Born in Ulm, Germany, in 1879, Einstein was interested in science from an early age. While he performed well in school, he disliked the academic environment and left at the age of fifteen. He took an entrance exam for the Swiss Federal Institute of Technology (ETH) in Zurich but failed; only after completing secondary school was he able to gain entrance to ETH, where he graduated in 1900. Unable to find a teaching position, Einstein accepted a job in the Swiss patent office in 1902.



Albert Einstein developed the famous equation $E=mc^2$.

electrons negatively charged subatomic particles

During his time as a patent clerk Einstein made some of his most important discoveries. In 1905 he published three papers, which brought him recognition in the scientific community. In one he described the physics of Brownian motion, the random motion of particles in a gas of liquid. In another paper he used the new field of quantum mechanics to explain the photoelectric effect, where metals give off **electrons** when exposed to certain types of light. Einstein published his third, and arguably most famous, paper in 1905, which outlined what later became known as the special theory of relativity. This theory showed how the laws of physics worked near the speed of light. The paper also included the famous equation $E=mc^2$, explaining how energy was equal to the mass of an object times the speed of light squared.

These papers allowed Einstein to exchange his patent clerk job for university positions in Zurich and Prague before going to Berlin as director of the Kaiser Wilhelm Institute of Physics. Shortly thereafter he published the general theory of relativity, which describes how gravity warps space and time. This theory was confirmed in 1919 when astronomers measured the positions of stars near the Sun during a solar eclipse and found that they had shifted by the amount predicted if the Sun's gravity had warped the light.

The acceptance of Einstein's general theory turned him into an international celebrity. During the 1920s he toured the world, giving lectures.

In 1922 he won the Nobel Prize for physics, although it was officially awarded for his work studying the photoelectric effect, not relativity. In 1932 he accepted a part-time position at Princeton University in Princeton, New Jersey, and planned to split his time between Germany and the United States. But when the Nazis took power in Germany one month after he arrived at Princeton, Einstein decided to stay in the United States.

Einstein spent the rest of his scientific career in an unsuccessful pursuit of a theory that would explain all the fundamental forces of nature. He also took a greater role outside of physics. In 1939 he cowrote a letter to President Franklin Roosevelt, urging him to investigate the possibility of developing an atomic bomb and warning him that Germany was likely doing the same. After the war he urged world leaders to give up nuclear weapons to preserve peace. In ill health for several years, he died in Princeton in 1955. SEE ALSO AGE OF THE UNIVERSE (VOLUME 2); ASTRONOMY, HISTORY OF (VOLUME 2); BLACK HOLES (VOLUME 2); COSMIC RAYS (VOLUME 2); COSMOLOGY (VOLUME 2); GRAVITY (VOLUME 2); WORMHOLES (VOLUME 4); ZERO-POINT ENERGY (VOLUME 4).

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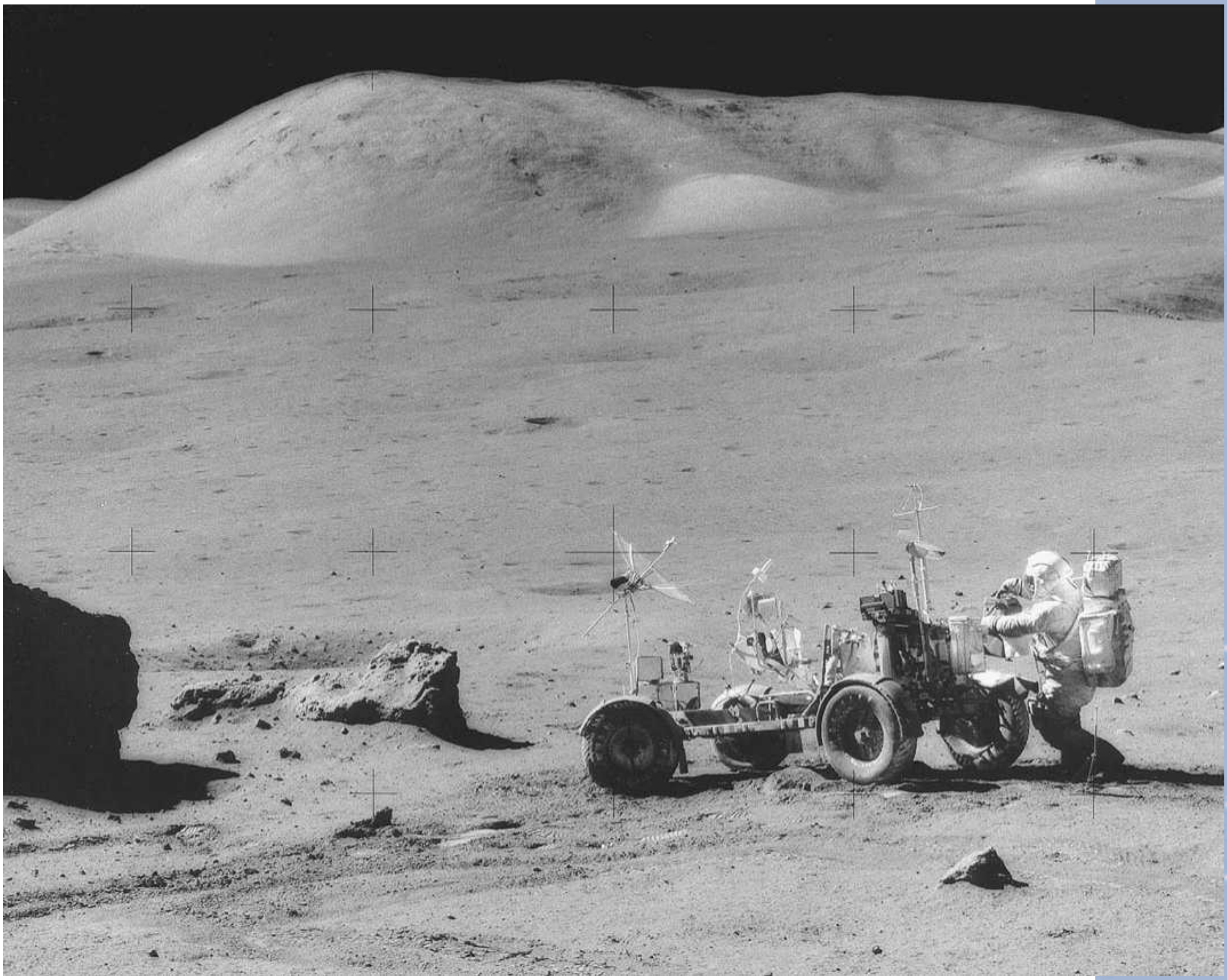
Exploration Programs

Prior to missions to the Moon and the planets in the solar system our knowledge of what lay beyond Earth was minimal. Five millennia of astronomical observation had produced an incomplete picture of the solar system. Although the Moon and planets were neighbors, there was only so much that could be learned from even the best telescopes. Only by sending spacecraft and astronauts on programs of exploration could we examine our neighbors in space more closely.

The first objective for both the United States and the Soviet Union was reaching the Moon. In September 1959 the Soviet probe Luna 2 struck the Moon. Three weeks later, Luna 3 sent back the first grainy images of the Moon's farside. For the United States, the Ranger project of the 1960s marked the first effort to launch probes toward the Moon. A variety of difficulties plagued the first several Ranger missions, and it was not until Ranger 7, in July 1964, that the program achieved complete success. Two more Ranger spacecraft were launched, including Ranger 8, which took 7,300 images before crash-landing in the Sea of Tranquility, where the Apollo 11 astronauts would land four and a half years later.

The Ranger program was the first of three intermediate steps leading to Apollo. Next came the Lunar Orbiter program, which photographed



Lunar surface experiments provided much data for scientists to evaluate, including several hundred kilograms of samples. The United States' Apollo astronauts often collected surface information themselves, while the Soviets used unpiloted Luna probes to gather their data.

potential Apollo landing sites. Altogether, five Lunar Orbiter spacecraft were launched from 1966 to 1967. By the end of the fourth mission, Lunar Orbiter probes had surveyed 99 percent of the front and 80 percent of the backside of the Moon. While Lunar Orbiters snapped photographs overhead, the Soviets and Americans perfected soft landing techniques. In February 1966, a 100-kilogram Soviet probe, shaped like a beach ball, touched down on the Moon and returned the first images of the lunar surface.

The Americans countered the Soviet success with a program called Surveyor. Once on the surface, the tripod-shaped Surveyors evaluated the lunar soil and environment. Surveyor 1 made a successful soft landing in three centimeters of dust in the Ocean of Storms in June 1966. Surveyors 3, 5, 6 and 7 landed at different sites and carried out experiments on the surface, including analyzing the chemical composition of the lunar soil. All told,

> **WHAT IS THE SEA OF TRANQUILITY?**
>
> The Sea of Tranquility is a dark spot located in the northern hemisphere of the Moon. The sea is not a body of water but a lower-altitude plain. As a result of earlier periods of lunar volcanism, it is filled with dark, solidified lava.

Surveyors acquired almost 90,000 images from five landing sites. The success of the Ranger and Surveyor programs and that of the five Lunar Orbiters gave the National Aeronautics and Space Administration (NASA) the confidence that humans could go the Moon.

In July 1969, Apollo 11 became the first mission to land humans on the Moon when Neil Armstrong and Edwin "Buzz" Aldrin piloted their lunar module "Eagle" to the Sea of Tranquility. Four months later, Apollo 12 landed at the site where Surveyor 3 had touched down in the Sea of Storms. Four more Apollo missions visited the Moon through December 1972. By the end of the program, Apollo astronauts had returned nearly 380 kilograms of samples from the Moon. Besides the samples, data from lunar-orbital experiments and information from lunar surface experiments were returned. Over the same time period, the Soviet Union retrieved several hundred grams of lunar material using Luna probes.

Beyond the Moon

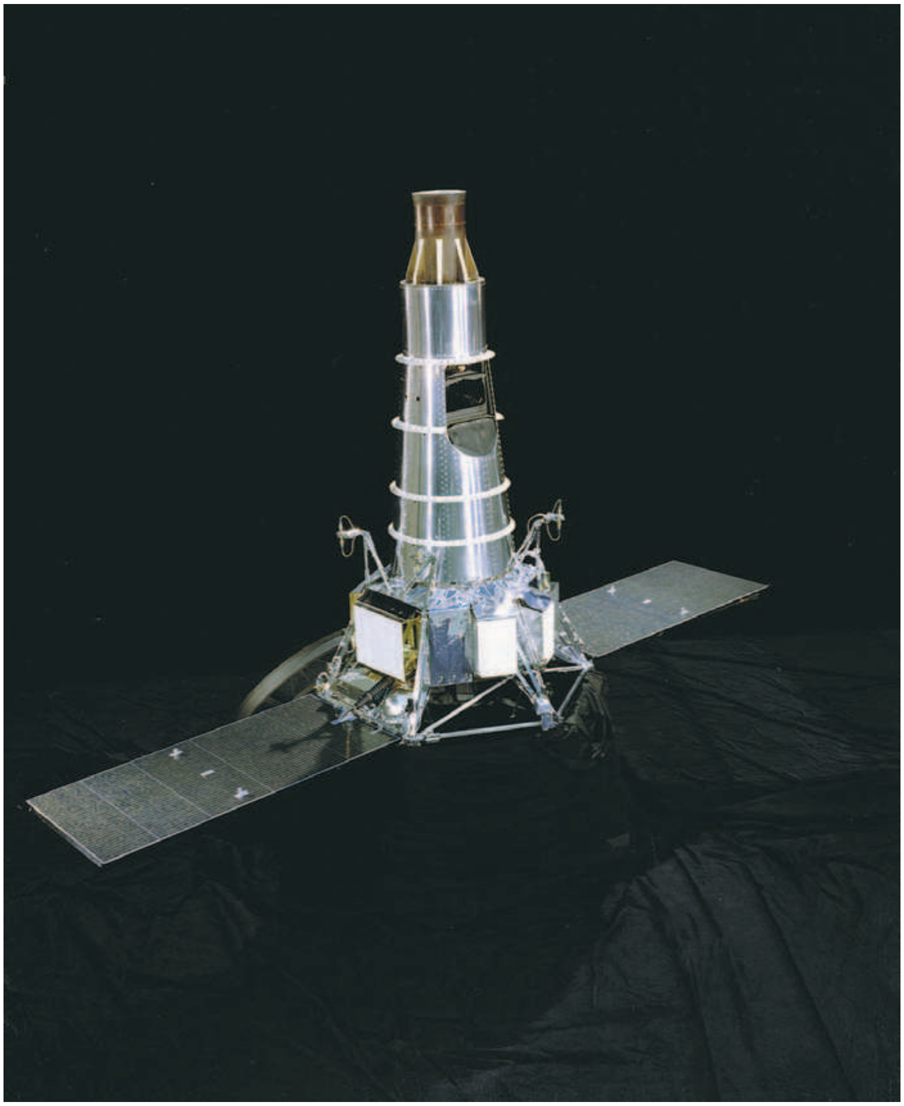
As plans were getting under way to explore the Moon, NASA also focused on the rest of the solar system. The Mariner series of missions were designed to be the first U.S. spacecraft to reach other planets. Mariner 2 became Earth's first interplanetary success. After a flawless launch, the Mariner 2 spacecraft encountered Venus at a range of 35,000 kilometers in December 1962. As it flew by, Mariner 2 scanned the planet and revealed that Venus has an extremely hot surface. Mariner 2 also measured the solar wind, a constant stream of charged particles flowing outward from the Sun.

In July 1965, Mariner 4 provided the first close look at Mars. The twenty-two fuzzy images returned by Mariner 4 revealed a planet pocked with craters. Four years later, Mariner 6 and 7 provided 200 more images of the Red Planet. Late in 1971, Mariner 9 went into orbit around Mars and a new era of Mars exploration dawned. Previous missions had been **flybys**, but Mariner 9 became the first artificial satellite of Mars. Upon arrival, a dust storm obscured the entire planet, but after the dust cleared, Mariner 9 revealed a place of incredible diversity that included volcanoes and a canyon stretching 4,800 kilometers. More surprisingly, Mariner 9 radioed back images of ancient riverbeds carved in the landscape.

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

Mariner 9 was followed in 1976 by Viking 1 and 2, each consisting of a lander and an orbiter. Each orbiter-lander pair entered Mars orbit; then the landers separated and descended to the planet's surface. The Viking 1 lander touched down on the western slope of Chryse Planitia ("Plains of Gold") on July 20, 1976, the seventh anniversary of the Apollo 11 Moon landing. Within an hour of landing, the first photos of Mars' surface were radioed back to Earth. Besides taking photographs, both Viking 1 and 2 landers conducted biology experiments to look for signs of life. These experiments discovered unusual chemical activity in the Martian soil, but provided no clear evidence for the presence of microorganisms. However, both landers provided a wealth of data about the Martian surface, and the Viking 1 and 2 orbiters took thousands of images from above.

While the United States focused much attention on Mars throughout the 1960s and 1970s, the Soviet Union flew a series of missions to Venus. Venera 4 became the first mission to place a probe into the Venusian atmosphere in June 1967. In June 1975, probes released by Venera 9 and 10



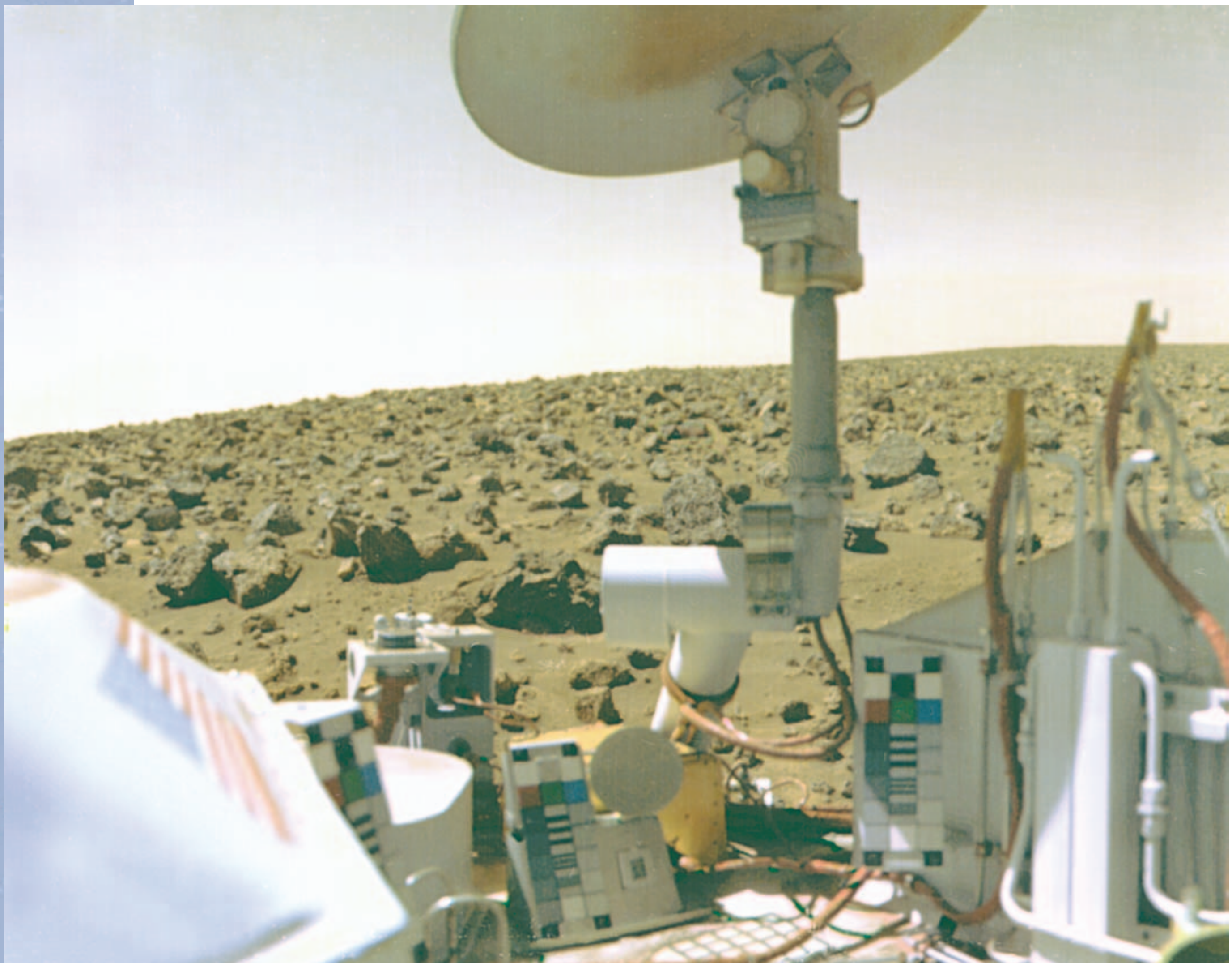
The Ranger project's spacecraft allowed the first live television transmissions of the Moon from lunar orbit. The project was the first of three steps leading to the Apollo mission.

transmitted the first black and white images of Venus' surface. Other missions followed, including Venera 15 and 16, which produced **radar** images of the Venusian surface. Venus was also a target of NASA's Mariner 10 mission in 1973 to 1974, which used a "gravity assist" to send the spacecraft on to Mercury. Gravity assist techniques were to play a crucial role in NASA's next phase of planetary exploration—journeys to Jupiter and beyond.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Pioneer 10 and 11 were the first spacecraft to venture beyond the asteroid belt into the realm of the outer planets. Pioneer 11 safely passed through the asteroid belt and passed 42,000 kilometers (26,098 miles) below Jupiter's south pole in December 1974, exactly a year after Pioneer 10's closest approach. Using Jupiter's immense gravity like a slingshot, Pioneer 11 encountered Saturn in September 1979. After passing Saturn, Pioneer 11 plunged into deep space, carrying a plaque similar to that aboard Pioneer 10 in the hope that intelligent life would someday find it.

NASA mission designers recognized that the giant outer planets—Jupiter, Saturn, Uranus and Neptune—would soon align in such a way that a single spacecraft might be able to use gravity assists to hop from one planet



The Viking 2 lander looks out over Mars' Utopia Plain in 1976. Both the Viking 1 and 2 missions took thousands of photos of the planet and conducted biological experiments to search for signs of life, uncovering unusual chemical activity but no clear proof of microorganisms.

to the next. Taking advantage of this alignment, NASA approved the Voyager Project. Voyager 1 made its closest approach to Jupiter in March 1979, and Voyager 2 came within 570,000 kilometers (354,182 miles) of Jupiter in July 1979. Voyager 1 and 2 flybys of Saturn occurred nine months apart, with the closest approaches occurring in November 1980 and August 1981. Voyager 1 then headed out of the orbital plane of the planets. However, Voyager 2 continued onward for two more planetary encounters, coming within 81,500 (50,642 miles) kilometers of Uranus' cloud tops in January 1986, and making a flyby of Neptune in August 1989. Both Voyagers continue to operate and are approaching interstellar space.

While the Voyager missions were highly successful, the pace of planetary exploration slowed in the 1980s. One of the few new missions was Magellan, which went into orbit around Venus in August 1990. Over the next four years Magellan used radar to map 99 percent of the Venusian surface. After concluding its radar mapping, Magellan made global maps of Venus's gravity field. Flight controllers also tested a new maneuvering technique called aerobraking, which uses a planet's atmosphere to slow a spacecraft.

NASA managers also followed up the initial **reconnaissance** of Jupiter with the Galileo mission. En route to Jupiter, Galileo flew by two asteroids—Gaspra and Ida—the first such visits by any spacecraft. Galileo arrived at Jupiter in December 1995, and dropped an instrumented probe into the giant planet's atmosphere. Since then, Galileo has made dozens of orbits of Jupiter, usually flying close to one of its four major moons. Among its discoveries, Galileo uncovered strong evidence that Jupiter's moon Europa has a saltwater ocean beneath its surface.

reconnaissance a survey or preliminary exploration of a region of interest

In the mid-1980s, the European Space Agency launched its first deep space mission, part of an ambitious international mission to Comet Halley. The plan was to send an armada of five spacecraft—two Soviet (Vega 1 and 2), two Japanese (Sakigake and Suisei) and one European (Giotto)—towards the comet in 1986. A series of images sent back by Giotto revealed the comet nucleus to be a dark, peanut-shaped body, about 15 kilometers long. NASA did not send a mission to Comet Halley for budgetary reasons. Instead, NASA planed to return to Mars after a seventeen-year pause. In September 1992, the United States launched Mars Observer, but the mission ended in failure when contact was lost with the spacecraft as it approached Mars.

A New Strategy: Faster, Better, Cheaper

The loss of Mars Observer prompted NASA to rethink its strategy for planetary exploration. The few large and expensive missions that characterized the preceding fifteen years were replaced by greater numbers of focused, cheaper missions, a strategy described as "faster, better, cheaper." Ironically, it was a joint project between the U.S. military and NASA, called Clementine, which underscored the potential of this concept. Clementine was launched in January 1994 and mapped the lunar surface, providing preliminary evidence of ice at the Moon's poles.

In the early 1990s, NASA established the Discovery program to select low-cost solar system exploration missions with focused science goals. The first Discovery mission was the Near Earth Asteroid Rendezvous (NEAR) mission. NEAR entered orbit around the asteroid Eros in February 2000, beginning a yearlong encounter. The car-sized spacecraft gathered ten times more data during its orbit than originally planned, and completed all the mission's science goals before becoming the first spacecraft to land on the surface of an asteroid.

Mars Pathfinder, the second Discovery class mission, landed on Mars on July 4, 1997, assisted by airbags to cushion the impact. The landing site, known as Ares Vallis, was chosen because scientists believed it was the site of an ancient catastrophic flood. Onboard Pathfinder was a six-wheeled rover named Sojourner. From landing until the last transmission in September 1997, Mars Pathfinder returned more than 16,500 images from the lander and 550 images from the rover, in addition to chemical analyses of rocks and soil plus data on winds and other weather phenomena.

Coinciding with Pathfinder's mission was the arrival of the Mars Global Surveyor (MGS) spacecraft in orbit around the Red Planet in September 1997. Although not a Discovery mission, MGS applied the aerobraking skills pioneered by Magellan. After a year and a half trimming its orbit, MGS began its prime mapping mission in March 1999. From orbit, MGS took pictures of gullies and debris features that suggest there may be current sources of liquid water at or near the planet's surface. In addition, **magnetometer** readings showed that the planet's magnetic field is localized in particular areas of the crust. MGS completed its primary mission in January 2001, but continues to operate in an extended mission phase.

magnetometer an instrument used to measure the strength and direction of a magnetic field

Since Mars Pathfinder, more Discovery class missions have been launched, including Lunar Prospector, Stardust, and Genesis. The small spin-stabilized Lunar Prospector spacecraft lifted off in January 1998 and spent almost two years measuring the Moon's magnetic and gravitational fields and looking for natural resources, such as **minerals** and gases, which could be used to sustain a human lunar base or manufacture fuel. Mission scientists believe that Lunar Prospector detected between 10 to 300 million tons of water ice scattered inside craters at the lunar poles.

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

Stardust, the fourth Discovery mission, was launched in February 1999 and is slated to fly through the cloud of dust that surrounds Comet Wild–2, and bring cometary samples back to Earth in January 2006. Stardust will be the first mission to return extraterrestrial material from outside the orbit of the Moon. Launched in August 2001, the Genesis spacecraft is headed toward an orbit around Lagrangian 1 (L1), a point between Earth and the Sun where the gravity of both bodies is balanced. Once it has arrived, Genesis will begin collecting particles of solar wind that imbed themselves in specially designed high purity wafers. After two years, the sample collectors will be returned to Earth.

In addition to the Discovery program, the U.S. space agency has embarked on a series of New Millennium missions to test advanced technologies. The first New Millennium mission was Deep Space 1, which validated **ion propulsion** and tested other new technologies, such as autonomous optical navigation, several microelectronics experiments, and software to plan and execute onboard activities with only general direction from the ground.

ion propulsion a propulsion system that uses charged particles accelerated by electric fields to provide thrust

While the trend in planetary exploration has been toward cheaper, smaller missions, the joint American/European Cassini mission to Saturn represents the opposite approach. Launched in October 1997, Cassini is the most ambitious effort in planetary space exploration ever mounted and involves sending a sophisticated robotic spacecraft to orbit the ringed planet and study the Saturnian system over a four-year period. Onboard Cassini is a scientific probe called Huygens that will parachute through the atmosphere to the surface of Saturn's largest moon, Titan. Cassini will enter Saturn orbit in July 2004, and the Huygens probe will descend to the surface of Titan in November of that year. Building on the spectacular success of exploration programs over the past forty years, future missions are planned to the Moon, Mars, Mercury, Jupiter's moons and beyond. SEE ALSO Apollo (Volume 3); Apollo Lunar Landing Sites (Volume 3); Astrobiology (Volume 4); Life in the Universe, Search for (Volume 2); Planetary Exploration (Volume 1); Planetary Exploration, Future of (Volume 2); Robotic Exploration of Space (Volume 2).

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Extrasolar Planets

The question of whether or not other planetary systems similar to our own exist has intrigued astronomers and the general public alike for centuries. It was only in the in the 1990s that astronomers began to discover direct evidence for planets outside the solar system.

Method of Detection

The planets of the solar system are visible because of the sunlight that they reflect. Unfortunately, planets that orbit other stars are far too faint relative to their stars for current astronomical telescopes to observe them directly as faint points of light next to their much brighter stars. Instead, astronomers use a variety of techniques to indirectly infer the presence of these extrasolar planets.

The method by which all of the known extrasolar planets have been discovered is the radial velocity (or Doppler) technique. The mass of the orbiting planet causes the central star to be pulled around in an orbit. Astronomers detect the resulting small, periodic shifts in the apparent speed of the star. By measuring the shape of the resulting Doppler curve over time, they are able to deduce a lower limit on the mass of the planet and estimate the separation of the planet from the star. This planet-star distance is typically expressed in astronomical units (AUs); one AU is the average distance from Earth to the Sun.

Extrasolar Discoveries

The first detection of a planet orbiting another Sun-like star was accomplished in 1995 using the radial velocity technique. This planet, orbiting the star 51 Pegasi, was found by two Swiss astronomers, Michel Mayor and Didier Queloz, of the Geneva Observatory. A pair of American astronomers, Geoffrey Marcy and Paul Butler, soon followed with the announcement of several other new planets. Each of these teams has since expanded into large groups that are now surveying thousands of Sun-like stars in search of new worlds.

These radial velocity surveys are able to detect only massive planets, that is, planets which have masses similar to Jupiter.✶ Less-massive planets produce a correspondingly smaller tug on their parent star and are thus more difficult to detect. Recently, observers of radial velocity have increased the sensitivity of their measurements, and announced the discovery of several planets with masses similar to that of Saturn (one-third that of Jupiter's mass). Future improvements in the technique should allow for the detection of planets with even lower masses. Unfortunately, stars themselves are somewhat variable, and the flutter that results from their intrinsic variability implies that small, rocky worlds similar to Earth (a mere 1/300th of Jupiter's mass) will not be detectable by this method.

✶Jupiter is the largest planet in the solar system.

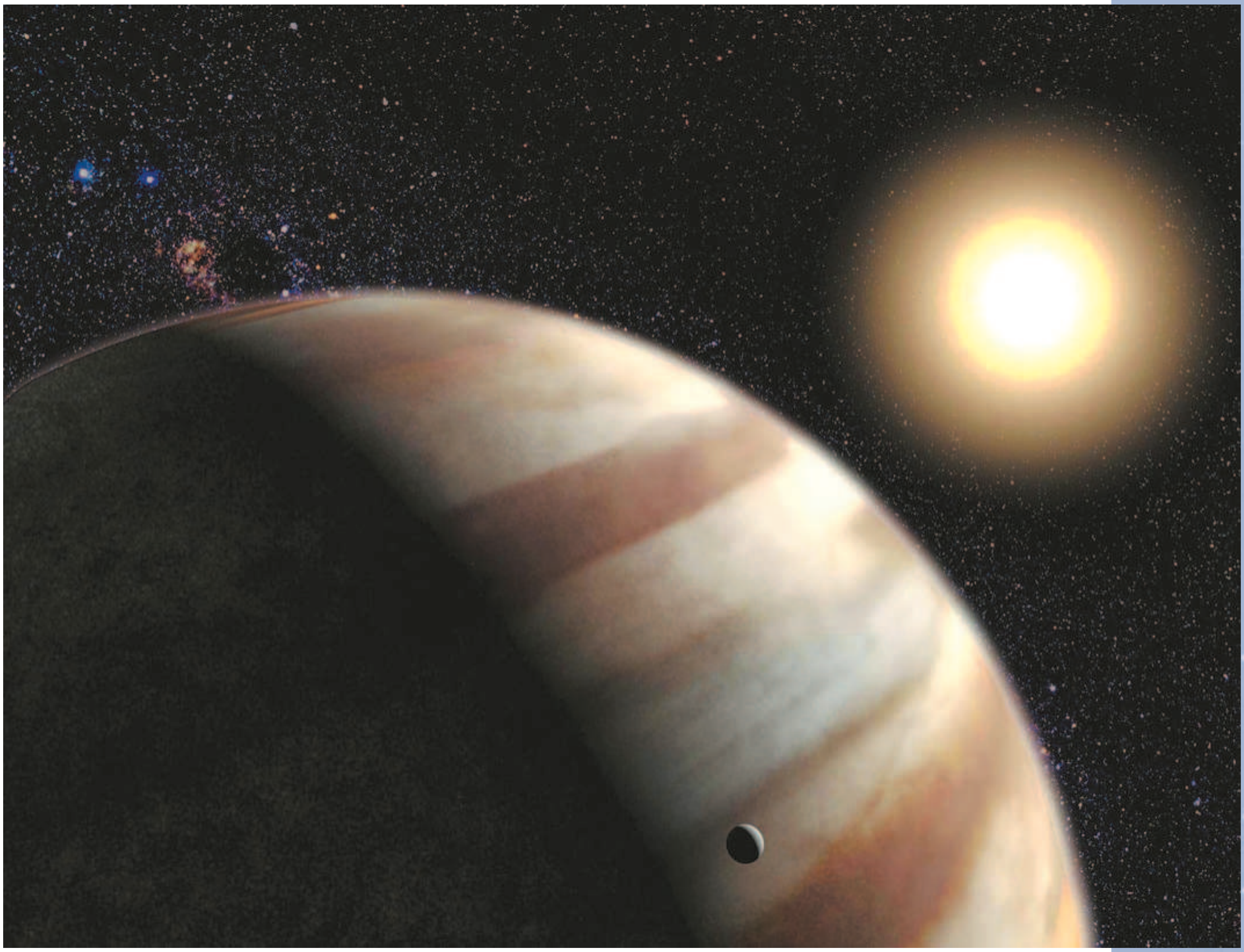
By early 2002, more than seventy extrasolar planets have been discovered. Based on the total number of stars in the current surveys, this implies that at least 7 percent of Sun-like stars have at least one planet. This estimate, however, is only a lower limit: The surveys have not been in operation long enough to see planets at large distances from their stars. Our own Jupiter takes nearly twelve years to circle the Sun. Planetary systems similar to our own—that is, those with massive planets in large, circular orbits far from the central star—would not yet have been detected. One of the chief goals of the radial velocity surveys between 2002 and 2012 is to search for such systems.

After astronomers find a planet orbiting a given star, they continue to monitor that star in the hope of detecting additional planets. In 1999, Butler and colleagues announced the first detection of a multiple-planet system, in orbit about the Sun-like star Upsilon Andromedae. Recently, six other stars have been demonstrated to harbor multiple planets, and many other stars show hints that they too possess multiple planets.

Hot Jupiters

The first distinct subclass of extrasolar planets to emerge from radial-velocity surveys consists of the so-called Hot Jupiters (or 51-Peg-type planets). These planets have masses similar to that of Jupiter, but they are located 100 times closer to their stars than Jupiter is from the Sun. The existence of such planets challenges conventional theories of planet formation. Gas giants such as Jupiter presumably form at large distances from their stars, where the environment is sufficiently cool for a core of ice and rock to **coagulate** and nucleate the formation of the planet. If this theory is correct, then the Hot Jupiters must have undergone a migration from the site of their formation to their current location. The cause of this migration mechanism and the details of why it did not operate in the solar system are the subjects of intensive theoretical investigation.

coagulate to cause to come together into a coherent mass



The presence of this extrasolar planet, 150 light-years from Earth, was discovered in 1999 when astronomers detected its subtle gravitational pull on the yellow, Sun-like star HD209458.

Due to the proximity to the parent star, there is a reasonable chance—one in ten—that the orbit of a Hot Jupiter is tilted at just the right angle so that the planet will be observed, with each orbit, to pass in front of the disk of star. The resulting dimming of the light from the star, called a transit, was first observed in 1999 for the Sun-like star HD209458. These observations proved that the radial velocity variations, by which the planet had been initially detected, truly were due to an orbiting planet (and not some form of undiagnosed variability in the star). Moreover, for the first time, astronomers were to estimate both the physical size and mass of a planet and thus calculate its density. Their conclusion was that this planet was indeed a gas giant, similar in mass and size to Jupiter. Later, astronomers further scrutinized this star with the Hubble Space Telescope. By observing how light of different colors is filtered by the outer reaches of the planet, they detected its atmosphere, the first such detection for a planet outside the solar system.

Astronomical Missions

The successes of the techniques described above, and the realization that these ground-based methods will not allow for the detection of small, rocky worlds similar to Earth, have inspired several astronomical satellites.

In 2009 the National Aeronautics and Space Administration (NASA) plans to launch the Space Interferometry Mission (SIM). Using SIM, astronomers will perform very precise **astrometry** to detect the **reflex motion** of stars due to orbiting planets. They hope to survey hundreds of stars for large **terrestrial planets** (greater than 5 Earth masses), orbiting at distances of several AU from their stars.

astrometry the measurement of the positions of stars on the sky

reflex motion the orbital motion of one body, such as a star, in reaction to the gravitational tug of a second orbiting body, such as a planet

terrestrial planets small rocky planets with high density orbiting close to the Sun; Mercury, Venus, Earth, and Mars

In the decade after SIM, NASA will launch the Terrestrial Planet Finder, with the objective of enabling astronomers to detect extrasolar planets that are true analogs of Earth and to study the atmospheres of those planets. In particular, NASA plans to search for atmospheric components, such as ozone, which may be attributable to life. SEE ALSO Hubble Space Telescope (volume 2); Jupiter (volume 2); Stars (volume 2); Sun (volume 2).

David Charbonneau

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Galaxies

Galaxies are collections of stars, gas, and dust, combined with some unknown form of **dark matter**, all bound together by gravity. The visible parts come in a variety of sizes, ranging from a few thousand **light years** with a billion stars, to 100,000 light-years with a trillion stars. Our own Milky Way galaxy contains about 200 billion stars.

dark matter matter that interacts with ordinary matter by gravity but does not emit electromagnetic radiation; its composition is unknown

light years one light year is the distance that light in a vacuum would travel in one year, or about 9.5 trillion kilometers (5.9 trillion miles)

Types of Galaxies

The invisible parts of galaxies are known to exist only because of their influence on the motions of the visible parts. Stars and gas rotate around galaxy centers too fast to be gravitationally bound by their own mass, so dark matter has to be present to hold it together. Scientists do not yet know the size of the dark matter halos of galaxies; they might extend over ten times the extent of the visible galaxy. What we see in our telescopes as a giant galaxy of stars may be likened to the glowing hearth in the center of a big dark house.

Imagine viewing a galaxy through a small telescope, as pioneering astronomers William and Caroline Herschel and Charles Messier did in the late eighteenth century. You would see mostly a dull yellow color from countless stars similar to the Sun, all blurred together by the shimmering Earth atmosphere. This light comes from stars that formed when the universe was only a tenth of its present age, several billion years before Earth existed.

American astronomer Edwin P. Hubble used a larger telescope starting in the 1920s and saw a wide variety of galaxy shapes. He classified them into

Spiral galaxies such as NGC 4414, a dusty spiral galaxy, form from fast spinning hydrogen gas. Central regions of the galaxy contain older yellow and red stars, with younger blue stars on the outer spiral arms, which are replete with clouds of interstellar dust.

elliptical, with a smooth texture; disk-like with spirals; and everything else, which he called irregular.

Elliptical Galaxies. Elliptical galaxies are three-dimensional objects that range from spheres to elongated spheroids like footballs. Some may have developed from slowly rotating hydrogen clouds that formed stars in their first billion years. Others may have formed from the merger of two or more smaller galaxies. Most ellipticals have very little gas left that can form new stars, although in some there is a small amount of star formation within gas acquired during recent mergers with other galaxies.

Spiral Galaxies. Spiral galaxies, which include the Milky Way, formed from faster-spinning clouds of hydrogen gas. Theoretical models suggest they got this spin by interacting with neighboring galaxies early in the universe. The center of a spiral galaxy is a three-dimensional bulge of old stars, surrounded by a spinning disk flattened to a pancake shape.

Hubble classified spiral galaxies according to the tightness of the spirals that wind around the center, and the relative size of the disk and bulge. Galaxies with big bulges tend to have more tightly wrapped spirals; they are designated type Sa. Galaxies with progressively smaller bulges and more open arms are designated Sb and Sc. Barred galaxies are similar but have long central barlike patterns of stars; they are designated SBa, SBb, and Sbc, while intermediate bar strengths are designated SAB.

Type Sa galaxies rotate at a nearly constant speed of some 300 kilometers per second (186 miles per second) from the edge of the bulge to the far outer disk. Sc galaxies have a rotation speed that increases more gradually from center to edge, to typically 150 kilometers per second (93 miles per second). The rotation rate and the star formation rate depend only on the average density. Sa galaxies, which are high density, converted their gas into stars so quickly that they have very little gas left for star formation today. Sc galaxies have more gas left over and still form an average of a few new stars each year. Some galaxies have extremely concentrated gas near their centers, sometimes in a ring. Here the star formation rate may be higher, so these galaxies are called starbursts.

The pinwheel structures of spiral galaxies result from a concentration of stars and gas in wavelike patterns that are driven by gravity and rotation. Bright stars form in the concentrated gas, highlighting spiral arms with a bluish color. Theoretical models and computer simulations match the observed spiral properties. Some galaxies have two long symmetric arms that give them a "grand design." These arms are waves of compression and **rarefaction** that ripple through a disk and organize the stars and gas into the spiral shape. These galaxies change shape slowly, on a timescale of perhaps ten rotations, which is a few billion years. Other galaxies have more chaotic, patchy arms that look like fleece on a sheep; these are called flocculent galaxies. The patchy arms are regions of star formation with no concentration of old stars. Computer simulations suggest that each flocculent arm lasts only about 100 million years.

rarefaction decreased pressure and density in a material caused by the passage of a sound wave

Irregular Galaxies. Irregular galaxies are the most common type. They are typically less than one-tenth the mass of the Milky Way and have irregular shapes because their small sizes make it difficult for spiral patterns to develop. They also have large reservoirs of gas, leading to new star formation. The varied ages of current stars indicate that their past star formation rates were highly nonuniform. The dynamical processes affecting irregulars are not easily understood. Their low densities and small sizes may make them susceptible to environmental effects such as collisions with larger galaxies or intergalactic gas clouds. Some irregulars are found in the debris of interacting galaxies and may have formed there.

Some small galaxies have elliptical shapes, contain very little gas, and do not see any new star formation. It is not clear how they formed. The internal structures of irregulars and dwarf ellipticals are quite different, as are their locations inside clusters of galaxies (the irregulars tend to be in the outer parts). Thus it is not likely that irregulars simply evolve into dwarf ellipticals as they age.

The spiral arms and dust clouds of the Whirlpool galaxy are the birthplace of large, luminous stars. Galaxies are composed of billions to trillions of stars, as well as gas, dust, and dark matter, all bound together by gravity.

Active Galaxies, Black Holes, and Quasars

In the 1960s, Dutch astronomer Maarten Schmidt made spectroscopic observations of an object that appeared to be a star but emitted strong radio radiation, which is uncharacteristic of stars. He found that the normal **spectral lines** emitted by atoms were shifted to much longer **wavelengths** than they have on Earth. He proposed that this redshift was the result of rapid motion away from Earth, caused by the cosmological expansion of the universe discovered in the 1920s by Hubble. The velocity was so large that the object had to be very far away. Such objects were dubbed quasi-stellar objects, now called **quasars**. Several thousand have been found.

With the Hubble Space Telescope, astronomers have recently discovered that many quasars are the bright centers of galaxies, some of which are interacting. They are so far away that their spatial extents cannot be resolved through the shimmering atmosphere. Other galaxies also show the unusually strong radio and infrared emissions seen in quasars; these are called active galaxies.

spectral lines the unique pattern of radiation at discrete wavelengths that many materials produce

wavelength the distance from crest to crest on a wave at an instant in time

quasars luminous objects that appear starlike but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

Energy sources for active galaxies are likely to be black holes, the mass of which can be millions to billions of times greater than that of the Sun.

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

X rays a form of high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

radio lobes two regions of radio emission above and below the planes of active galaxies; thought to originate from powerful jets being emitted from the accretion disk surrounding the massive black hole at the center of active galaxies

The energy sources for quasars and active galaxies are most likely **black holes** with masses of a billion suns. Observers sometimes note that black holes are surrounded by rapidly spinning disks of gas. Theory predicts that these disks accrete onto the holes because of friction. Friction also heats up the disk so much that it emits **X rays**. Near the black hole, magnetic and hydrodynamic processes can accelerate some of the gas in the perpendicular direction, forming jets of matter that race far out into intergalactic space at nearly the speed of light. Nearby galaxies, including the Milky Way, have black holes in their centers too, but they tend to be only one thousand to one million times as massive as the Sun.

Active spiral galaxies are called Seyferts, named after American astronomer Carl Seyfert. Their spectral lines differ depending on their orientation, and so are divided into types I and II. The lines tend to be broader, indicating more rapid motions, if Seyfert galaxies are viewed nearly face-on. Active elliptical galaxies are called BL Lac objects (blazars) if their jets are viewed end-on; they look very different, having giant **radio lobes**, if their jets are viewed from the side. These radio lobes can extend for hundreds of millions of light-years from the galaxy centers.

Galaxy Interactions

Galaxies generally formed in groups and clusters, so most galaxies have neighbors. The Milky Way is in a small group with another large spiral galaxy (Andromeda, or Messier 31), a smaller spiral (Messier 33), two prominent irregulars (the Large and Small Magellanic Clouds), and two dozen tiny galaxies. In contrast, the spiral galaxy Messier 100 is in a very large cluster, Virgo, which has at least 1,000 galaxies. With so many neighbors, galaxies regularly pass by each other and sometimes merge together, leading to violent gas compression and star formation. In dense cluster centers, galaxies merge into giant ellipticals that can be 10 to 100 times as massive as the Milky Way. There is a higher proportion of elliptical and fast-rotating spiral galaxies in dense clusters than in small groups. Presumably the dense environments of clusters led to the formation of denser galaxies.

The Milky Way Galaxy

In the 1700s the philosophers Thomas Wright, Immanuel Kant, and Johann Heinrich Lambert speculated that our galaxy has a flattened shape that makes the bright band of stars called the Milky Way. Because English physicist and mathematician Isaac Newton (1642–1727) showed that objects with mass will attract each other by gravity, they supposed that our galaxy disk must be spinning in order to avoid collapse. In the early 1800s William Herschel counted stars in different directions. The extent of the Milky Way seemed to be about the same in all directions, so the Sun appeared to be near the center.

In the 1900s American astronomer Harlow Shapley studied the distribution of **globular clusters** in our galaxy. Globular clusters are dense clusters of stars with masses of around 100,000 Suns. These stars are mostly lower in mass than the Sun and formed when the Milky Way was young. Other galaxies have globular clusters too. The Milky Way has about 100 globular clusters, whereas giant elliptical galaxies are surrounded by thousands of globulars.

Shapley's observations led to an unexpected result because he saw that the clusters appear mostly in one part of the sky, in a spherical distribution around some distant point. He inferred that the Sun is near the edge of the Milky Way—not near its center as Herschel had thought. Shapley estimated the distance to clusters using variable stars. Stars that have finished converting hydrogen into helium in their cores change their internal structures as the helium begins to ignite. For a short time, they become unstable and oscillate, changing their size and brightness periodically; they are then known as variable stars. American astronomer Henrietta Leavitt (1868–1921) discovered that less massive, intrinsically fainter stars vary their light faster than higher mass, intrinsically brighter stars. This discovery was very important because it enabled astronomers to determine the distance to a star based on its period and apparent brightness. Much of what we know today about the size and age of the universe comes from observations of variable stars.

Shapley applied Leavitt's law to the variable stars in globular clusters. He estimated that the Milky Way was more than 100,000 light years across, several times the previously accepted value. He made an understandable mistake in doing this because no one realized at the time that there are two different types of variable stars with different period-brightness relations: the so-called RR Lyrae stars in globular clusters are fainter for a given period than the younger **Cepheid variables**.

The Discovery of Galaxies

In the 1920s astronomers could not agree on the size of the Milky Way or on the existence of other galaxies beyond. Several lines of conflicting evidence emerged. Shapley noted that nebulous objects tended to be everywhere except in the Milky Way plane. He reasoned that there should be no special arrangement around our disk if the objects were all far from it, so

WHEN GALAXIES COLLIDE

Collisions between galaxies can form spectacular distortions and bursts of star formation. Sometimes bridges of gas and stars get pulled out between two galaxies. In head-on collisions, one galaxy can penetrate another and form a ring. Interactions can create bars in galaxy centers and initiate spiral waves that make grand design structure. Close encounters can also strip gas from disks, which then streams through the cluster and interacts with other gas to make X rays.

globular clusters roughly spherical collections of hundreds of thousands of old stars found in galactic haloes

Cepheid variables a class of variable stars whose luminosity is related to their period; periods can range from a few hours to about 100 days—the longer the period, the brighter the star this peculiar distribution made him think they were close. Actually the objects are distant galaxies, and dust in the Milky Way obscures them. The distance uncertainty was finally settled in the 1930s when Hubble discovered a Cepheid variable star in the Andromeda galaxy. He showed from the period-brightness relationship that Andromeda is far outside our own galaxy.

Next Generation Space Telescope the telescope scheduled to be launched in 2009 that will replace the Hubble Space Telescope

nuclear black holes black holes that are in the centers of galaxies; they range in mass from a thousand to a billion times the mass of the Sun

Galaxy investigations will continue to be exciting in the coming decades, as new space observatories, such as the **Next Generation Space Telescope**, and new ground-based observatories with flexible mirrors that compensate for the shimmering atmosphere, probe the most distant regions of the universe. Scientists will see galaxies in the process of formation by observing light that left them when the universe was young. We should also see quasars and other peculiar objects with much greater clarity, leading to some understanding of the formation of **nuclear black holes**. SEE ALSO AGE OF THE UNIVERSE (VOLUME 2); BLACK HOLES (VOLUME 2); COSMOLOGY (VOLUME 2); GRAVITY (VOLUME 2); HERSCHEL FAMILY (VOLUME 2); HUBBLE CONSTANT (VOLUME 2); HUBBLE, EDWIN P. (VOLUME 2); HUBBLE SPACE TELESCOPE (VOLUME 2); SHAPLEY, HARLOW (VOLUME 2).

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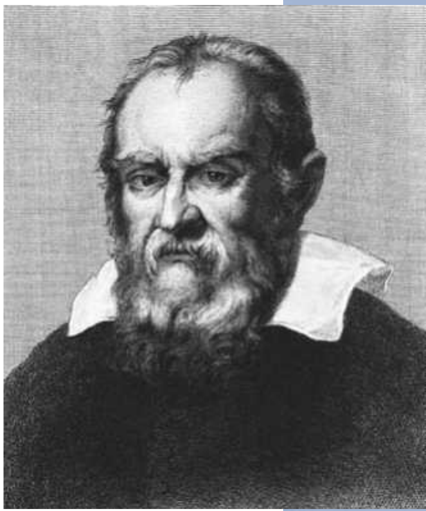
Galilei, Galileo

Italian Astronomer, Mathematician, and Physicist
1564–1642

Galileo Galilei (commonly known as Galileo) was a founder of modern physics and modern astronomy. He was born in Pisa, Italy, in 1564, and was a professor from 1592 through 1610 at Padua, which was part of the Venetian Republic. While in Pisa, he noticed a chandelier swinging in the cathedral and developed the physical law that shows that pendulums of the same length swing in the same time interval. Using a pendulum for timing, he experimentally worked out how objects accelerate while falling. In these experiments, he rolled objects down an inclined plane; the traditional story that he dropped weights from the Leaning Tower of Pisa was a myth.

In 1609 Galileo heard of a device that existed that could magnify distant objects. Using his experimental abilities, he ground lenses and assembled a telescope. He demonstrated its possibilities for aiding commerce by showing Venetian nobles that they could see ships approaching farther out than ever before. Starting that same year, Galileo also turned his telescope toward the sky. He subsequently discovered that the Moon had mountains and craters on it, that Jupiter had moons orbiting it, and that Venus went through a complete set of phases. These observations indicated that Greek philosopher Aristotle's (384–322 B.C.E.) view of the universe as unchanging and perfect was not true, and Galileo endorsed Polish astronomer Nicholas Copernicus's (1473–1543) idea that the Sun instead of Earth is the center of the solar system. Galileo's book *Sidereus nuncius* (The starry messenger; 1610) brought his discoveries to a wide audience.



Galileo Galilei faced an inquisition from the Roman Catholic Church in 1616 for endorsing Nicholas Copernicus's theory that the Sun, not Earth, was the center of the solar system.

Soon Galileo discovered sunspots, showing that the Sun is not a perfect body. But a controversy with a Jesuit astronomer over who discovered sunspots set the Roman Catholic Church against him. In 1616 the Church's Inquisition warned him against holding or defending Copernicus's ideas. To get his agreement, they showed him instruments of torture.

Galileo was relatively quiet until his book *Dialogo sopra i due massimi sistemi del mondo* (Dialogue on the two great world systems) was published in 1632. It was written in his native Italian instead of the scholarly Latin, to spread his discussion widely. The Inquisition then convicted him of teaching Copernicanism and sentenced him to house arrest. But even under those conditions, and the blindness that came on, he continued his scientific work. He died in Florence in 1642. In 1992 Pope John Paul II agreed that Galileo was correct to endorse Copernicanism, though Galileo was not pardoned. SEE ALSO Astronomy, History of (volume 2); Copernicus, Nicholas (volume 2); Jupiter (volume 2); Moon (volume 2); Religion (volume 4); Saturn (volume 2); Venus (volume 2).

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Government Space Programs

While the United States leads the world in space initiatives and exploration, it is not the only country with active interests off the planet. Rivaling the achievements of the National Aeronautics and Space Administration (NASA) in space exploration is Russia, which inherited the Soviet Union's space assets and cherished space history. Although economic uncertainties undermine the stability and future of the Russian space program, at the end of 2001 it remained the only country, other than the United States, which could launch people into orbit.

The Russian Focus on Space Stations

As a major partner in the International Space Station program, Russia is responsible for sending Progress unpiloted cargo ships and Soyuz capsules to the outpost. The Soyuz spacecraft is a small, three-person vessel that serves

The Soyuz-Frigate rocket is prepared for launch in July 2000. It carries the Cluster satellite of the joint ESA-NASA mission.

as an emergency escape system for the station crew. Russian cosmonauts are scheduled to be part of every space station crew, and the commander's post is to alternate between a Russian cosmonaut and an American astronaut. Rosviakosmos, the Russian Aviation and Space Agency, works closely with the prime Russian aerospace contractor, the Korolev Rocket & Space Corporation Energia, which is also known as RKK Energia.

Russian companies built the station's base block, called Zarya, under a subcontract with the Boeing Company. Russia built and paid for the station's service module, named Zvezda, which serves as the living quarters for the station's crew and as the early command and control center. Russia has plans to build two research modules and docking compartments for the space station. Energia entered into a commercial agreement with the U.S. company Spacehab to develop one of the modules, which also could be used as temporary living quarters for visitors.

Russia had its own space station until 2001, when ground controllers shepherded the Mir space station through a fiery demise in Earth's atmosphere and burial at sea. Attempts to commercialize Mir failed and the Russian government ran out of funds to operate the space station. Most of the limited Russian government funding for space is earmarked for the International Space Station program.

Although Russian government funding for its space program is less than what is spent by the United States and many other countries, Russia has been remarkably resourceful in coming up with ways to finance and launch space hardware. For example, to the consternation of NASA and the other partners in the International Space Station program, Russia earned about $20 million by flying the first space tourist, American Dennis Tito, to the station in April of 2001. That amount of money would not even pay for a shuttle launch in America, but in Russia $20 million is enough to pay for several Soyuz and Progress flights to the station.

The Cooperative Efforts of Europe

Europe has been active in space for decades, working independently and with both the Americans and Russians long before the former Cold War foes began working together. While individual European countries maintain national space programs, most space initiatives are a combined effort managed through the fifteen-nation European Space Agency (ESA), which was founded in 1975. The countries that belong to ESA are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

Europe operates four space centers: the European Space Research and Technology Centre in the Netherlands; a control center in Germany; a hub for collecting and distributing information from Earth observation satellites in Italy; and the European Astronaut Centre in Germany, home to ESA's sixteen-member astronaut corps. Europe has its own launch system, the Ariane family of rockets, and a dedicated launch site in Kourou, French Guiana. Ariane rockets are sold commercially through Arianespace, which was formed in 1980 to market Ariane launch services worldwide. ESA's program includes both robotic and human space initiatives. ESA developed the Spacelab equipment that flew more than two dozen missions on NASA's space shuttles, and the agency sent astronauts to live on the Russian space station Mir.

ESA is a prime partner in the International Space Station program. Its contributions include the Columbus space laboratory, slated for launch in 2004, and a robotic arm for the Russian segments of the station. ESA also has plans for an automated cargo ferry for the station. Europe is a partner with NASA in the Hubble Space Telescope, the Ulysses solar probe, several Earth observation satellite systems, and several space-based observatories, including the Solar and Heliospheric Observatory, which is studying the Sun. ESA built the Huygens probe, which is en route to Saturn aboard the Cassini spacecraft. Huygens is to parachute through the hazy atmosphere of Titan, the largest moon of Saturn. Other planetary research projects include the Mars Express mission and the Rosetta comet probe. Space technology initiatives include the Artemis telecommunications satellites, the Galileo navigation satellites, and the SMART-1 spacecraft, the purpose of which is to demonstrate the use of solar-electric propulsion on a mission to the Moon.

Japan's Wide-Ranging Space Program

Japanese efforts to develop and market its own space launch system have been marred by difficulties, but the country has been a dedicated and stable space partner for the United States and Europe. Japan's space efforts are coordinated by the National Space Development Agency of Japan (NASDA), but several institutes, including the Institute of Space and Astronautical Sci-

China's space program launched the second of a series of unpiloted test flights that the government intends to culminate in a piloted space voyage early in the twenty-first century.

ence and the Science and Technology Agency, are also involved in space programs. Japan has a small astronaut corps that trains at the Johnson Space Center in Houston, Texas, alongside NASA astronauts.

Since the launch of its first satellite in February 1970, Japan has pursued advanced space technology. On July 4, 1998, Japan became only the third country in history to launch a probe to another planet, sending the Nozomi probe for a 2004 encounter with Mars. For the International Space Station, the Japanese are building a science laboratory called Kibo that includes an exposed back porch and a small robotic crane to operate experiments in the **vacuum** of space. In addition, Japan is developing a cargo

vacuum a space where air and all other molecules and atoms of matter have been removed transfer vehicle to ferry supplies to the station. Japan also is working on a system to land a spacecraft on the Moon. The project, which is targeted for launch in 2003, is called Selene ("Moon goddess") NASDA is backing a wide range of research efforts, including the development of a next-generation reusable space plane, new communications satellites, and Earth **remote sensing** systems.

remote sensing the act of observing from orbit what may be seen or sensed below Earth

Canada's Five-Pronged Program

The Canadian Space Agency has five major interests in space: Earth remote sensing, space science, human presence in space, satellite communications, and space technologies. Canada has a small but enthusiastic astronaut corps, which trains primarily at NASA's Johnson Space Center. Canada's first Earth-observing satellite, Radarsat, was launched in November 1995 and is being used for a variety of commercial and scientific projects including agricultural research, cartography, hydrology, forestry, oceanography, ice studies, and coastal monitoring.

Along with Russia, Europe, and Japan, Canada joins the United States as a full partner in the International Space Station program. Canada is providing a $1.6-billion remote manipulator system for the space station, which includes a 17.4-meter-long (57-foot-long) robotic arm, a mobile base, and robotic fingers to handle delicate assembly tasks.

The Ambitious Chinese Program

China has an ambitious space plan, which hopes to launch its own astronauts into orbit in 2003. Russia has trained Chinese astronauts at its cosmonaut training center in Star City, outside of Moscow. China unveiled its new spacecraft in a one-day, unpiloted test flight on November 20, 1999. In January 2001 the Shenzhou ("magic vessel") flew for a second test flight that lasted for a week. China has already launched its first navigation positioning satellite, the Beidou Navigation Test Satellite–1. Several institutes have joined together to develop a pair of microsatellites to map Earth and monitor natural disasters. Chinese officials have stated that the long-range goal of China's human space program is to build a space station. China, which is not a member of the International Space Station partnership, has developed and operated an unpiloted orbital platform in space.

The nation's Long March boosters have flown more than seventy missions since their debut in 1970, although the rocket has had some significant setbacks and spectacular failures. China also has had mixed success marketing its sixteen versions of the Long March rockets, with twenty-one commercial **payloads** flown through mid-2001. The country also is developing a new system of reusable launchers, as well as liquid- and solid-fuel boosters to carry small payloads into orbit.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

India's Emerging Program

Another emerging player in the world space community is India, which founded its space program in 1972 and has launched at least twenty-six satellites, nine of which have been dedicated to improving the country's communications. India is developing its own heavy-lift launcher to send communications satellites into desirable orbital slots 35,786 kilometers

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

(22,300 miles) above the planet. The country has delivered its own Earth-imaging satellites to **low Earth orbit** and flew a commercial mission in May 1999 with the Polar Satellite Launch Vehicle.

Other space initiatives include a proposal to send a robotic scientific probe to the Moon in 2005, in what would be India's first venture into deep space. This mission would also make India only the fourth nation—after the United States, Russia, and Japan—to send a spacecraft to the Moon. The lunar probe would be launched on the new heavy-lift booster under development, the Geostationary Satellite Launch Vehicle, which made its debut test flight on April 18, 2001.

Israel's Boosters and Satellites

With national security an overriding concern, the young Israeli space program is focused on remote sensing technology, launch vehicle development, and lightweight minisatellites. Israel's Shavit launcher made its debut on September 19, 1988, when it placed the Ofeq 1 engineering test satellite into a low Earth orbit.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

The Shavit booster is a small, three-stage, solid propellant booster based on a **ballistic** missile design. Israel Aircraft Industries, which developed the booster, is continuing to work on expanding the rocket's capabilities. An upgraded Shavit ("comet") was launched in 1995 to place the Ofeq 3 satellite into orbit. A launch failure in 1998 claimed the fourth satellite in the series, but a more advanced follow-on program, the Earth Resources Observation Satellite, has been successful.

Brazil's Developing Program

Brazil's space program is still young. Efforts to develop launch technology were stalled with the 1998 failure of its VLS-1 space booster. The accident also claimed a Brazilian research satellite. In October 1999, a joint Chinese-Brazilian Earth remote-sensing satellite was launched on a Chinese Long March booster, and the countries signed an agreement a year later to jointly develop and fly a follow-on mission. Brazil also developed a satellite to monitor the Amazon rain forest and has positions reserved in low Earth orbit for an eight-satellite communications network.

A junior partner in the International Space Station program, Brazil agreed to provide experiment platforms for use on the orbital outpost. The Technology Experiment Facility is intended to provide experiments involving long-term exposure to the space environment. Brazil also will provide a pallet that can be used to attach small payloads to the station's outer truss segments. Other equipment that Brazil has promised to supply to the space station include a research facility for optical experiments and Earth observations using the station's telescope-quality window; and an unpressurized cargo carrier that can be mounted in the shuttle's cargo bay and loaded with equipment for the space station. In exchange for these contributions, Brazil will have access to space station facilities for research and will be able to fly a Brazilian astronaut to the station to conduct experiments. SEE ALSO International Cooperation (volume 3); NASA (volume 3).

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Gravity

The term "gravity" implies to many the notion of weight. Since antiquity, objects have been observed to "fall down" to the ground, and it therefore seemed obvious to associate gravity with Earth itself. Earth pulls all material bodies downward, but some appear to fall faster. For example, a rock and a feather fall to the ground at appreciably differing rates, and the logical conclusion of such great intellects as Greek philosopher Aristotle (384–322 B.C.E.) was that heavier objects fall faster than lighter ones. In fact, many erroneously believe this today, but it is found not to be true when tested in a controlled experimental manner. Air resistance is the confusing culprit and, when removed or minimized, all bodies are observed to hit the ground in the same amount of time when dropped from the same height.

Newton's Law of Universal Gravitation

In 1687, English physicist and mathematician Isaac Newton examined the laws of motion and universal gravitation in a classic text, *The Principia*, making it possible to explain and predict the motions of the planets and their newly discovered moons. Gravity is not just a property of Earth but of any matter in the universe. The essence of Newton's law of universal gravitation is demonstrated by imagining a "point mass," which is a certain amount of matter concentrated into a space of virtually zero volume. Now, suppose there is another point mass located some distance away from the first mass. According to Newton, these two masses mutually attract one another along the straight line drawn directly between them. In other words, the first mass feels a "pull" towards the second mass and the second mass feels an equal amount of "pull" towards the first. Of course, the universe contains far more than just these two isolated masses. The gravitational interaction is between any given mass and any other mass. A particular mass has a total gravitational force acting upon it that is the **vector sum** of all the attractions from every other mass paired with it. Every other mass will attract the mass in question independently, as if the others are not present. Intervening matter does not block gravity.

vector sum sum of two vector quantities taking both size and direction into consideration

The more massive and closer neighbors to our imaginary test mass will exert a larger gravitational force on it than less massive, more distant objects. The force between the test mass and any other point mass is directly proportional to the product of these masses and inversely proportional to the square of the distance between them. Expressing the statement in the form of an algebraic equation yields:

$$F_{grav} = G \times \frac{m_1 \times m_2}{d^2}$$

F_{grav} is the gravitational force existing between point masses m_1 and m_2, and d is the distance between the two masses. G is a constant making the units consistent. Its value was unknown to Newton and was later experimentally determined.

Real objects are not point masses but occupy a volume of space and have an infinite variety of shapes. Newton's law applies here by assuming that any object is composed of many particles, each of which is a close approximation to the ideal point mass previously described. Since gravitation is a very weak force compared to electrical or nuclear interactions, small objects that are normally encountered are not held together by self-gravitation. Instead, the electrically based chemical and molecular bonds are responsible. Nonetheless, the object behaves gravitationally like a collection of point particles each pulling independently on any other separate object's collection of point particles.

Fortunately, most large celestial bodies, such as planets and stars, are nearly spherical in shape, have mass that is symmetrically distributed, and are fairly distant from each other compared to their diameters. Under these assumptions, we can treat each object as a point particle and use Newton's formulation. Near Earth, an object's weight is the combined attraction of every particle in it with every particle that makes up the planet. Since Earth is a rather symmetrically distributed sphere, the net attraction of all its mass points on the object is directed (more or less) toward its center, and the object accelerates or "falls" straight down when released. The attraction is mutual, as Earth accelerates "upward" towards the falling object. But Earth is very massive compared to the object, so its inertia or resistance to acceleration is much greater. Its acceleration is immeasurable and we simply observe objects falling "down" to the ground. Heavier objects accelerate downward at the same rate as lighter ones (neglecting air resistance) because of their correspondingly greater inertia.

Einstein's General Theory of Relativity

Throughout the 1800s, Newton's law of gravitation was applied with increasing precision to the observed orbits of planets and double stars. The planet Neptune was discovered in 1846 from the gravitational disturbance it created on the orbit of Uranus. Even modern space science relies on Newton's law of gravitation to determine how to send spacecraft to any place in the solar system with pinpoint accuracy. To better understand gravity's fundamental nature and account for observable departures from Newton's law, however, an entirely new approach was needed. German-born American physicist Albert Einstein provided this in 1915 with the general theory of relativity.

Rather than the "action-at-a-distance" concept inherent to Newton's formulation, Einstein reasoned that a mass literally distorts the shape of the "space" surrounding it. If a beam of light is sent through empty space, it will define a "straight-line" path and hence the shortest distance between two points. The presence of mass, however, will cause the beam to bend its direction of propagation from a straight line and therefore define a curvature to space itself.

To visualize this, imagine a stretched rubber sheet onto which a large mass is placed. This mass creates a depression in the area surrounding it

Astronauts and cosmonauts prepare to share a meal in the Zveda Service Module on the International Space Station (ISS). The absence of gravity can turn the simple act of opening a can into a challenge.

while the membrane is essentially "flat" farther out. The larger the mass, the larger and deeper the depression. If another smaller mass is placed on the sheet, it will "fall" into the dimple well created by the heavier object and appear to be "attracted" to it. Likewise, if friction could be eliminated, it is possible to project the lighter mass into the edge of the well at just the right speed and angle to cause it to circle the massive object indefinitely just as the planets orbit the Sun. The Sun is massive enough, Einstein calculated, to cause a measurable deviation in the direction of distant starlight passing near it. The accurate positional measurement of stars appearing near the Sun's edge was successfully made in 1919 during a total solar eclipse, and Einstein's predictions were verified. SEE ALSO EINSTEIN, ALBERT (VOLUME 2); MICROGRAVITY (VOLUME 2); NEWTON, ISAAC (VOLUME 2); ZERO GRAVITY (VOLUME 3).

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H

Herschel Family

William Herschel, his sister Caroline, and his son John constitute one of the most famous families in astronomy.

William Herschel (1738–1822) was born in Hanover, Germany, and moved to England in 1757 to pursue a career as a musician. However, his interests shifted and William began studying astronomy in 1766. He cataloged celestial objects in an attempt to determine the three-dimensional structure of the galaxy. William discovered over 800 double stars and showed that many of them revolve around each other. On March 13, 1781, William became the first person to discover a new planet: Uranus. He also discovered four moons: Titania and Oberon at Uranus, and Enceladus and Mimas at Saturn.

Caroline Herschel (1750–1848) joined William in England in 1772 to pursue a career as a singer. She began assisting William full-time with his astronomical observations in 1782 and also started observing on her own that year. She discovered eight comets, a record by a female astronomer until 1987. Caroline also compiled catalogs of star clusters and **nebulae**.

nebulae clouds of interstellar gas and/or dust

John (1792–1871) used the Sun's spectrum to determine its chemical composition and made long-term observations of solar phenomena. In the 1830s, he traveled to South Africa to observe southern hemisphere star clusters and nebulas and revised the nomenclature of southern stars. SEE ALSO Astronomy, History of (volume 2); Comets (volume 2); Small Bodies (volume 2); Stars (volume 2); Uranus (volume 2).

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Hubble Constant

Big Bang name given by astronomers to the event marking the beginning of the universe, when all matter and energy came into being

In the standard **Big Bang** model, the universe expands according to the Hubble law, a simple relation expressed as $v=H_o d$, where v is the velocity of a galaxy at a distance d, and H_o is the Hubble constant. The Hubble constant characterizes both the scale and age of the universe. A measurement of the Hubble constant, together with the ages of the oldest objects in the universe, and the average density of the universe, are all separately required to describe the universe's evolution. Measuring an accurate value of H_o was one of the motivating reasons for building the Hubble Space Telescope (HST).

The measurement of most distances in astronomy cannot be done directly because the size scales are simply too big. In general, the basis for estimating distances in astronomy is the inverse square radiation law, which states that the brightness of an object falls off in proportion to the square of its distance from us. (We all experience this effect in our own lives. A street light in the distance appears fainter than the one beside us.) Astronomers identify objects that exhibit a constant brightness (so-called "standard candles"), or those where the brightness is perhaps related to a quantity that is independent of distance (for example, period of **oscillation**, rotation rate, or color). The standard candles must then be independently calibrated (to absolute physical units) so that true distances (in meters or megaparsecs, where 1 megaparsec = 3.08×10^{22} meters) can be determined using the inverse square law.

oscillation energy that varies between alternate extremes with a definable period

Cepheid Variables

The most precise method for measuring distances is based on the observations of **Cepheid variables**, stars whose atmospheres pulsate regularly for periods ranging from 2 to about 100 days. Experimentally it has been established that the period of pulsation is correlated with the brightness of the star. High resolution is the key to discovering Cepheids in other galaxies—in other words, the telescope must have enough resolving power to distinguish Cepheids from other stars that contribute to the overall light of the galaxy. The resolution of the Hubble Space Telescope is about ten times better than can be generally obtained through Earth's turbulent atmosphere.

Cepheid variables a class of variable stars whose luminosity is related to their period; periods can range from a few hours to about 100 days—the longer the period, the brighter the star

The reach of Cepheid variables as distance indicators is limited, however, even with the HST. For distances beyond 20 megaparsecs or so, brighter objects than ordinary stars are required; for example, bright supernovae or the brightnesses of entire galaxies. The absolute calibration for all of these methods is presently established using the Cepheid distance scale. A Key Project of the HST has provided Cepheid distances for a sample of galaxies useful for setting the absolute distance scale using these and other methods.

Until recently, a controversy has existed about the value of the Hubble constant, with published distances disagreeing by a factor of two. However the new Cepheid distances from the HST have provided a means of calibrating several distance methods. For the first time, to within an uncertainty of 10 percent, all of these methods are consistent with a value of the Hubble constant in the range of about 60 to 70 kilometers (37.28 to 43.5 miles) per second per megaparsec. This implies an age of the universe of between 13,000 and 15,000 million years. SEE ALSO Hubble, Edwin P. (volume 2); Hubble Space Telescope (volume 2); Age of the Universe (volume 2).

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Hubble, Edwin P.

American Astronomer
1889–1953

American astronomer Edwin Powell Hubble's (1889–1953) key discovery was his finding that the universe is expanding.✶ Hubble received undergraduate degrees in math and astronomy from the University of Chicago.

✶NASA's Hubble Space Telescope, launched in 1990, bears this noted astronomer's name.

Edwin P. Hubble is best known for his determination that the more distant the galaxy, the quicker it moves away from Earth. This implied that the universe was expanding and led the way to the Big Bang theory.

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

nebulae clouds of interstellar gas and/or dust

Big Bang name given by astronomers to the event marking the beginning of the universe, when all matter and energy came into being

Upon graduation, he was awarded a Rhodes scholarship to Oxford University, where he studied law. After some time as a lawyer and teacher, he returned to the University of Chicago to pursue a doctorate in astronomy. During his studies, World War I (1914–1918) began. Hubble enlisted in the army and rose to the rank of major.

After the war, Hubble worked at Mount Wilson Observatory, California, which then contained the largest telescope in the world. In the early 1920s, scientists knew about our own **galaxy**, the Milky Way, but they did not know if anything was outside of it. Some had conjectured that **nebulae**, faint cloudy features in the night sky, were actually "island universes" or other galaxies. Hubble measured the distance to some of these nebulas and found that they indeed lay far outside the Milky Way. In further studies, he showed that these nebulas are actually other galaxies, and he went on to classify them.

After this work, he made the most remarkable discovery of his career. He found that the more distant the galaxy, the faster it is moving away from Earth. This relationship implies that the universe is expanding, and this knowledge led to the formation of the **Big Bang** theory describing the formation of the universe. The constant that describes the relationship between galaxy speed and distance is called the Hubble constant. SEE ALSO Astronomy, History of (volume 2); Astronomy, Kinds of (volume 2); Galaxies (volume 2); Hubble Constant (volume 2); Hubble Space Telescope (volume 2).

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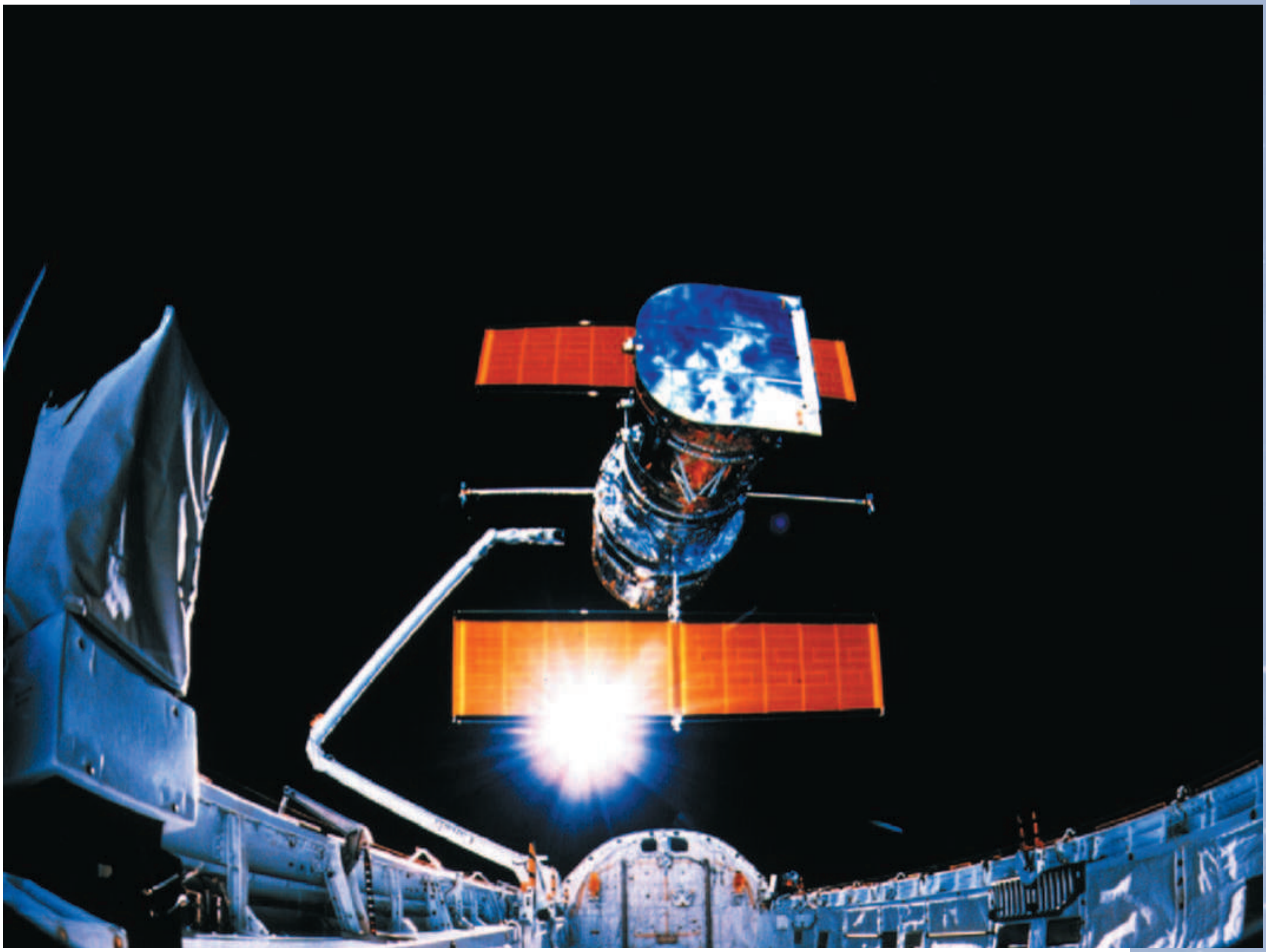
Hubble Space Telescope

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

The National Aeronautics and Space Administration's Hubble Space Telescope (HST) is the first major **infrared**-optical-**ultraviolet** telescope to be placed into orbit around Earth. The telescope is named after American astronomer Edwin P. Hubble, who found galaxies beyond the Milky Way in the 1920s, and discovered that the universe is uniformly expanding.

Located high above Earth's obscuring atmosphere, at an altitude of 580 kilometers (360 miles), the HST has provided the clearest views of the universe yet obtained in optical astronomy. Hubble's crystal-clear vision has fostered a revolution in optical astronomy. It has revealed a whole new level of detail and complexity in a variety of celestial phenomena, from nearby stars to galaxies near the limits of the observable universe. This has provided key insights into the structure and evolution of the universe across a broad scale. Its location outside of Earth's atmosphere has also provided Hubble with the ability to view astronomical objects across a wide swath of



Named after American astronomer Edwin Hubble, the Hubble Space Telescope is the first major infrared-optical-ultraviolet telescope placed into orbit around Earth. It can clearly observe objects less than one-billionth as bright as what can be seen by the human eye.

the **electromagnetic spectrum**, from ultraviolet light through visible and on to near-infrared **wavelengths**.

The heart of the telescope is the primary mirror, which is 94.5 inches (2.4 meters) in diameter. It is the smoothest optical mirror ever polished, with surface tolerance of one-millionth of an inch. It is made of fused silica glass and weighs about 670 kilograms (1,800 pounds).

Outside the blurring effects of Earth's turbulent atmosphere, the telescope can resolve astronomical objects ten times more clearly than can be seen with even larger ground-based optical telescopes. Hubble can see objects less than one-billionth as bright as what can be seen with the human eye. Hubble can detect objects as faint as thirty-first magnitude, which is comparable to the sensitivity of much larger Earth-based telescopes.

Hubble images have exceptional contrast, which allows astronomers to discern faint objects near bright objects. This enables scientists to study the environments around stars and to search for broad circumstellar disks of dust that may be forming into planets.

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

wavelength the distance from crest to crest on a wave at an instant in time

Launch and Servicing Missions

spectrograph an instrument that can permanently record a spectra

photometer instrument to measure intensity of light

The HST was launched by the space shuttle Discovery on April 24, 1990. Hubble initially was equipped with five science instruments: the Wide-Field Planetary Camera, the Faint Object Camera, the Faint Object **Spectrograph**, the High-Resolution Spectrograph, and the High-Speed **Photometer**. In addition, Hubble was fitted with three fine guidance sensors used for pointing the telescope and for doing precision astrometry—the measurement of small angles on the sky.

After Hubble was launched, scientists discovered that its primary mirror was misshapen because of a fabrication error. This resulted in spherical aberration: the blurring of starlight because the telescope could not bring all the light to a single focus. Using image-processing techniques to reduce the blurring in HST images, scientists were able to do significant research with Hubble until an optical repair could be developed.

In December 1993, the first HST servicing mission carried replacement instruments and supplemental optics aboard the space shuttle Endeavour to restore the telescope to full optical performance. A deployable optical device, called the Corrective Optics Space Telescope Axial Replacement (COSTAR), was installed to improve the sharpness of the first-generation instruments. The COSTAR was outfitted with pairs of small mirrors that intercepted the incoming light from the primary mirror and reconstructed the beam so that it was in crisp focus. In addition, the original Wide-Field Planetary Camera was replaced with a second camera, the Wide-Field Planetary Camera 2, which has a built-in correction for the aberration in the primary mirror.

In March 1997 the space shuttle Discovery returned to the HST for a second servicing mission. Two advanced instruments, the Near Infrared Camera and Multi-Object Spectrometer and the Space Telescope Imaging Spectrograph were installed to replace two first-generation instruments. Astronauts also replaced or enhanced several electronic subsystems and patched unexpected tears in Hubble's shiny, aluminized, thermal insulation blankets, which give the telescope its distinctive foil-wrapped appearance and protect it from the heat and cold of space.

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

In December 1999 a third servicing mission replaced a number of subsystems but added no new instruments. About a month before the mission a critical **gyroscope** had failed, leaving Hubble with only two operational gyros out of a total of six onboard. This had left the telescope incapable of precision pointing. The December mission restored Hubble to six fully functioning gyroscopes. The telescope's main computer was upgraded from a 1960s computer with 48 kilobytes of memory, to an Intel 486 microprocessor.

In March 2002, the next and most ambitious serving mission in the series, involving five exhausting six-hour space walks by pairs of astronauts, took place. They installed a high-efficiency camera called the advanced camera for surveys. The mission also performed "heart surgery" by replacing a complex power control unit, which required completely shutting off the telescope's electrical power. The telescope also got stubby new solar panels that increased the power enough for all of the instruments to operate simultaneously.

In 2004, the last servicing mission will install the wide-field planetary camera 3 and the cosmic origins spectrograph. Hubble will be on its own until 2010, when NASA stops the observing program and must decide whether to retrieve Hubble and install a rocket propulsion system that will put it into a safe higher orbit or let it reenter the atmosphere and largely burn up over the ocean.

How Hubble Operates

Hubble is controlled at the Goddard Space Flight Center in Greenbelt, Maryland. The Space Telescope Science Institute (STSI), located at the Johns Hopkins University in Baltimore, Maryland, directs the science mission. Space telescope research and funding engages a significant fraction of the worldwide community of professional astronomers. Astronomers compete annually for observation time on Hubble.

Observing proposals are submitted to peer review committees of astronomers. The STSI director makes the final decision and can use his or her own discretionary time for special programs. Accepted proposals must be meticulously planned and scheduled by experts at STSI to maximize the telescope's efficiency.

The space telescope is not pointed by "real-time" remote control but instead automatically carries out a series of preprogrammed commands over the course of a day. This is necessary because the telescope is in a **low Earth orbit**, which prevents any one ground station from staying directly in contact with it. Instead, controllers schedule intermittent daily linkups with the space observatory via a series of satellites in **geosynchronous orbit**.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis; an object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

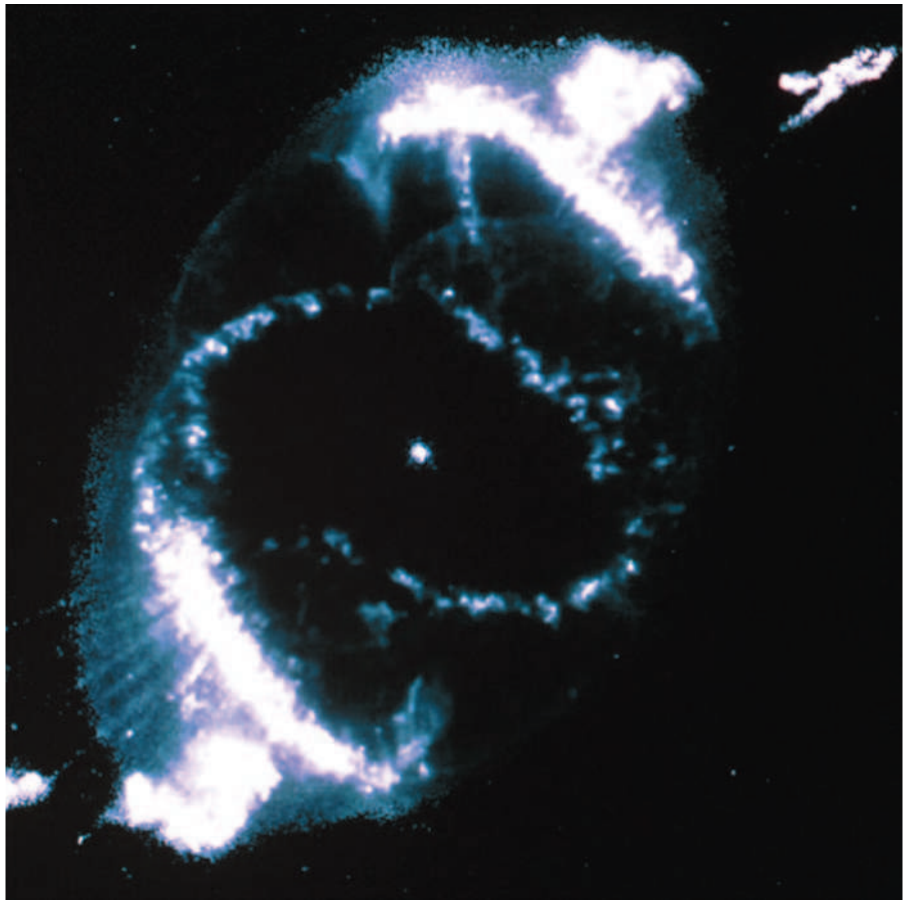
A date "pipeline," assembled and maintained by STSI, ensures that all observations are stored on optical disk for archival research. The data are sent to research astronomers for analysis, and then made available to astronomers worldwide one year after the observation.

By the turn of the twenty-first century, Hubble had looked at over 13,000 celestial targets and stored over 6 gigabytes of data onto large optical disks. The telescope had made nearly one quarter million exposures, approximately half of these were of astronomical targets and the rest were calibration exposures.

Hubble Provides New Insights

The HST has made dramatic inroads into a broad range of astronomical frontiers. Astronomers have used Hubble to look out into the universe over distances exceeding 12 billion light-years. Because the starlight harvested from remote objects began its journey toward Earth billions of years ago, the HST looks further back into time the farther away it looks into space (as do all large telescopes). Hubble has seen back to a time when the universe was only about 5 percent of its present age.

The Hubble Deep Field. Hubble's deepest views of the universe, made with its visible and infrared cameras, are collectively called the Hubble Deep Field. These "long exposures" of the universe reveal galaxies that existed when the universe was less than 1 billion years old. The Hubble Deep Field



The Hubble Space Telescope took the clearest images of the universe yet obtained in optical astronomy, including this image of the Cat's Eye Nebula, revealing a new level of detail and complexity in many celestial phenomena, and providing significant insights into the structure and evolution of the universe.

also uncovered hundreds of galaxies at various stages of evolution, strung along a corridor of billions of light years. The high resolution of Hubble images enables astronomers to actually see the shapes of galaxies in the distant past and to study how they have evolved over time.

Expansion and Age of the Universe. Another key project for the HST has been to make precise distance measurements for calculating the rate of expansion of the universe. This was achieved by measuring distances to galaxies much farther out than had previously been accomplished in decades of observing.

Determining the exact value of this rate is fundamental to calculating the age of the universe. In 1998, a team of astronomers triumphantly announced that they had accurately measured the universe's expansion rate to within an accuracy of 10 percent. This brought closure to a three-decade-long debate over whether the universe is 10 or 20 billion years old. The final age appears to be between 13 and 15 billion years, but this estimate is also affected by other parameters of the universe.

The HST was also used to find out if the universe was expanding at a faster rate long ago. This was done by using Hubble to peer halfway across the universe to find ancient exploding stars called supernovae. These stars can be used to calculate vast astronomical distances because they are so bright and shine at a predictable luminosity, which is a fundamental requirement for measuring distances.

Hubble observations, as well as other observations done with ground-based telescopes, show that the universe has not decelerated. In fact, to the surprise of astronomers, the expansion of the universe is accelerating, and therefore will likely expand forever. This realization offers compelling evidence that there is a mysterious repulsive force in space, first theorized by German-born American physicist Albert Einstein (1879–1955), which is pushing the galaxies apart—in addition to the original impetus of the **Big Bang**.

Big Bang name given by astronomers to the event marking the beginning of the universe, when all matter and energy came into being

This idea was bolstered in 2000 when Hubble astronomers accidentally discovered a supernova so far away, it exploded when the universe was actually decelerating. This supernova happened about 7 billion years ago, just before dark energy began accelerating the universe, like a car accelerating through a traffic light that has just turned green.

Black Holes. The HST has provided convincing evidence of the existence of supermassive black holes that are millions or even a billion times more massive than the Sun. Hubble's exquisite vision allows astronomers to zoom in on the environment around a black hole and make critical measurement of the motion of stars and gas around the hole, to precisely measure its mass. The measurements show that there is far more mass at the core of galaxies than can be accounted for by starlight. This unseen mass is locked away inside black holes.

HST observations of both quiescent and active galaxies, the latter of which pours out prodigious amounts of energy, have shown that supermassive black holes are commonly found at the hub of a **galaxy**. A Hubble census of black holes also showed that the mass of a black hole corresponds to the mass of the central bulge of a galaxy. Therefore, galaxies with large bulges have more massive black holes than galaxies with smaller bulges. This suggests that supermassive black holes may be intimately linked to a galaxy's birth and evolution.

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

Quasars. Hubble's keen ability to discern faint objects near bright objects allowed for definitive observations that showed the true nature of quasars, which are compact powerhouses of light that resemble stars and that reside largely at the outer reaches of the universe. HST observations conclusively showed that quasars dwell in the cores of galaxies, which means they are powered by supermassive black holes that are swallowing material at a furious rate.

Gamma-Ray Bursts. Hubble played a key role in helping astronomers resolve questions regarding the nature of mysterious gamma-ray bursts. Gamma-ray bursts are powerful blasts that come from random directions in the universe about once per day. Hubble observations found host galaxies associated with some of these blasts. This places the bursts at cosmological distances rather then being localized phenomena within our galaxy. Hubble also showed that the blasts occur among the young stars in the spiral arms of a host galaxy. This favors **neutron star** collisions or neutron star–black hole collisions as the source of the bursts.

neutron star the dense core of matter composed almost entirely of neutrons that remains after a supernova explosion has ended the life of a massive star

Stellar Environments. The HST has unveiled a wide variety of shapes, structures, and fireworks that accompany the birth and death of stars. HST images have provided a clear look at pancake-shaped disks of dust and gas swirling around and feeding embryonic stars. Besides helping build the star, the disks are also the prerequisite for condensing planets. Hubble images also show blowtorch-like jets of hot gas streaming from deep within the disks. These jets are an "exhaust product" of star formation.

In dramatic images, HST has shown the effects of very massive young stars on their surrounding nebulae. The astronomical equivalent of a hurricane, the intense flow of visible and ultraviolet radiation from an exceptionally massive young star eats into surrounding clouds of cold hydrogen gas, laced with dust. This helps trigger a firestorm of star birth in the neighborhood around the star.

The HST has produced a dazzling array of images of colorful shells of gas blasted into space by dying stars. These intricate structures are "fossil evidence" showing that the final stages of a star's life are more complex than once thought. An aging star sheds its outer layers of gas through stellar winds. Late in a star's life, these winds become more like a gale, and consequently sculpt strikingly complex shapes as they plow into slower-moving material that was ejected earlier in the star's life.

The most dramatic star-death observation for the HST has been tracking the expanding wave of debris from the explosion of supernova 1987A. HST observations show that debris from the supernova blast is slamming into a ring of material around the dying star. The crash has allowed scientists to probe the structure around the supernova and uncover new clues about the star's final years.

Extrasolar Planets. Even Hubble's powerful vision is not adequate to see the feeble flicker of a planet near a star. Nevertheless, Hubble was still very useful for conducting the first systematic search for a special type of planet far beyond our stellar neighborhood. For ten consecutive days Hubble peered at the globular cluster 47 Tucane to capture the subtle dimming of a star due to the eclipse-like passage of a Jupiter-sized planet in front of the star. Based on extrasolar planet discoveries in our own stellar neighborhood, astronomers predicted that seventeen planets should have been discovered. However, Hubble did not find any, which means that conditions favoring planet formation may be different elsewhere in the galaxy.

Aiming at a known planet 150 light-years away, Hubble made the first-ever detection of an atmosphere around a planet. When the planet passed in front of its star, Hubble measured how starlight was filtered by skimming through the atmosphere. Hubble measures the presence of sodium in the atmosphere. These techniques could eventually lead to the discovery of oxygen in the atmospheres in inhabited terrestrial extrasolar planets. SEE ALSO Astronomy, Kinds of (volume 2); Extrasolar Planets (volume 2); Gyroscopes (volume 3); Hubble, Edwin P. (volume 2); Observatories, Space-Based (volume 2).

Ray Villard

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Huygens, Christiaan

Dutch Astronomer and Mathematical Physicist
1629–1695

Christiaan Huygens (1629–1695) was born in the Hague, Netherlands. He is remembered for his work in optics, astronomy, and timekeeping.

Christiaan Huygens developed and patented the pendulum time-keeping device. The pendulum system of modern grandfather clocks grew from his idea.

Huygens developed lens-shaping techniques better than those of Italian mathematician and astronomer Galileo Galilei (1564–1642) and greatly improved the telescope. This permitted the use of high magnifications, leading to Huygens's discovery of Saturn's largest moon, Titan, in 1655. Huygens was also the first to recognize a ring around Saturn, and published a thorough explanation of it in *Systema Saturnium* in 1659, resolving a long-standing mystery that began with Galileo's first observation of Saturn. This book also contained a drawing showing two dark bands on Jupiter and a dark band on Mars.

Galileo had used a pendulum for timekeeping, but Huygens invented the pendulum clock in 1656 and patented it in 1657. Huygens developed the mathematical theory of the pendulum, including a formula for its behavior. Along with his studies of the pendulum, he theorized about the motions of bodies along various curves and drew conclusions related to planetary motions governed by gravity. Oddly, though, he did not accept English physicist and mathematician Isaac Newton's explanation of gravity.

Huygens later went back to the study of optics and developed long focal length lenses used in "aerial telescopes."

Huygens is the namesake of the European Space Agency's atmospheric probe of Titan, which is being carried by the Cassini orbiter to Saturn in 2004. The Cassini Program is a joint effort of the National Aeronautics and Space Administration, European Space Agency, and the Italian Space Agency to study the Saturn system. SEE ALSO Astronomy, History of (volume 2); Galilei, Galileo (volume 2); Government Space Programs (volume 2); NASA (volume 3); Robotic Exploration of Space (volume 2); Saturn (volume 2).

Stephen J. Edberg

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J

Jupiter

Jupiter is the largest planet in the solar system and is easily visible in the night sky. Jupiter's mass (1.9×10^{27} kilograms [4.2×10^{27} pounds]) is nearly two and a half times the mass of the rest of the solar system's planets combined. Jupiter's volume, filled mostly with gas, is 1,316 times that of Earth. The fifth planet from the Sun, Jupiter's year is 11.86 Earth years but its day is short, only nine hours and fifty-five minutes. Jupiter resembles a small star: its composition, like the Sun's, is mostly hydrogen and helium. It emits about twice the energy that it receives from the Sun and puts out over 100 times more heat than Earth. If Jupiter had been about 50 to 100 times larger, it might have evolved into a star rather than a planet.

Historic Observations of Jupiter

Jupiter has intrigued humans since antiquity. It is named for the king of the Roman gods, and most of its twenty-eight moons are named after the god's many lovers. In 1609 and 1610, Italian mathematician and astronomer Galileo Galilei and German astronomer Simon Marius began telescopic studies of Jupiter and its system. Galileo is credited with the discovery of Jupiter's four largest moons: Io, Europa, Ganymede, and Callisto, now called the Galilean satellites in his honor. These moons had an impact on the thinking of those times. It was believed then that Earth was the center of the universe and that all the planets and moons revolved around Earth. Galileo's observations showed that the four moons revolved around Jupiter, not Earth. This discovery contributed to Galileo's doom. He was condemned by the Catholic Church, forced to recant his discovery, and only in 1992 did Pope John Paul II agree that Galileo was right to support Copernicanism.

As telescopes improved, other astronomers continued to observe Jupiter and to study its colorful bands and the long-lived storm known as the Great Red Spot. Twenty-four other smaller satellites have been discovered, from Amalthea in 1892 to Leda in 1974 to twelve new moons in 2001. Observations from Earth showed that Jupiter has a massive **magnetosphere** and that the planet emits radiation at radio **wavelengths**. From this, astronomers deduced that Jupiter is surrounded by **radiation belts**, similar to Earth's **Van Allen radiation belts**, and that the planet must have a strong magnetic field.

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field; it is formed by the interaction of the solar wind with the planet's magnetic field

wavelength the distance from crest to crest on a wave at an instant in time

radiation belts two wide bands of charged particles trapped in a planet's magnetic field

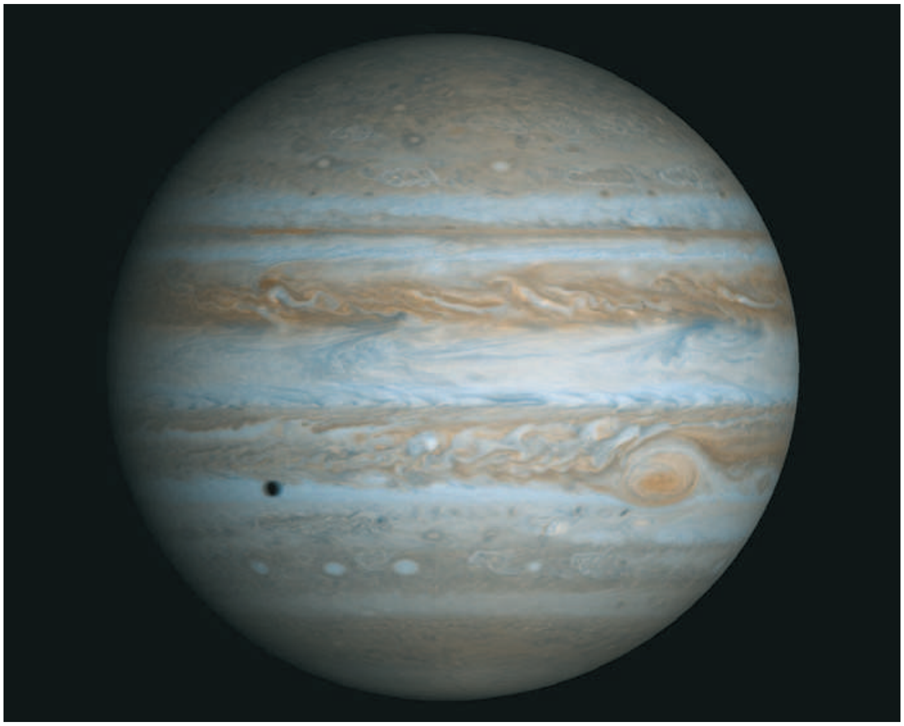
Van Allen radiation belts two belts of high energy charged particles captured from the solar wind by Earth's magnetic field

auroras atmospheric phenomena consisting of glowing bands or sheets of light in the sky caused by high-speed charged particles striking atoms in a planet's upper atmosphere

Spacecraft Explorations

Space missions allowed scientists to make great leaps forward in the exploration of Jupiter and its moons. The first spacecraft to fly by Jupiter were Pioneer 10 (in 1973) and Pioneer 11 (in 1974). They passed as close as 43,000 kilometers (26,660 miles) from Jupiter. Their suite of instruments made important observations of the atmosphere, magnetosphere, and space environment around the planet. In 1979 the spacecraft Voyager 1 and Voyager 2 passed close to Jupiter and its moons, making startling discoveries that included **auroras** on Jupiter, a ring system surrounding the planet, and active volcanoes on the moon Io.

In 1995, the Galileo spacecraft became the first to orbit Jupiter. It dropped a probe into the planet that survived for 57.6 minutes, until it was crushed by Jupiter's enormous pressure. The probe's instruments sent back



Named after the king of the Roman gods, Jupiter is the largest planet in the solar system—its mass is nearly two and a half times greater than the mass of the rest of the planets combined.

valuable information on the temperature, pressure, composition, and density of the upper atmosphere.

The Galileo probe provided scientists with their first glimpse inside the top layers of the atmosphere. One surprising discovery was that Jupiter has thunderstorms that are many times larger than those on Earth. The cause of the thunderstorms is the vertical circulation of water vapor in the top layers of Jupiter's atmosphere.

The main Galileo spacecraft has been making observations of Jupiter, its moons, and its environment since 1995, and these were slated to continue until 2002. Scientific observations continue to be made using Earth-based telescopes and the Hubble Space Telescope, which is in orbit around Earth. The combination of many sets of observations over time is extremely valuable for understanding Jupiter and its system.

The Atmosphere and Interior of Jupiter

Jupiter's atmosphere has alternating patterns of dark and light belts and zones. Within these belts and zones are gigantic storm systems such as the Great Red Spot. The locations and sizes of the belts and zones change gradually over time, and many of them can be seen through a telescope. The Great Red Spot has lasted for at least 100 years, and probably as long as 300 years. It rotates counterclockwise every six days, and this direction, plus its location in the southern hemisphere, indicates that it is a high-pressure zone. This differs from the cyclones that occur on Earth, which are low-pressure zones. The red color of the spot is something of a mystery. Several chemicals, including phosphorus, have been suggested as the cause of the red color but, on the whole, the reasons for Jupiter's different colors are not yet understood.

This image of Jupiter's Great Red Spot was captured by the spacecraft Voyager 1 in 1979 from a distance of 5.7 million miles (9.2 million kilometers) from the planet.

The atmosphere of Jupiter consists of about 81 percent hydrogen and 18 percent helium, with small amounts of methane, ammonia, phosphorus, water vapor, and various hydrocarbons. Observations by Galileo showed a cloud of fresh ammonia ice downstream from the Great Red Spot. Jupiter's atmosphere has strong winds, but the mechanisms that drive them are not well understood. There are at least twelve different streams of prevailing winds, and they can reach velocities of up to 150 meters per second (492 feet per second) at the equator. On Earth, winds are driven by large differences in temperature, differences that do not exist, at least not on the top part of Jupiter's atmosphere, where the temperature at the poles is about the same as that at the equator (−130°C [−202°F]).

The cloud layer, which is thought to be only about 50 kilometers (31 miles) thick, comprises only a small part of the planet. What is the interior of Jupiter like? The pressure inside Jupiter, which increases with depth, is enormous—it may reach about 100 million times the pressure on Earth's surface. Although we cannot directly observe Jupiter's interior, theory plus observations of the atmosphere and the surrounding environment suggest that below the cloud layer there is a 21,000-kilometer-thick (13,000-mile-thick) layer of hydrogen and helium. This layer gradually changes from gas to liquid as the pressure increases. Beneath this layer is a sea of liquid metallic hydrogen about 40,000 kilometers (24,800 miles) deep. Metallic hydrogen does not form on Earth, because our planet lacks the extreme pressures necessary to break up the hydrogen molecules and pack them so tightly that they break up and become electrically conductive. This electrically conductive metallic hydrogen is what drives Jupiter's strong magnetic field. Deeper still in Jupiter's interior is the core, which may be solid and rocky. It is estimated that the core is about one and a half times Earth's diameter, but ten to thirty times more massive. It is also very hot: about 30,000°C (54,000°F). This heat comes up through the layers and is detected at "hot spots" in the atmosphere, which are cloud-free holes.

Magnetic Field and Rings

Jupiter's sea of metallic hydrogen causes it to have the strongest magnetic field of any planet in the solar system. The field is inverted relative to Earth's, that is, a compass there would always point south. The region around the planet that is dominated by the magnetic field is called the magnetosphere. The stream of charged particles sent by the **solar wind** causes Jupiter's magnetosphere to be shaped like a teardrop, pointing directly away from the Sun. Inside the magnetosphere is a swarm of ions, **protons**, and **electrons**, which are called plasma. The plasma rotates along with Jupiter's magnetic field, blasting off charged particles. Some of them impact on the surfaces of the moons. On Io, volcanoes eject material into space, and the particles get caught up in Jupiter's magnetosphere. This creates a doughnut-shaped region of charged particles at about the distance from Jupiter of Io's orbit. This is called the Io plasma torus. It was first observed by the Pioneer spacecraft.

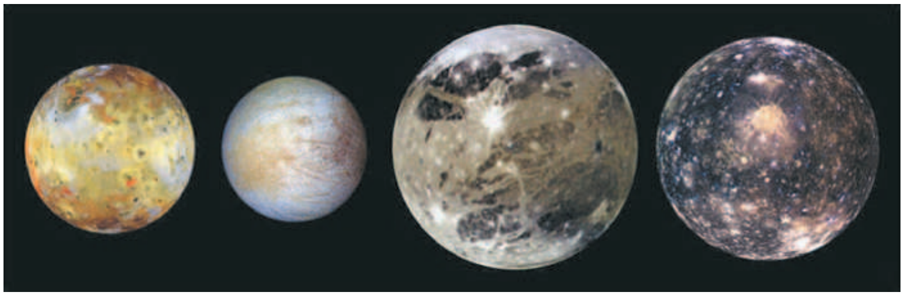
The Voyager missions showed that Jupiter is surrounded by faint rings. Unlike Saturn's rings, which are made up of icy particles, Jupiter's rings are made up of small dust particles. Two small satellites, Adrastea and Metis, are embedded within the rings. Observations by Galileo spacecraft showed that the dust comes from **meteoroids** impacting the satellites closest to Jupiter.

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

protons positively charged subatomic particles

electrons negatively charged subatomic particles

meteoroid a piece of interplanetary material smaller than an asteroid or comet



The four largest of Jupiter's sixteen moons include, from left to right, the volcanically active Io, the icy and mottled Europa, the large and rocky Ganymede, and the heavily cratered Callisto.

The Galilean Satellites

The Galilean satellites are all different from one another. Io and Europa have greater densities than Ganymede and Callisto, suggesting that the two inner moons (Io and Europa) contain more rock, and the outer moons more water ice.

Io. Io is the most volcanically active body in the solar system. It is the only place outside Earth where eruptions of hot magma have been observed. Other planets and moons in the solar system have been volcanically active in the distant past. Io is about the same size as Earth's Moon and, had it not been for its peculiar orbit, it too would have cooled down and volcanism would have ceased. Tidal stresses are produced within Io as a result of the gravitational pull of Jupiter, Europa, and Ganymede. These stresses cause the interior of Io to heat up, leading to active volcanism. About 100 active volcanoes have been seen so far on Io, many of which were discovered from their thermal signature in **infrared** observations made by the Galileo spacecraft. Some of the active volcanoes have plumes that can reach 300 kilometers (186 miles) high. Io's surface is very young as a result of many continuous volcanic eruptions, and no impact craters have been seen. The colors of the surface—vivid reds, yellows, greens, and black—are different from those seen on other solid bodies in the solar system. These colors are a result of sulfur and silicates on the surface. Io's lavas are hotter than those seen on Earth today, reaching temperatures of 1,500°C (2,700°F). They may be similar in composition to **ultramafic lavas** on Earth, which erupted millions of years ago.

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

ultramafic lavas dark, heavy lavas with a high percentage of magnesium and iron; usually found as boulders mixed in other lava rocks

Europa. Europa is particularly intriguing because of the possibility that it might harbor life. Observations by Galileo spacecraft showed that Europa's cracked surface resembles the ice floes seen in Earth's polar regions. High-resolution images show that some of the broken pieces of the ice crust have shifted away from one another, but that they fit together like a jigsaw puzzle. This suggests that the crust has been, or still is, lubricated from underneath by warm ice or liquid water. The two most basic ingredients for life are water and heat. Like Io, Europa is subject to tidal stresses because of

THE GALILEAN SATELLITES

Name	Radius	Distance from Jupiter	Density
Io	1,821 km	421,600 km	3.53 gm/cm^{-3}
Europa	1,565 km	670,900 km	2.97 gm/cm^{-3}
Ganymede	2,634 km	1,070,000 km	1.94 gm/cm^{-3}
Callisto	2,403 km	1,883,000 km	1.85 gm/cm^{-3}

Jupiter and Ganymede's gravitational pull. While Europa has no evidence of current active silicate volcanism, the tidal stresses may cause heating of the interior, providing the other key ingredient for life. Europa's surface does show evidence of ice volcanism. There are places where material appears to have come up from underneath as slushy ice and flowed on the surface. Europa has very few impact craters, indicating that its surface is young. Slushy ice flowing over the surface probably erased many impact craters. Europa's surface composition is dominated by water, but Galileo detected other compounds, including hydrogen peroxide (H_2O_2) on the surface and a thin oxygen atmosphere. The behavior of Jupiter's magnetic field around Europa implies that there may be ions circulating globally beneath the icy surface.

Ganymede. Larger than the planets Mercury and Pluto, Ganymede was the first moon known to have a magnetic field, one of the earliest discoveries made by the Galileo mission. The field is stronger than that of Mercury. Ganymede has a core made up of metallic iron or iron sulfides. If the core is molten and moving, it would produce the strong magnetic field observed by Galileo. Ganymede's surface shows a complex geologic history. The surface is characterized by large dark areas and by bright grooved terrains. The grooves are thought to have formed when the crust separated along lines of weakness. Other images showed hillcrests and crater rims capped by ice, and old terrain cut by furrows and marked by impact craters. Observations in the ultraviolet made from the Hubble Space Telescope showed the presence of oxygen on Ganymede, and Galileo observations detected hydrogen escaping from Ganymede into space. These results indicate that Ganymede has a thin oxygen atmosphere. Astronomers believe that the atmosphere is produced when charged particles trapped in Jupiter's magnetic field come down to Ganymede's surface. The charged particles penetrate the icy surface, disrupting the water ice. The hydrogen escapes into space, whereas the heavier oxygen atoms are left behind.

Callisto. About the same size as the planet Mercury, Callisto is Jupiter's second largest moon. Its surface is heavily cratered, implying that it is extremely old, probably dating from about 4 billion years ago, which is close to the time when the solar system formed. Callisto's surface is icy and has some large impact craters and basins surrounded by concentric rings. The largest impact basin is called Valhalla, and it has a bright central region 600 kilometers (372 miles) in diameter, with rings extending to 3,000 kilometers (1,860 miles) in diameter. Galileo observations showed that Callisto has a magnetic field. Underneath its icy crust, Callisto may have a liquid ocean, which, if it is as salty as Earth's oceans, could carry enough electrical currents to produce the magnetic field. A major discovery made by the Galileo mission is that Callisto has a thin atmosphere of carbon dioxide. SEE ALSO Exploration Programs (volume 2); Galilei, Galileo (volume 2); NASA (volume 3); Planetary Exploration, Future of (volume 2); Robotic Exploration of Space (volume 2); Shoemaker, Eugene (volume 2); Small Bodies (volume 2).

Rosaly M. C. Lopes

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Kepler, Johannes

German Mathematician and Astronomer
1571–1630

Johannes Kepler was a German mathematician and astronomer who discovered three key laws that govern planetary motion. Born in Weil der Stadt, Germany, in 1571, Kepler studied astronomy and theology at the University of Tübingen before becoming an astronomy and mathematics professor in Graz, Austria, in 1594. In 1600 he accepted an invitation from Danish astronomer Tycho Brahe to become Brahe's assistant in Prague, and study the orbit of the planet Mars.

Johannes Kepler developed what came to be known as Kepler's three laws of planetary motion.

After Brahe's death in 1601, Kepler acquired Brahe's extensive astronomical records and studied them for years in an effort to prove the Copernican model of the solar system. During this time he discovered what are now known as Kepler's three laws of planetary motion. The first law, published with the second in 1609, revealed that planets do not orbit in perfect circles, as had been previously assumed, but in ellipses, with the Sun at one focus. The second law found that planets sweep out equal areas in equal periods of time. The third law, published separately in 1619, stated that the square of a planet's orbital period is proportional to the cube of the orbit's mean radius. During this time Kepler also made advances in optics and mathematics. He died after a brief illness in Regensburg, Germany, in 1630. SEE ALSO ASTRONOMY, HISTORY OF (VOLUME 2); COPERNICUS, NICHOLAS (VOLUME 2); MARS (VOLUME 2).

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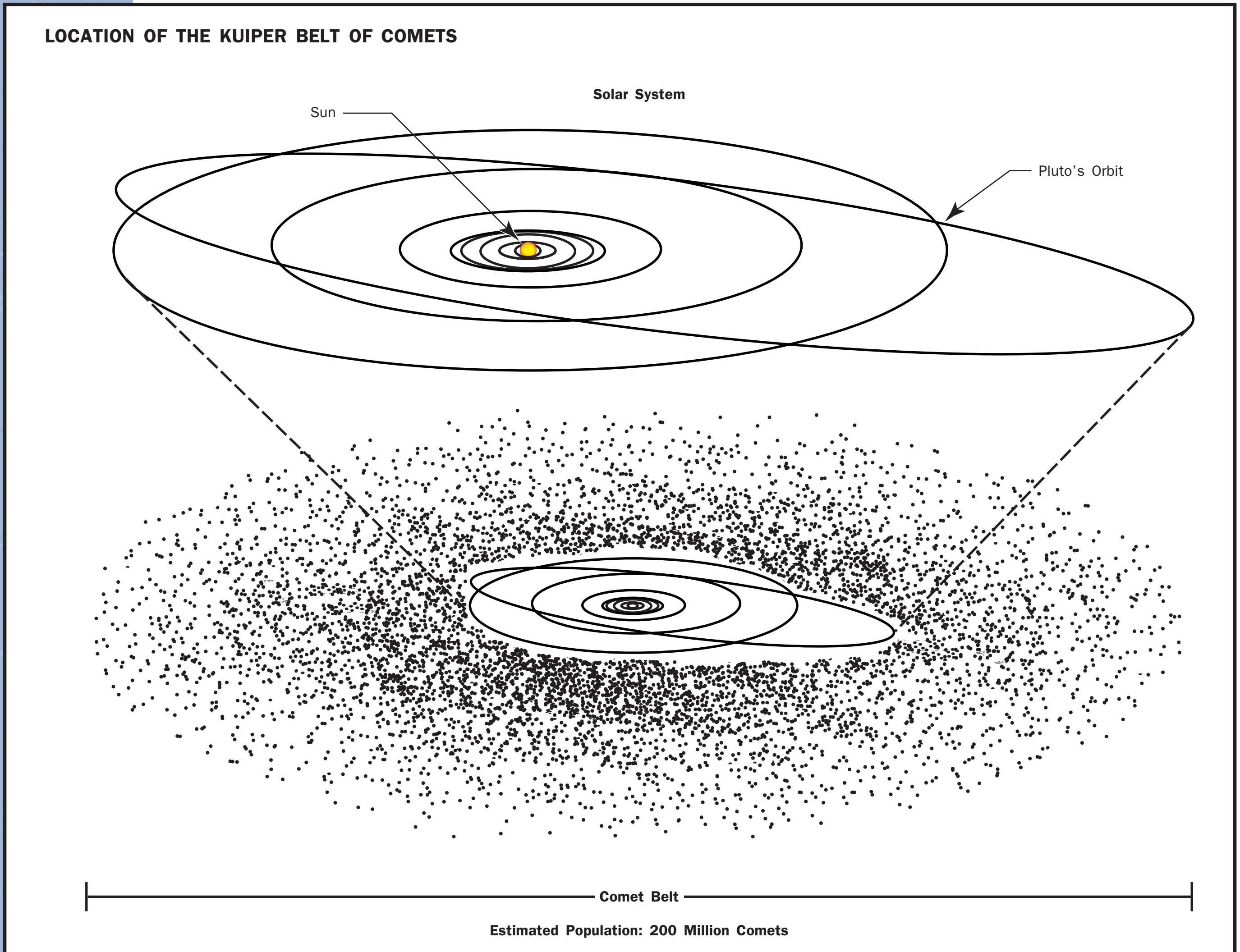
Kuiper Belt

Comets are some of the most spectacular objects in the night sky. About once per decade, a truly bright comet comes along and can be viewed by the unaided eye. Where do these comets come from? Where do they spend most of their lives?

Some comets orbit the Sun once every thousand years or so and can be easily viewed only when they are in the inner solar system. These are known as long period comets. Nonperiodic comets appear in the inner solar



SOURCE: Adapted from the Space Telescope Science Institute, PR-95-26, created June 14, 1995. <http://www.boulder.swri.edu/clark/chance/09kbelt.jpg>

system only once. Some comets, however, enter the inner solar system repeatedly and predictably. These are the short period comets.

ecliptic the plane of Earth's orbit

All of these comets are in orbit around the Sun but, unlike the planets, which all revolve around the Sun in the same direction and are confined to approximately the same plane as Earth's orbit (the plane of the **ecliptic**), cometary orbits show no preferred orientations. The shortest period comets (orbital periods of less than twenty years) are an exception. Comets in this group, called the Jupiter family comets (JFCs), revolve around the Sun near the plane of the ecliptic in the same direction as Earth's orbit.

Noting the different nature of the JFC orbits, astronomers sought explanations. It had been believed that all comets originated in the Oort cloud, a halo of comets at extremely large distances from the Sun. But in 1988, Martin J. Duncan, Thomas R. Quinn, and Scott Tremaine showed that it was impossible to have the random orientations of Oort cloud comets converted to the planar orientations of JFCs. They proposed that, in addition to the Oort cloud as a reservoir for comets, there must be a disk-like reservoir of comets with its inner edge near Neptune. They called this disk the Kuiper belt after Dutch-born American astronomer Gerard P. Kuiper, who postulated in 1951 that the solar system could not end at Neptune because that would imply a sharp edge to the disk out of which planets formed.✶

✶**In 1949 Irish astronomer Kenneth Edgeworth published an analysis similar to Kuiper's, but Kuiper's work was better known; in recognition of Edgeworth's contribution, some people call the comet reservoir the Edgeworth-Kuiper belt.**

The objects in the Kuiper belt represent remnants from the formation of our solar system. When the planets formed 4.6 billion years ago, they formed from an agglomeration of many planetesimals, or small solid celestial bodies. Beyond Neptune, the density of planetesimals was too low and the time for them to collide and accumulate was too long for another planet to form. Thus, the planetesimals remained in the outer solar system, past Neptune's orbit. They are called Kuiper belt objects (KBOs).

The existence of the Kuiper belt was confirmed in the 1990s. In 1992 David Jewitt and Jane Luu found the first KBO, designated 1992 QB_1. By 2000 many surveys had been performed and a total of 345 KBOs had been found.

In 2001, some one trillion planetesimals still existed in KBO orbits from Neptune outwards. Most remained in the Kuiper belt, interacting with one another or Neptune. Some of these were just barely visible from Earth through the most sensitive telescopes; others were too faint to see. But they do exist. And, as time passes, some will be perturbed into the inner solar system, where they will become Jupiter-family comets and appear periodically. SEE ALSO COMETS (VOLUME 2); KUIPER, GERARD PETER (VOLUME 2); OORT CLOUD (VOLUME 2); ORBITS (VOLUME 2); PLANETESIMALS (VOLUME 2); SMALL BODIES (VOLUME 2).

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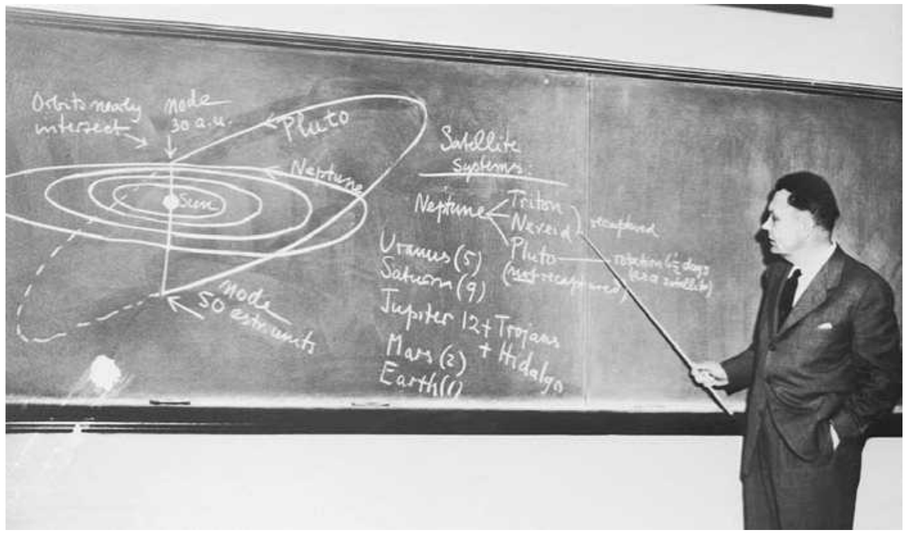
Kuiper, Gerard Peter

Dutch-American Astronomer
1905–1973

Gerard Peter Kuiper was the father of modern planetary astronomy. His work ran the gamut from star and planetary system formation to the study of the planets themselves. He used techniques ranging from visual observations to those requiring the latest technology, including **infrared** detectors, airborne observatories, and spacecraft.

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

Kuiper was born in Harenkarspel, the Netherlands. While in his native country, Kuiper made important contributions to the study of binary stars,



Gerard Peter Kuiper, astronomer and professor at Yerkes Observatory of the University of Chicago, explaining his theory that there is a disk of comets beyond Neptune's orbit.

which led to work on planetary system formation after he moved to the United States.

spectrographic studies studies of the nature of matter and composition of substances by examining the light they emit

During the winter of 1943–1944, Kuiper made **spectrographic studies** of the major planets and satellites, leading to the discovery that Saturn's largest moon, Titan, had an atmosphere containing methane. Studies of the brightnesses of the moons of Uranus and Neptune led to the discovery of additional satellites: Miranda, orbiting Uranus, in 1948; and Nereid, orbiting Neptune, in 1949.

In 1951, he proposed that a disk of comet nuclei extends from the solar system's planetary zone out to as much as 1,000 times the Earth-Sun distance (the astronomical unit [AU]). This is now called the Kuiper Belt and is recognized to extend from Neptune's distance (about 30 AU) to perhaps 50 to 100 AU.

✶A now-retired National Aeronautics and Space Administration airborne observatory that made groundbreaking infrared observations from the stratosphere was named after Kuiper.

In 1960, Kuiper founded the Lunar and Planetary Laboratory at the University of Arizona. He remained active in his later years, traveling and conducting site surveys for new observatories. Kuiper died in 1973.✶ SEE ALSO ASTRONOMY, HISTORY OF (VOLUME 2); CAREERS IN SPACE SCIENCE (VOLUME 2); COMETS (VOLUME 2); KUIPER BELT (VOLUME 2); NEPTUNE (VOLUME 2); SATURN (VOLUME 2); URANUS (VOLUME 2).

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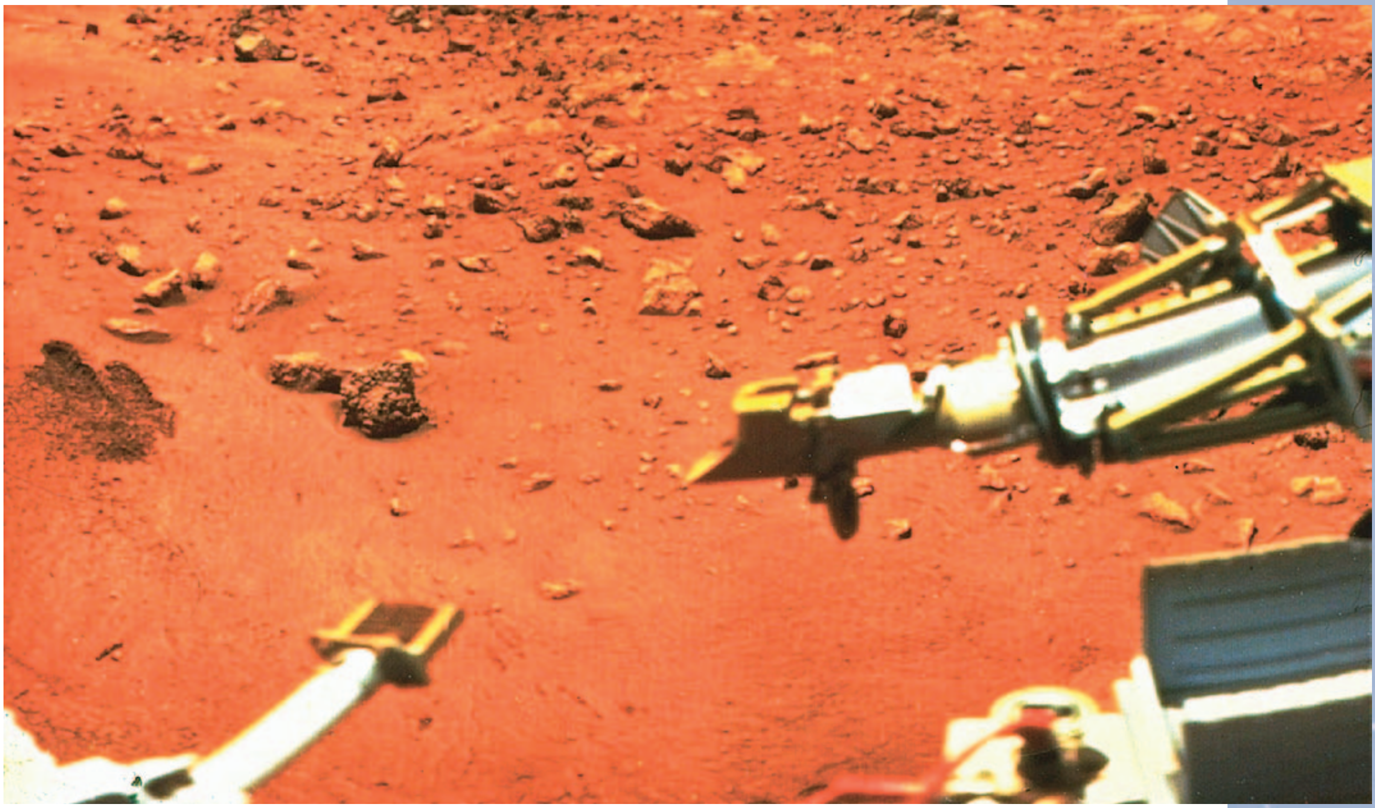
Life in the Universe, Search for

It is an old question, and a persistent one: Is there life elsewhere in the cosmos? Is the universe more than just an enormous collection of dead rock and glowing gas, with only one inhabited world?



The Viking 1 lander set down on the surface of Mars on July 20, 1976. It had a robotic arm that would scoop up samples of the martian soil and place them in three biology experiments onboard the lander. Although results from these experiments were ambiguous, most scientists believe that no life currently exists on the martian surface.

While speculation about life in space is an old pastime, a serious, scientific search for it is very new. Despite the impression one may get from movies and television, scientists still have not found any conclusive evidence of biology beyond Earth—not even evidence of the simplest microbes. But many scientists expect that this situation will soon change.

Part of their optimism is due to an astounding fact revealed by centuries of studying the heavens: The physics and chemistry of the farthest galaxies are the same as the physics and chemistry found on Earth. Astronomers have proven this by analyzing the light of distant objects with spectrographs. When they use these instruments to break up starlight into its constituent colors, they see the telltale "fingerprints" of atoms that are found on Earth: the ninety-two elements listed on the familiar periodical table of elements.

The light elements such as hydrogen, carbon, nitrogen, and oxygen are especially plentiful in space. These are the building blocks of all life on our planet. If the stuff of life is so commonplace, might not life itself also be widespread?

WHAT IS A SPECTROGRAPH?

Spectrographs are devices used by astronomers to break up the light collected by a telescope into its various colors, or wavelengths. Usually a prism or diffraction grating is used for this purpose. The resultant "rainbow" is then recorded on film or electronically. The lines (either bright or dark) that inevitably show up in such spectra indicate the composition of the gases in the outer regions of the stars or planets being examined.

How to Find Extraterrestrial Life

There are several obvious—and a few not-so-obvious—methods used in the hunt for extraterrestrial biology.

We could simply send rockets to other worlds and look for it. Since the mid-1960s, this has been done on a limited basis. Spacecraft have landed on the Moon, Venus, and Mars (although only the Moon has been visited by humans), and camera-toting probes have investigated all the other solar system planets except Pluto. Of these familiar locales, only the Moon and Mars have been examined in much detail. The Moon is sterile, which given its lack of atmosphere and liquid water, is hardly surprising. Mars is less obviously dead.✶

✶**The continuing efforts to find Martians are described in the section "What Have We Found?"**

Another approach is to use spacecraft to gather rocks from other worlds so they can be scrutinized in the laboratory. The Moon rocks lugged back by Apollo astronauts are an example of this, and the National Aeronautics and Space Administration (NASA) hopes to eventually use robot craft to bring back small pieces of Mars.

Still another way of getting extraterrestrial evidence is to find it on Earth. When **meteorites** hit nearby worlds, they kick up bits of rock, some of which might have enough speed to escape from their planet entirely. These rocky runaways then wander around the inner solar system. Some, by chance, will hit Earth. If they are large enough to avoid being completely incinerated as they plunge through our atmosphere, they could end up in a laboratory collection. A dozen meteorites from Mars have been found to date, brought here by nature rather than NASA.

meteorite any part of a meteoroid that survives passage through a body's atmosphere

For investigating distant worlds that orbit other stars, there is no hope of sending rockets or collecting meteorite samples. Instead, astronomers can use incoming electromagnetic radiation (more commonly known as light and radio) to search for certain "signatures" of life. Making a spectrographic analysis of the light reflected by the atmosphere of a far-off planet would permit scientists to check for the presence of oxygen or methane. Either one might be a clue to the presence of bacteria or possibly more advanced biological forms. The oxygen in Earth's atmosphere is the result of billions of years' worth of exhaust gases from bacteria and plants. Much of the methane is due to the digestive activities of cows and pigs. Finding large amounts of either of these gases in the atmosphere of a distant, Earth-sized planet would suggest an inhabited world.

A final technique is to look for radio or light signals that have been deliberately sent by sophisticated beings on other planets. Hunting for artificially produced signals is known as SETI, the Search for Extraterrestrial Intelligence. Since 1960, SETI scientists have used large radio antennas (and more recently, specially outfitted conventional telescopes) to scan for signals from intelligent aliens.

Where Do We Expect to Find Life?

All life on Earth is based on carbon chemistry and uses **DNA** as its blueprint for reproduction. Alien life might not sport DNA, but the odds are good that it would still be carbon-based. This is a sure bet because carbon has an exceptional ability to link up with other atoms into long chains, or polymers. To encourage this sort of chemical complexity, a solvent in which the atoms and molecules can easily move and meet is essential. Liquid water is the best such solvent, and therefore most researchers assume that the first step in tracking down extraterrestrial life is to find cosmic niches where liquid water is likely to both exist and persist.

DNA deoxyribonucleic acid; the molecule used by all living things on Earth to transmit genetic information

Until recently, astronomers felt that liquid water would be abundant only on Earth-like worlds that were situated at the right distance from their suns—neither too close, where water would boil, nor too far, where it would freeze. In our own solar system, orbital radii greater than that of Venus and less than that of Mars seem right, a region referred to as the Habitable Zone (HZ). For stars dimmer than the Sun, the HZ would be closer in and smaller; for brighter stars, it would be larger and farther out.

This straightforward idea has lately been modified. For one thing, an atmosphere can make a big difference in keeping a planet's surface warm. Mars is cold and dry today, but in the past, when it had a thicker atmosphere of carbon dioxide—an efficient greenhouse gas—there was liquid water gurgling across its landscape. So the extent of the HZ depends on a planet's atmosphere.

In addition, life has been discovered on Earth thriving in decidedly unfriendly environments. Tube worms and bacteria coexist in the inky darkness of ocean deeps. No type of photosynthesis will work in this environment, so the inhabitants of this strange ecosystem take advantage of the chemical nutrients that come churning out of hot water vents (some above 100°C [212°F]) in the ocean crust. Bacteria have also been found in another unexpected environment: kilometers under the ground, where they can live off of chemical nutrients naturally present in rock. The conditions in this environment are brutal: temperatures are high (again, often above 100°C), and the elbowroom, consisting of pores in the rock, is low. A little bit of liquid water in these pressure cooker environments allows these **extremophiles**, as they are called, to survive.

extremophiles microorganisms surviving in extreme environments such as high salinity or near boiling water

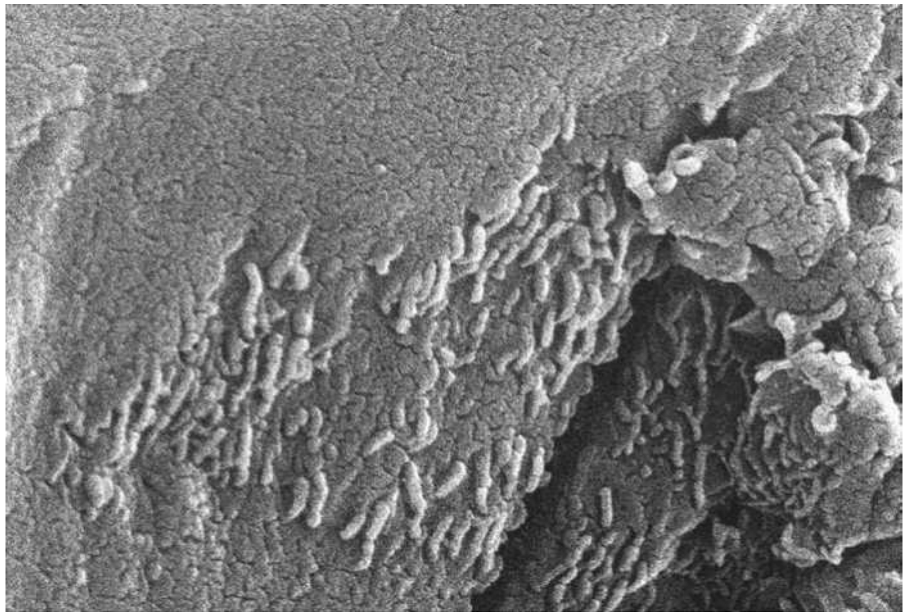
If life can exist in such difficult conditions on Earth, why not in space? These discoveries have challenged scientists with new thoughts about exactly what kinds of worlds are "habitable." The conventional concept of an HZ has been stretched to include icy moons and underground retreats, and this has encouraged scientists to look for life in what were once considered all the wrong places.

What Have We Found?

What is the scorecard on the search for life? Broadly speaking, the quest for extraterrestrial biology has been a two-pronged affair: a search for nearby, simple biology (e.g., microbes on Mars) and a hunt for distant, intelligent beings (SETI).

Mars. Of the possible nearby sites for life, Mars has traditionally been everyone's favorite. In the late nineteenth century, some astronomers astounded the world (and their colleagues) by claiming that thin, straight lines could be seen crisscrossing the surface of Mars. These "canals" bespoke the existence of an advanced society on the Red Planet. Unfortunately, the canals turned out to be optical illusions. Nevertheless, of all the worlds in our solar system, Mars is most like Earth. It beckons us with the prospect of nearby, alien life.

In 1976 NASA placed two robot spacecraft on the rusty surface of Mars: the Viking Landers. They were essentially mobile biological laboratories and spent days analyzing the Martian soil for the presence of microbes. They did not look for alien bacteria directly (for example, with a microscope), but searched for organic molecules in the soil, or soaked it with nutrient solu-



An electron microscope image of unknown tube-like structures on Mars. Some scientists believe that these structures are microscopic fossils of organisms that lived on the planet more than 3.6 billion years ago.

tions and watched for exhaust gases that would betray microbial metabolism. The conclusion of the Viking science team was that the Martian surface was sterile, although it is worth noting that two team members disagreed. This indicates how difficult it may be to design unambiguous experiments to look for extraterrestrial life.

Despite the failure of this sophisticated effort to find Martians directly, there is growing evidence that Mars may once have been a more hospitable environment for life. High-resolution photos from the orbiting Mars Global Surveyor reveal what look like sedimentary rock layers, strongly suggesting that more than 3 billion years ago Mars had lakes—environments that might have spawned life. This same spacecraft had an onboard **altimeter** and discovered an enormous flat region in Mars's northern hemisphere. This may once have been an ocean.

altimeter an instrument designed to measure altitude above sea level

In 1996, NASA scientists examined one of the known Martian meteorites (ALH 84001) and claimed to find several lines of evidence for fossilized microbes within. This evidence included the presence of various chemicals associated with biology, as well as small bits of iron (magnetite) that is commonly found in earthly bacteria. The scientists also made microscope photos of the meteorite's interior, which showed tiny rod- and wormlike structures that look very much like single-celled creatures. Unfortunately, there is great disagreement in the science community about whether this evidence is really due to long-dead Martians or to some inorganic phenomenon.

NASA is planning to send additional orbiters and rovers to Mars in the early years of the twenty-first century. The major goal of these expeditions is to learn more about the history of liquid water on the planet, as this is the key to an improved search for life. Ancient fossils may yet turn up, and some researchers speculate that the descendents of these ancient microbes (if there were any) might still be eking out a dark existence deep under the Martian surface where it is still relatively warm and wet.

Other Solar System Sites. Mars may not be the only solar system site for life other than Earth. Ever since the late 1970s, when the Voyager spacecraft made the first close-up photos of Jupiter's large moons, astronomers have considered whether life might exist even in these cold, dim environs. Europa is the most promising of the moons for biology. Its surface is bright white ice, cracked and glazed like a billiard ball with a bad paint job. The temperature on Europa is −160°C (−256°F), and one might naively assume that no liquid water could exist. But Europa is in a gravitational tug-of-war with its sister moons, and this keeps it in an egg-shaped orbit. The consequence is that Jupiter's changing gravitational pull squeezes and squishes Europa, heating it up the way pastry dough gets warm when kneaded. There is increasing evidence that beneath Europa's granite-hard, icy skin is a 100-kilometer-thick (62-mile-thick) liquid ocean, one that has been there for billions of years. At the bottom of this ocean, vents may spew hot water and chemicals, much as they do on Earth. Needless to say, if this picture of Europa is correct, some simple forms of life may be swimming in these dark, unseen waters.

In 1995, NASA's Galileo spacecraft began taking photos of Europa and other **Jovian** moons. That mission will be followed by an improved orbiter, probably to be launched in 2009, that will carry **radar** equipment to examine the Europan ice. The plan is to find out if the unseen ocean really exists, and if so, whether there any thin spots in the ice where future landers might be able to drill holes and drop equipment down into Europa's briny deep.

Jovian relating to the planet Jupiter

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Even Saturn's large moon Titan (which is bigger than Mercury) might conceivably host a bit of biology. Titan sports a substantial atmosphere, one that is denser than Earth's and that seems to be perpetually shrouded in smog. The air on Titan is mostly nitrogen and neon, but hydrocarbons and complex polymers make up the smog, together with a haze of methane (natural gas) crystals and ethane clouds. Some researchers suspect that lakes of liquid ethane, or even a moon-girdling ocean of ethane, methane, and propane, may exist on Titan.

All this hydrocarbon chemistry is discouragingly cold, −180°C (−292°F). Nevertheless, despite resembling an arctic oil refinery gone wild, it is possible that over the course of billions of years, Titan's hydrocarbons have spawned exotic life-forms. In 2004 a probe from the Cassini spacecraft will be dropped into Titan's chilly clouds for the first close-up glimpse of this oddball moon.

SETI. While NASA and other space organizations search for relatively simple living neighbors, SETI scientists turn their large antennas in the directions of nearby stars, hoping to find broadcasts from intelligent beings. The type of signals they look for are called narrowband, which means they are at one spot on the radio dial. Such transmissions could pack a lot of radio energy into a small frequency range, making detection even light-years away much easier. The most sensitive of these searches is Project Phoenix, which uses the 305-meter (1,000-foot) diameter radio antenna at Arecibo, Puerto Rico, to scrutinize about 1,000 Sunlike stars less than 150 light-years distant. Another SETI experiment is called SERENDIP, a project that is less sensitive but searches large tracts of the sky.

While SETI scientists still have not come up with a confirmed, extraterrestrial signal, they are greatly improving their equipment. In the next decades, they will scrutinize as many as a million star systems or more. In addition, new experiments using conventional optical telescopes have been started up. These look for very short (a billionth of a second), very bright laser pulses that an alien civilization might be sending earthward to catch our attention.

The discovery in recent years that many Sun-like stars have planets has greatly encouraged this type of search. It has also prompted space agencies around the world to consider building mammoth space telescopes that could uncover Earth-like planets around other stars. If this is done, then a spectrographic analysis of the atmospheres of these planets might turn up the traces of life—even simple life.

What Finding Extraterrestrial Life Would Mean

As noted earlier, we still have no convincing proof that there are any life-forms other than those found on Earth. Life is complex, and we still do not understand how it got started on our own planet. But to find living creatures—even microbes—on other worlds would tell us that biology is not some miraculous, extraordinary phenomenon. If SETI succeeds, and we find other intelligence, we might learn much about the universe and long-term survival. In either case, we would know that Earth and its carpet of living things is not the only game in town, but that we share the universe with a vast array of other life. SEE ALSO Extrasolar Planets (volume 2); First Contact (volume 4); SETI (volume 2); Robotic Exploration of Space (volume 2).

Seth Shostak

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Long Duration Exposure Facility (LDEF)

The Long Duration Exposure Facility (LDEF) project, originally called the Meteoroid and Exposure Module, was begun in 1970. Conceived and managed by the National Aeronautics and Space Administration's (NASA) Langley Research Center in Hampton, Virginia, the LDEF was designed as a large structure on which various tests of systems and materials could be carried out. One of its most important functions was to gather data on **meteoroids**, radiation, and other space hazards.

meteoroid a piece of interplanetary material smaller than an asteroid or comet

NASA's Long Duration Exposure Facility was designed to provide long-term data on the space environment. The LDEF was launched in 1984, and spent the next 5.7 years orbiting Earth.

The LDEF was a 9-meter-long (30-foot-long) hexagonal-shaped structure designed to fit snugly into the space shuttle orbiter's cargo bay. The research programs involved corporations, universities, and U.S. and foreign governments. The LDEF was a platform both for engineering and systems development studies and for pure scientific research.

One goal of the LDEF program was to see how a wide variety of materials, such as plastic and glass coverings for solar power (**photovoltaic**) cells, would react to spending a long time in **low Earth orbit** (LEO). The stability of certain plastics was tested. Some of the polymers were found completely unsuitable for use in space.

photovoltaic pertaining to the direct generation of electricity from electromagnetic radiation (light)

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Another goal was to measure the number and composition of meteoroids, debris, and radiation in LEO. The LDEF was a way for NASA to find out what sort of materials would be needed in any future space stations or satellites that would spend years in LEO. The experiments were mounted on eighty-six separate trays, normally one experiment per tray. Some experiments were carried out using multiple trays, such as the Space Environment Effects on Spacecraft Materials Experiment, which used four different trays, and the High Resolution Study of Ultraheavy Cosmic Rays, which used fifteen.

The LDEF was launched inside space shuttle Challenger on mission STS 41-C in April 1984. Commanded by Robert Crippen, this was the twelfth shuttle mission. The LDEF was placed in orbit at an altitude of 442 kilometers (275 miles) above Earth. It was intended that the LDEF would stay in orbit for just one year, but because of the Challenger disaster in January 1986, the facility was not recovered until January 1990. Thus, it ended up spending five years and seven months in space.

When it was picked up by the space shuttle Columbia, the LDEF was only a few weeks away from falling into Earth's atmosphere and burning up. Over the years, its orbit had decreased to about 280 kilometers (175 miles). As it moved closer to Earth, it also became closer to the upper layers of the planet's atmosphere. Thus, the particles of the atmosphere began to strike it and reduce both its speed and its altitude. The closer it got to Earth the faster it began to fall. The STS-32 mission, commanded by Dan Brandenstein, got there just in time.

Back on Earth, NASA found that the silicon-based adhesives they used on the LDEF spacecraft (as well as on the shuttle) had let off a form of gas that was transformed, by exposure to atomic oxygen, into silicates (SiO_2) and had contaminated some of the surfaces of the LDEF. This showed that there is a danger of silicate contamination of surfaces that have critical optical needs, such as windows, solar cells, and mirrors.

Following completion of the LDEF project, NASA's Langley Research Center built the Modular International Space Station Experiment. This is a test facility, about the size of a suitcase, which will continue the work started by the LDEF. A new wave of Passive Experiment Containers will be attached to the International Space Station and will provide data for the next generation of spacecraft. SEE ALSO Challenger (Volume 3); Exploration Programs (Volume 2); Space Shuttle (Volume 3).

Taylor Dinerman

Internet Resources

Long Duration Exposure Facility. NASA Langely Research Center. <http://setas-www.larc.nasa.gov/LDEF/index.html>.

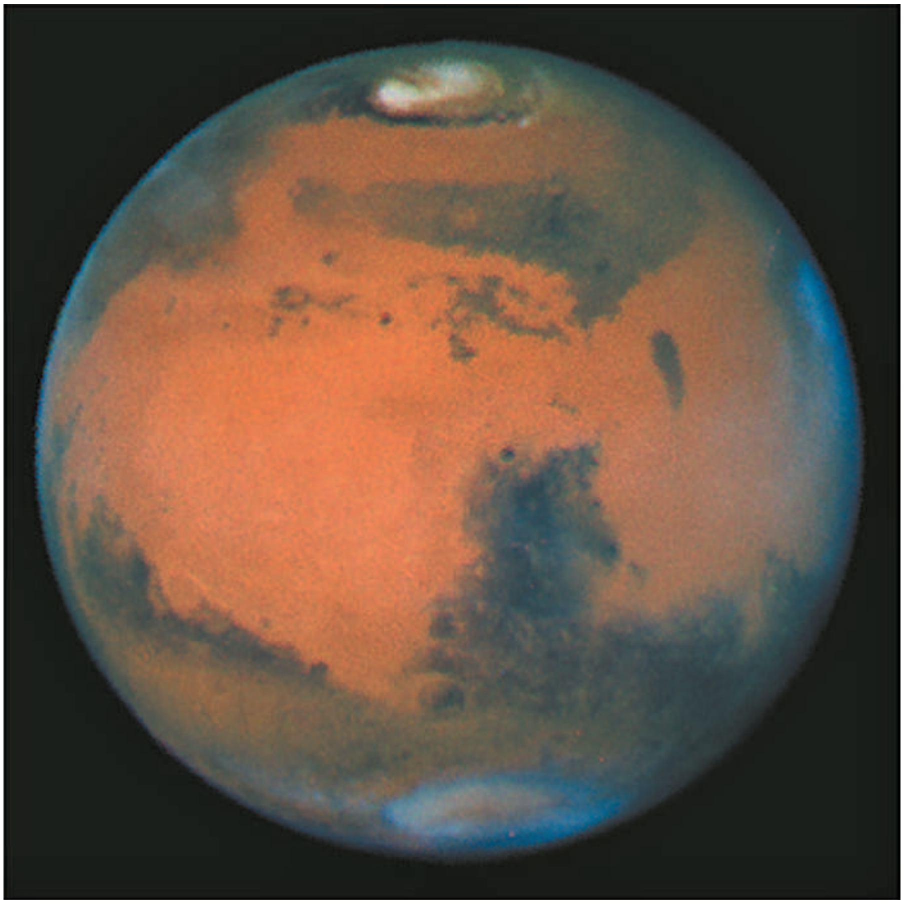
M

Mars

Mars has fascinated humans throughout history. It appears as a blood-red star in the sky, which led the Romans to name it after their war god. Its motions across the sky helped German astronomer Johannes Kepler (1571–1630) derive his laws of planetary motion, which dictate how celestial bodies move. Two small moons, Phobos and Deimos, were discovered orbiting Mars in 1877. But it is primarily the question of life that has driven scientists to study Mars.

Basic Physical and Orbital Properties

Mars displays a number of Earth-like properties, including a similar rotation period, seasons, polar caps, and an atmosphere. In the 1800s

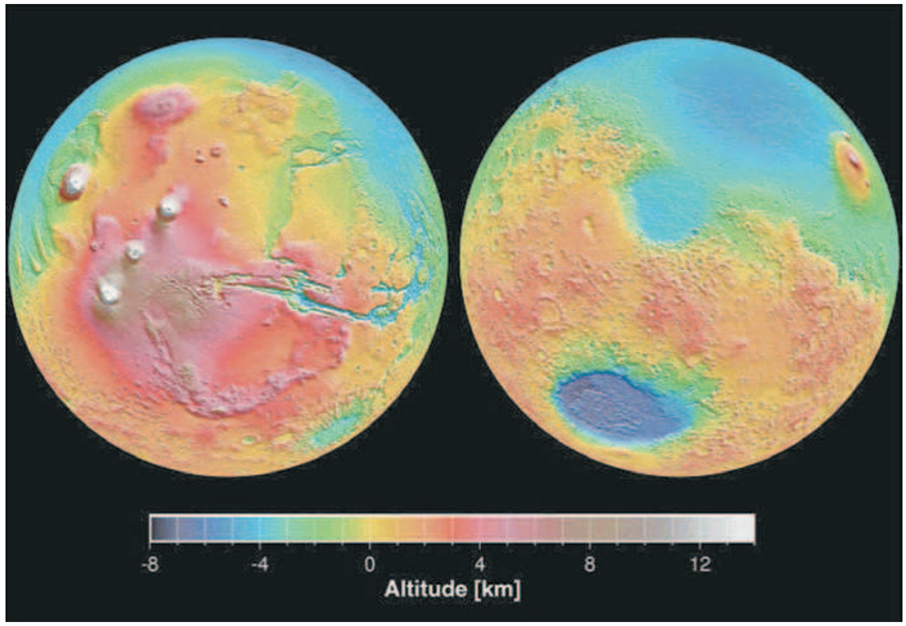


View of Mars from the Hubble Space Telescope. This image is centered on the dark feature known as Syrtis Major, which was first seen by astronomers in the seventeenth century. To the south of Syrtis is a large circular feature called Hellas, a deep impact crater.

astronomers also noted seasonal changes in surface brightness, which they attributed to vegetation. In 1877 Italian astronomer Giovanni Schiaparelli reported the detection of thin lines crossing the planet, which he called *canali*, Italian for "channels." But the term was mistranslated into English as "canals," which implies waterways constructed by intelligent beings. American astronomer Percival Lowell (1855–1916) popularized the idea of canals as evidence of a Martian civilization, although most of his colleagues believed these features were optical illusions. This controversy continued until the 1960s when spacecraft exploration of the planet showed no evidence of the canals.

Telescopic observations revealed the basic physical and orbital properties of Mars, as well as the presence of clouds and dust storms, which indicated the presence of an atmosphere. Dust storms can be regional or global in extent and can last for months. Global dust storms typically begin in the southern hemisphere around summer solstice because this is also when Mars is closest to the Sun and heating is the greatest. Temperature differences cause strong winds, which pick up the dust and move it around. Astronomers now know that the seasonal variations in surface brightness are caused by a similar movement of dust and not by vegetation.

Spectroscopic analysis suggested that the Martian atmosphere is composed primarily of carbon dioxide (CO_2), and this was confirmed by measurements made by the Mariner 4 spacecraft in 1965. The atmosphere is 96



Global false-color topographic views of Mars at different orientations from the Mars Orbiter Laser Altimeter. The right image features the Hellas impact basin (in purple), while the left shows the Tharsis topographic rise (in red and white).

percent carbon dioxide, 3 percent nitrogen, and about 1 percent argon, with minor amounts of water vapor, oxygen, ozone, and other substances. The atmosphere is very thin—the pressure exerted by the atmosphere on the surface is only 0.006 bar (the atmospheric pressure at sea level on Earth is 1 bar). This thin atmosphere is unable to retain much heat; hence the Martian surface temperature is always very cold (averaging −63°C [−81°F]). This thin atmosphere also is unable to sustain liquid water on the surface of Mars—any liquid water immediately evaporates into the atmosphere or freezes into ice. Geologic evidence suggests, however, that surface conditions have been warmer and wetter in the past.

A Geologically Diverse Planet

The geologic diversity of Mars was first realized from pictures taken by the Mariner 9 spacecraft in 1971–1972. Three earlier spacecraft (Mariner 4 in 1965 and Mariner 6 and Mariner 7 in 1969) had returned only a few images of the planet as they flew past. These images primarily revealed a heavily cratered surface, similar to the lunar highlands. Mariner 9, however, orbited Mars and provided pictures of the entire planet. Mariner 9 revealed that while 60 percent of the planet consists of ancient, heavily cratered terrain, the other 40 percent (mostly found in the northern hemisphere) is younger. Mariner 9 revealed the existence of the largest volcano in the solar system (Olympus Mons, which is about three times higher than Mt. Everest), a huge canyon system (Valles Marineris) that stretches the distance of the continental United States and is seven times deeper than the Grand Canyon, and a variety of channels formed by flowing water. These channels are not the same thing as the canals—no evidence of engineered waterways has been found on Mars, indicating that the canals are optical illusions. The discovery of channels formed by flowing water, however, reignited the question of whether life may have existed on Mars.

Findings of the Viking Missions

The Viking missions were designed to determine if life currently exists on Mars. Viking 1 and Viking 2 were each composed of an orbiter and a lander. Viking 1's lander set down in the Chryse Planitia region of Mars on July 20, 1976. Viking 2's lander followed on September 4, 1976, in the Utopia Planitia region to the northeast of where the first lander set down. Both landers were equipped with experiments to look for microbial life in the Martian soil as well as cameras to search for any movement of larger life-forms. All the experiments produced negative results, which together with the lack of organic material in the soil led scientists to conclude that no life currently exists on Mars.

The Viking orbiters, meanwhile, were providing the best information of the Martian surface and atmosphere to date. Scientists discovered that seasonal changes in the polar cap sizes are major drivers of the atmospheric circulation. They also discovered that the polar caps are primarily composed of carbon dioxide ice, but that the residual cap that remained at the North Pole even at the height of summer is probably composed of water ice. The frequency, locations, and extents of dust storms were studied in better detail than what Earth-based telescopes could do, providing new information on the characteristics of these events.

Is There Water on Mars?

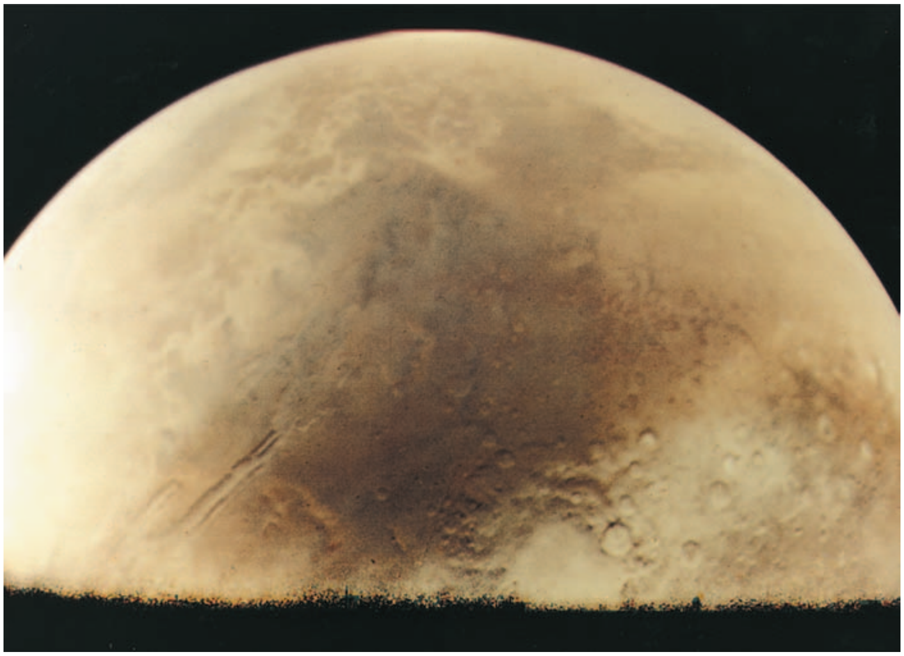
The surface also continued to reveal new surprises. Fresh **impact craters** are surrounded by fluidized **ejecta** patterns, likely produced by impact into subsurface water and ice. Detailed views of the volcanoes, channels, and canyons provided improved understanding of how these features formed and how long they were active. But most intriguing was the accumulating evidence that liquid water has played a major role in sculpting the Martian surface. Curvilinear features interpreted as shorelines were found along the boundary between the lower northern plains and the higher southern highlands, leading to suggestions that the northern plains were filled with an ocean at least once in Martian history.

impact craters bowl-shaped depressions on the surfaces of planets or satellites that are the result of the impact of space debris moving at high speeds

ejecta the material thrown out of an impact crater during its formation

Smooth-floored craters whose rims are cut by channels suggest that lakes collected in these natural depressions. The appearance of degraded craters in old regions of the planet suggests erosion by rainfall. Spectroscopic data from Earth-based telescopes as well as the Russian Phobos mission in 1989 indicate that water has affected the mineralogy of the surface materials over much of the planet.

Clearly Mars has been warmer and wetter in the past. Where did all that water go? Some water can be found as vapor in the thin Martian atmosphere and some is locked up as ice in the polar regions. But these two reservoirs contain a small percentage of the total amount of water that scientists believe existed on the planet. Some of the water likely has escaped to space because of Mars' small size and low gravity. But scientists now believe that a large amount of the water is stored in underground ice and water reservoirs. Liquid water, derived from these underground reservoirs, may exist again on the Martian surface in the future because of episodic changes in atmospheric thickness. Scientists now know that the amount of tilt of Mars's rotation axis changes on about a million-year cycle because of grav-



View of Mars from Viking I. Although the surface of Mars is dry, rocky, and covered with a thick powdery red soil, it is believed that the planet once had a more extensive atmosphere, allowing for the possible existence of ice and water.

itational influences from other planets. When the Martian poles are tipped more towards the Sun, the poles are exposed to more sunlight and the ices contained in these regions can vaporize to create a thicker atmosphere, which can cause higher surface temperatures by greenhouse warming.

Martian Meteorites

The Viking exploration of Mars ended in 1982, and few spacecraft provided information for the next fifteen years. The United States and Russia launched many spacecraft, but these missions were either failures or only partial successes. Nevertheless, new details were obtained during this time from a different source—meteorites. As early as the 1960s some scientists proposed that some unusual meteorites might be from Mars. These meteorites were volcanic rocks with younger formation ages (about 1 billion years) than typical meteorites (about 4 billion years). There are three major groups of these unusual meteorites: the shergottites, nakhlites, and chassignites (collectively called the SNC meteorites). In 1982 scientists discovered gas trapped in one of these SNC meteorites. When the gas was analyzed it was found to have **isotopic ratios** identical to those found in the Martian atmosphere. This discovery clinched the Martian origin for these meteorites. Scientists believe the meteorites are blasted off the surface of Mars during energetic impact events. The SNCs provide the only samples of the Martian surface that scientists can analyze in their laboratories because none of the Mars missions have yet returned surface material to Earth.

isotopic ratios the naturally occurring proportions between different isotopes of an element

The only Martian meteorite with an ancient formation age (4.5 billion years) was discovered in Antarctica in 1984. Analyses of **carbonate minerals** in the meteorite in 1996 revealed chemical residues that some scientists interpret as evidence of ancient bacteria on Mars. This discovery is still very controversial among scientists but it has raised the question of whether conditions on early Mars were conducive to the development of primitive life. This is a question that many future missions hope to address.

carbonate a class of minerals, such as chalk and limestone, formed by carbon dioxide reacting in water

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

Recent and Future Missions to Mars

Since 1997, spacecraft missions have made several new discoveries about Mars that have continued to support the hypothesis that the planet was warmer, wetter, and more active at times in the past. In 1997 the Mars Pathfinder mission landed on the surface of Mars in the mouth of one of the channels. The mission included a small rover called Sojourner, which was able to analyze a variety of rocks near the landing site. Sojourner revealed that the rocks display a variety of compositions, some of which suggest much more complicated geologic processes than scientists previously believed occurred on Mars. Images from the Mars Pathfinder cameras also suggest that more water flowed through this area than previously believed, increasing the estimates for the amount of water that has existed on the surface of the planet.

In late 1997 the Mars Global Surveyor (MGS) spacecraft began orbiting Mars. This mission is providing new information about atmospheric circulation, dust storm occurrence, and surface properties. MGS has provided scientists with the first detailed topography map of the planet. One of the major results of the topography map is that the northern plains are extremely smooth, a condition encountered on Earth only on sediment-covered ocean floors. This smooth surface, together with better definition of the previously proposed shorelines, lends further support to the idea that an ocean existed in the northern plains. A spectrometer on MGS revealed a large deposit of hematite in the heavily cratered highlands. Hematite is a mineral that is commonly formed by chemical reactions in hot, water-rich areas. Other instruments on MGS have determined that although Mars does not have an active magnetic field today, there was one in the past, as indicated by the remnant magnetization of some ancient rocks. This ancient magnetic field could have protected the early atmosphere from erosion by **solar wind** particles. Finally, the MGS cameras are revealing evidence of sedimentary materials in the centers of old craters and have found gullies formed by recent seepage of groundwater along the slopes of canyons and craters. Crater evidence suggests that some of the volcanoes have been active to more recent times than previously thought, suggesting that heat may be interacting with subsurface water even today. Such **hydrothermal** regions are known to be areas where life tends to congregate on Earth—could Martian biota have migrated underground and formed colonies around similar hydrothermal areas? Scientists do not know but there is much speculation about such a scenario.

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

hydrothermal relating to water at high temperature

The Mars Odyssey spacecraft successfully arrived at Mars in October 2001 and by January 2002 the spacecraft had settled into its final orbit. Its instruments are reporting strong spectroscopic evidence of near-surface ice across most of the planet.

Our view of Mars has changed dramatically from that of a cold, dry, geologically dead world to a warm, wet, oasis where life may have arisen and may yet thrive in certain locations. Several missions are planned in the next few years by the United States, the European Space Agency, Russia, and Japan to further explore Mars. These missions include a variety of orbiters, landers, rovers, and sample-return missions, which will allow scientists to answer additional questions about the history and future of Mars. Eventually humans will likely become directly involved in the exploration of Mars, and colonies may be established so that Mars can become our stepping-stone to further exploration of the universse. SEE ALSO Exploration Programs (volume 2); Government Space Programs (volume 2); Kepler, Johannes (volume 2); Life in the Universe, Search for (volume 2); NASA (volume 3); Planetary Protection (volume 4); Planetary Exploration, Future of (volume 2); Robotic Exploration of Space (volume 2); Sagan, Carl (volume 2).

Nadine G. Barlow

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Mercury

Mercury is the innermost and second smallest planet (4,878 kilometers [3,024 miles] in diameter) in the solar system (Pluto is the smallest). It has no known moons. As of the beginning of the twenty-first century, Mariner 10 had been the only spacecraft to explore the planet. It flew past Mercury on March 29 and September 21, 1974, and on March 16, 1975. Mariner 10 imaged only about 45 percent of the surface and only in moderate detail. As a consequence, there are still many questions concerning the history and evolution of Mercury. Two new missions to Mercury will be launched this decade. An American mission called MESSENGER will be launched in March 2004. It will make two **flybys** of Venus and two of Mercury before going into Mercury orbit in April 2009. A European mission called Bepi Colombo, after a famous Italian celestial dynamicist, is scheduled for launch in 2009.

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

elliptical having an oval shape

astronomical unit the average distance between Earth and the Sun (152 million kilometers [93 million miles])

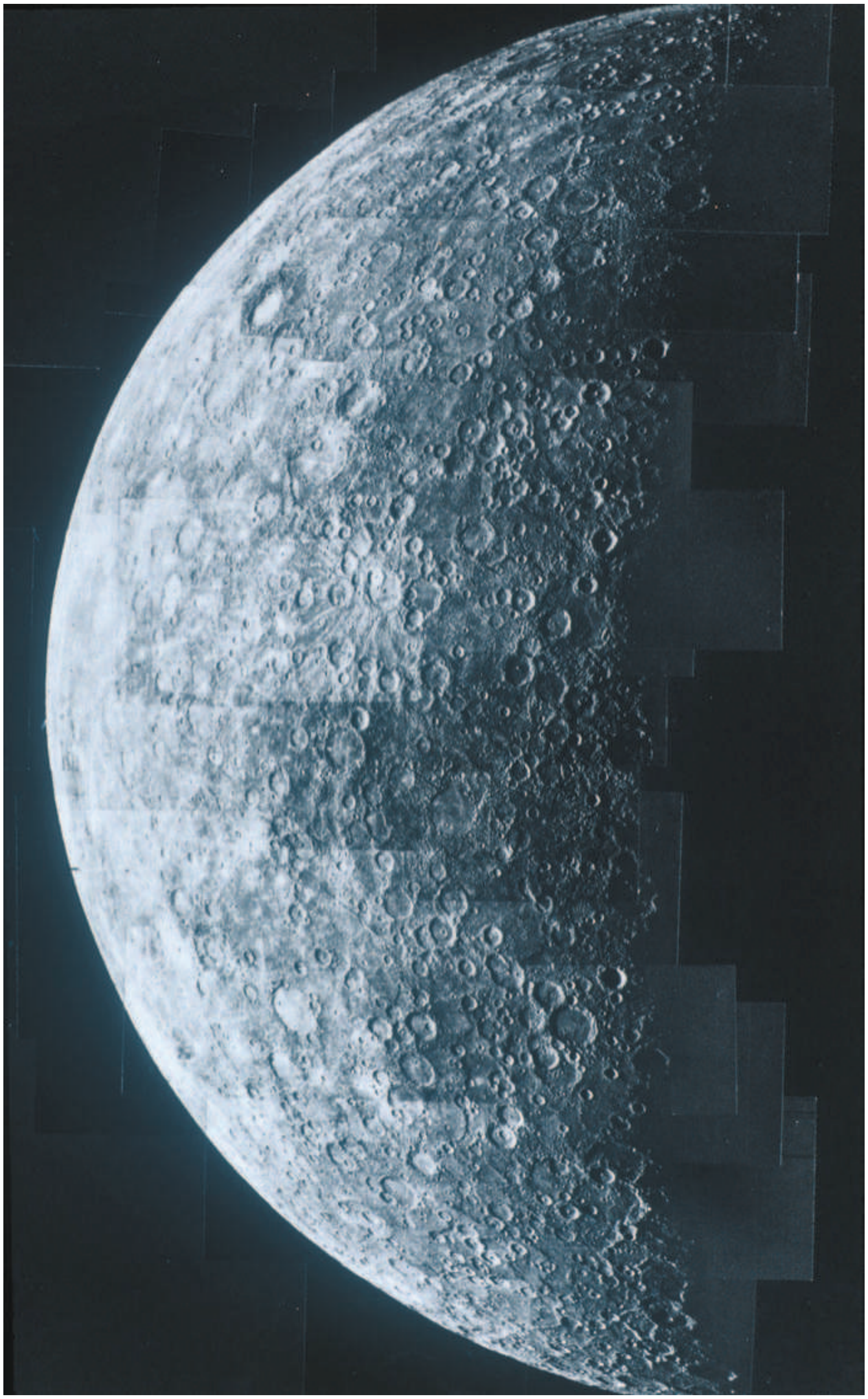
orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

Motion and Temperature

Mercury has the most **elliptical** and inclined (7 degrees) orbit of any planet except Pluto. Its average distance from the Sun is only 0.38 **astronomical unit** (AU). Because of its elliptical orbit, however, the distance varies from 0.3 AU when it is closest to the Sun to 0.46 AU when it is farthest away. Mercury's **orbital velocity** is the greatest in the solar system and averages 47.6 kilometers per second (29.5 miles per second). When it is closest to the Sun, however, it travels 56.6 kilometers per second (35.1 miles per second), and when it is farthest away it travels 38.7 kilometers per second (24 miles per second).

Mercury's rotational period is 58.6 Earth days and its orbital period is 87.9 Earth days. It has a unique relationship between its rotational and orbital periods: It rotates exactly three times on its axis for every two orbits around the Sun. Because of this relationship, a solar day (sunrise to sunrise) lasts two Mercurian years, or 176 Earth days.

Because Mercury is so close to the Sun, has no insulating atmosphere, and has such a long solar day, it experiences the greatest daily range in surface temperatures (633°C [1,171°F]) of any planet or moon in the solar sys-



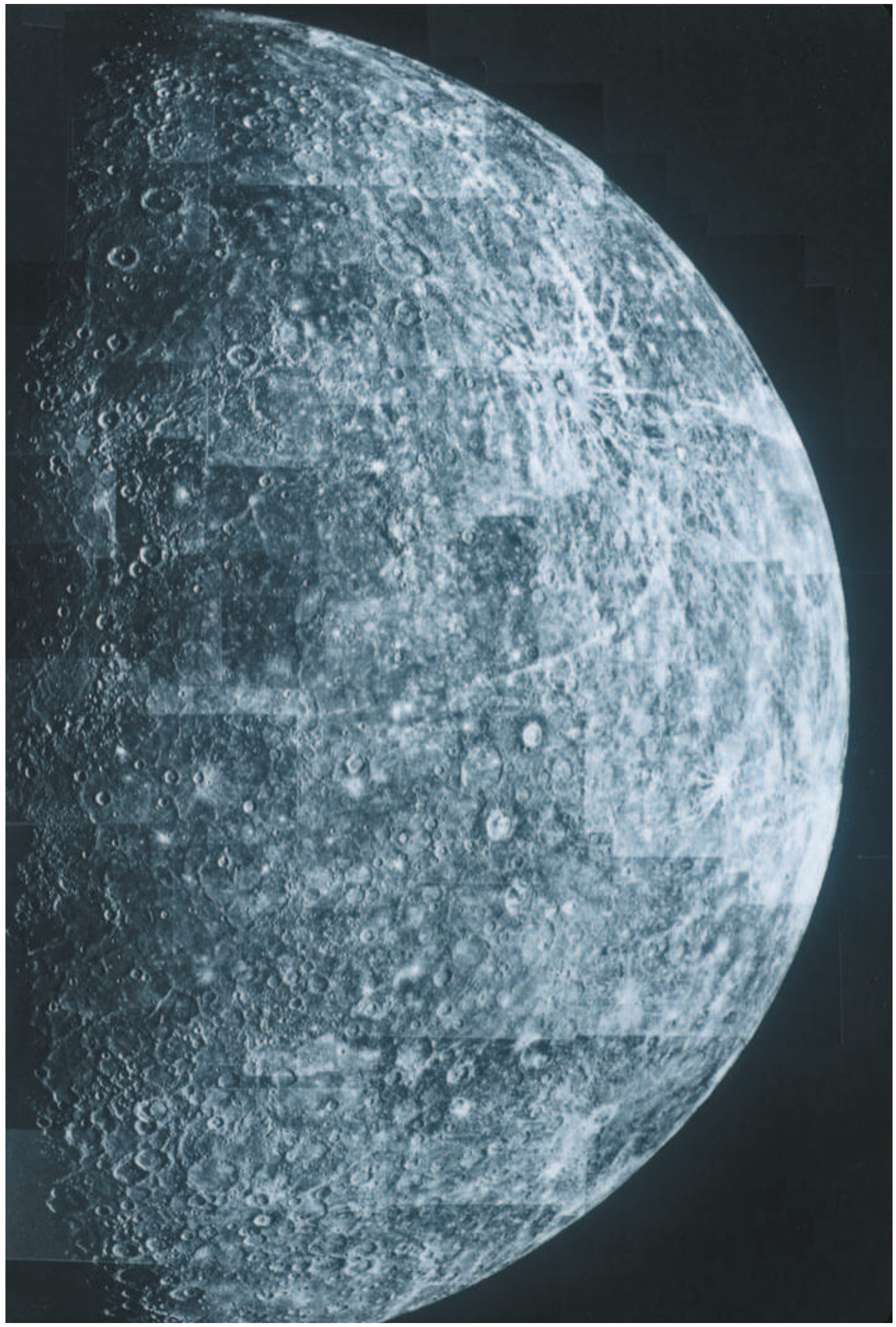
Mercury as viewed by Mariner 10 on its first approach in March 1974.

tem. Mercury's maximum surface temperature is about 450°C (842°F) at the equator when it is closest to the Sun, but drops to about −183°C (−297°F) at night.

Interior and Magnetic Field

Mercury's internal structure is unique in the solar system. Mercury's small size and relatively large mass (3.3×10^{23} kilograms [7.3×10^{23} pounds])

Mercury's opposite hemisphere viewed by Mariner 10 as it left the planet on the first encounter.



uncompressed density the lower density a planet would have if it did not have the force of gravity compressing it

means that it has a very large density of 5.44 grams per cubic centimeters (340 pounds per cubic foot), which is only slightly less than Earth's (5.52 grams per cubic centimeter [345 pounds per cubic foot]) and larger than Venus's (5.25 grams per cubic centimeter [328 pounds per cubic foot]). Because of Earth's large internal pressures, however, its **uncompressed density** is only 4.4 grams per cubic centimeter (275 pounds per cubic foot), compared to Mercury's uncompressed density of 5.3 grams per cubic centimeter (331 pounds per cubic foot). This means that Mercury contains a much larger fraction of iron than any other planet or moon in the solar system. The iron core must be about 75 percent of the planet diameter, or some 42 percent of its volume. Thus, its rocky outer region is only about 600 kilometers (370 miles) thick.

Mercury is the only **terrestrial planet**, aside from Earth, with a significant magnetic field. The maintenance of terrestrial planet magnetic fields is thought to require an electrically conducting fluid outer core surrounding a solid inner core. Therefore, Mercury's magnetic field suggests that Mercury currently has a fluid outer core of unknown thickness.

Exosphere

Mercury has an extremely tenuous atmosphere with a surface pressure a trillion times less than Earth's. This type of tenuous atmosphere is called an exosphere because atoms in it rarely collide. Mariner 10 identified the presence of hydrogen, helium, and oxygen in the atmosphere and set upper limits on the abundance of argon. These elements are probably derived from the **solar wind**. Later Earth-based telescopic observations detected sodium and potassium in quantities greater than the elements previously known. Sodium and potassium could be released from surface rocks by their interaction with **solar radiation** or by impact vaporization of **micrometeoroid** material. Both sodium and potassium show day-to-day changes in their global distribution.

Polar Deposits

High-resolution **radar** observations show highly reflective material concentrated in permanently shadowed portions of craters at the polar regions. These deposits have the same radar characteristics as water ice. Mercury's rotation axis is almost perpendicular to its orbit, and therefore Mercury does not experience seasons. Thus, temperatures in permanently shaded polar areas should be less than −161°C (−258°F). At this temperature, water ice is stable, that is, it is not subject to evaporation for billions of years. If the deposits are water ice, they could originate from comet or water-rich asteroid impacts that released the water, which was then cold-trapped in the permanently shadowed craters. Sulfur has also been suggested as a possible material for these deposits.

Geology and Composition

In general, the surface of Mercury can be divided into four major terrains: heavily cratered regions, **intercrater plains**, **smooth plains**, and hilly and lineated terrain. The heavily cratered uplands record the **period of heavy meteoroid bombardment** that ended about 3.8 billion years ago.

The largest relatively fresh impact feature seen by Mariner 10 is the Caloris basin, which has a diameter of 1,300 kilometers (806 miles). The floor structure consists of closely spaced ridges and troughs.

Directly opposite the Caloris basin (the **antipodal** point) is the unusual hilly and lineated terrain that disrupts preexisting landforms, particularly crater rims (see top image on following page). The hilly and lineated terrain is thought to be the result of seismic waves generated by the Caloris impact and focused at the antipodal region.

Mercury's two plains units have been interpreted to be old lava flows. The older intercrater plains are the most extensive terrain on Mercury (see

terrestrial planet a small rocky planet with high density orbiting close to the Sun; Mercury, Venus, Earth, and Mars

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

micrometeoroid any meteoroid ranging in size from a speck of dust to a pebble

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

intercrater plains the oldest plains on Mercury that occur in the highlands and that formed during the period of heavy meteoroid bombardment

smooth plains the youngest plains on Mercury; they have a relatively low impact crater abundance

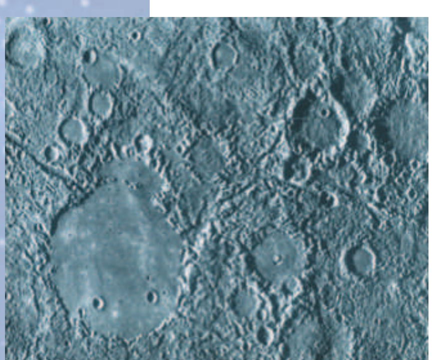
period of heavy meteoroid bombardment the earliest period in solar system history (more than 3.8 billion years ago) when the rate of meteoroid impact was very high compared to the present

antipodal at the opposite pole; two points on a planet that are diametrically opposite

Photomosaic of the 1,300-kilometer (806-mile) diameter Caloris impact basin showing the highly ridged and fractured nature of its floor.

lunar maria one of the large, dark, lava-filled impact basins on the Moon thought by early astronomers to resemble seas

anomalies phenomena that are different from what is expected



A portion of the hilly and lineated terrain antipodal to the Caloris impact basin. The image is 543 kilometers (337 miles) across.

bottom image on this page). The intercrater plains were created during the period of late heavy meteoroid bombardment. They are thought to be volcanic plains erupted through a fractured crust. They are probably about 4 to 4.2 billion years old.

The younger smooth plains are primarily associated with large impact basins. The largest occurrence of smooth plains fill and surround the Caloris basin, and occupy a large circular area in the north polar region that is probably an old impact basin about 1,500 kilometers (930 miles) in diameter. They are similar to the **lunar maria** and therefore are believed to be lava flows that erupted relatively late in Mercurian history. They may have an average age of about 3.8 billion years. If so, they are, in general, older than the lunar maria.

Three large radar-bright **anomalies** have been identified on the unimaged side of Mercury. High-resolution radar observations indicate that two of these are similar to the radar signature of a fresh impact crater, and another has a radar signature unlike any other in the solar system. One or both of these craters could account for the polar deposits if they were the result of comets or water-rich asteroid impacts.

Mercury displays a system of compressive **faults** (or **thrust faults**) called **lobate scarps**. They are more-or-less uniformly distributed over the part of Mercury viewed by Mariner 10. Presumably they occur on a global scale. This suggests that Mercury has shrunk. Stratigraphic evidence indicates that the faults formed after the intercrater plains relatively late in Mercurian history. The faults were probably caused by a decrease in Mercury's size due to cooling of the planet. The amount of radius decrease is estimated to have been about 2 kilometers (1.2 miles).

Very little is known about the surface composition of Mercury. A new color study of Mariner 10 images has been used to derive some compositional information of the surface over some of the regions viewed by Mariner 10. The smooth plains have an iron content of less than 6 percent by weight, which is similar to the rest of the regions imaged by Mariner 10. The surface of Mercury, therefore, may have a more homogeneous distribution of elements that affect color than does the Moon. At the least, the smooth plains may be low-iron **basalts**. The MESSENGER mission is designed to accurately determine the composition of the surface.

Geologic History

Knowledge about Mercury's earliest history is very uncertain. The earliest known events are the formation of the intercrater plains (more than 4 billion years ago) during the period of heavy meteoroid bombardment. These plains may have been erupted through **fractures** caused by large impacts in a thin crust. Near the end of heavy bombardment the Caloris basin was formed by a large impact that caused the hilly and lineated terrain from seismic waves focused at the antipodal region. Eruption of lava within and surrounding the large basins formed the smooth plains about 3.8 billion years ago. The system of lobate scarps formed after the intercrater plains, and resulted in a planetary radius decrease of about 2 kilometers (1.2 miles). Scientists will have to await the results of the MESSENGER and Colombo missions to fully evaluate the geologic history of Mercury.

Origins

How Mercury acquired such a large fraction of iron compared to the other terrestrial planets is not well determined. Three hypotheses have been put forward to explain the enormous iron core. One involves an enrichment of iron due to dynamical processes in the innermost part of the solar system. Another proposes that intense bombardment by solar radiation in the earliest phases of the Sun's evolution vaporized and drove off much of the rocky fraction of Mercury, leaving the core intact. A third proposes that a planet-sized object impacted Mercury and blasted away much of the planet's rocky mantle, again leaving the iron core largely intact. Discriminating among these hypotheses may be possible from the chemical makeup of the surface because each one predicts a different composition. MESSENGER is designed to measure the composition of Mercury's surface, so it may be possible to answer this vital question in the near future. SEE ALSO EXPLORATION PROGRAMS (VOLUME 2); PLANETARY EXPLORATION, FUTURE OF (VOLUME 2); ROBOTIC EXPLORATION OF SPACE (VOLUME 2).

Robert G. Strom

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fault a fracture in rock in the upper crust of a planet along which there has been movement

thrust fault a fault where the block on one side of the fault plane has been thrust up and over the opposite block by horizontal compressive forces

lobate scarp a long sinuous cliff

basalts dark, volcanic rock with abundant iron and magnesium and relatively low silica common on all of the terrestrial planets

fractures any break in rock, ranging from small "joints" that divide rocks into planar blocks (such as that seen in road cuts) to vast breaks in the crusts of unspecified movement

Meteorites

Most people have looked up into the night sky and seen the fleeting flashes of light that are known as meteors. These flashes are caused by small sand-sized particles that are debris from comets, which melt in the atmosphere and never reach the surface of Earth. Sometimes these flashes come in showers, such as the famous Perseid meteor shower, which occurs from July 23 to August 22 when Earth crosses the debris-strewn orbit of comet Swift-Tuttle.

Meteorites, on the other hand, are extraterrestrial material that have made it to Earth's surface and can weigh many tons. This material is not related to comets but rather to other astronomical bodies. Deceleration of meteorites begins high in the atmosphere where the surface of the incoming body heats up to **incandescence** causing melting and **ablation** and forming a (usually) black fusion crust on the exterior. Whether a meteoroid makes it to Earth's surface (and becomes a meteorite) or not depends on many factors including the mass, initial velocity, angle of entry, composition, and shape of the body. Like the Moon, Earth has been subjected in the past to periods of intense meteorite bombardment, but fortunately many incoming meteoroids disintegrate well up in the atmosphere.

incandescence glowing due to high temperature

ablation removal of the outer layers of an object by erosion, melting, or vaporization

The largest meteorite on Earth, weighing some 60 tons, is called Hoba and lies where it fell in Namibia. There are various other meteorite giants, including Chaco (Argentina), weighing 37 tons; Ahnighito (Greenland), 31 tons; and Bacubirito (Mexico), 22 tons.

The orbits of five recovered meteorites are shown in the figure below. Their orbits suggest that their origin lies in the asteroid belt between Mars and Jupiter. These orbits were calculated from photographs taken by networks of cameras in Europe, Canada, and the United States.

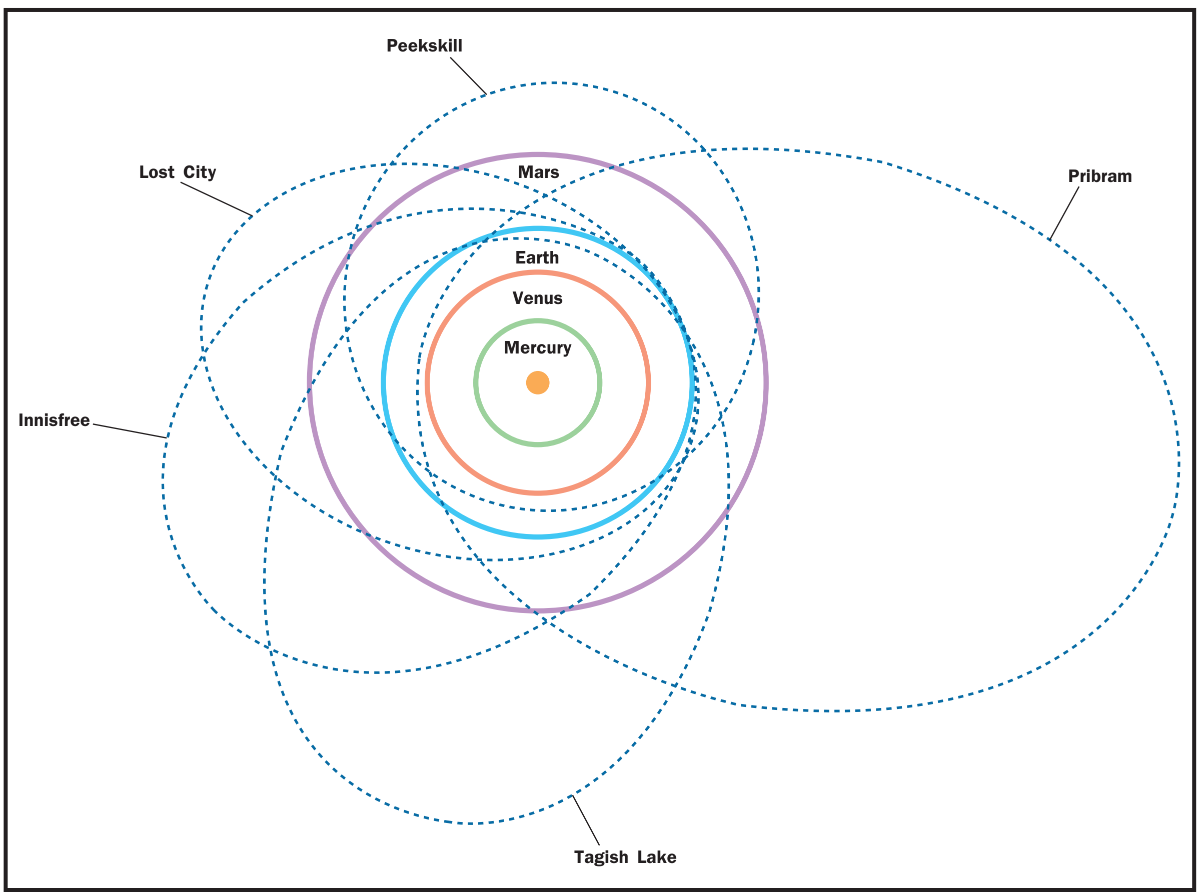
In 1982 a 31-gram (1.1-ounce) meteorite discovered in the Allan Hills region of Antarctica was determined to be from the Moon. Since then, more than twenty fragments of the Moon and more than twenty fragments of the planet Mars have been found on Earth.

radioisotope a naturally or artificially produced radioactive isotope of an element

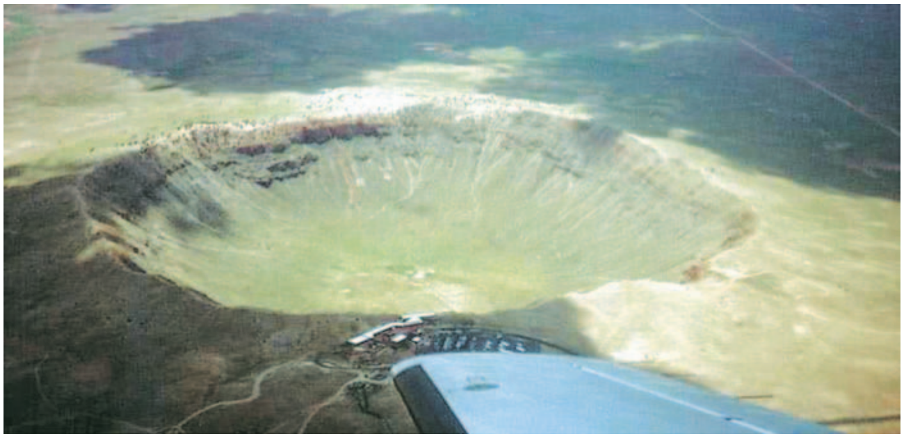
One interesting thing that can be done with meteorites, and one of the reasons why they are so important to science, is to date them by **radioisotope** methods. It turns out that most meteorites have a formation age around 4.56 billion years, when the solar nebula (the hot swirling cloud of dust and gas from which the Sun formed) began to cool enough for solid material, and hence planets, to form. Thus, meteorites represent a fossil record of the early conditions of the solar nebula.

Meteorite Craters

A consequence of large meteorites striking Earth is the formation of craters. This occurs when a large body weighing in excess of 100 tons strikes Earth's



The orbits of five recovered meteorites, showing their connection with the asteroid belt. *Figure adapted from Science Graphics.*



An aerial view of Meteor Crater, which is 1.2 kilometers wide and over 200 meters deep. Tons of nickel-iron meteorite debris have been found in the surrounding area from the original 50-meter-wide impactor.

surface at sufficiently high velocity. The **kinetic energy** of the meteorite is converted to heat, which vaporizes the surrounding rock as well as much of the meteorite, producing an explosion equivalent to a large nuclear device. One of the most famous craters is Meteor Crater (also called Barringer Crater) near Flagstaff, Arizona, which is about 50,000 years old and 1.2 kilometers (0.7 miles) in diameter. The impacting iron mass was approximately 50 meters (164 feet) across, and the consequence of it striking Earth at 60,000 kilometers per hour (37,200 miles per hour) can be seen in the accompanying image.

kinetic energy the energy an object has due to its motion

Meteor Crater is not particularly large among the 150 or so **impact craters** that exist on Earth, and even larger ones can produce global climatic and environmental changes. The asteroid that is thought to have wiped out the dinosaurs was about 10 kilometers (6.2 miles) in diameter and struck off the coast of Yucatan, Mexico, 65 million years ago, producing a crater 300 kilometers (186 miles) in diameter. This event is theorized to have created enormous amounts of dust, which blocked out the Sun, possibly for years, and led to the extinction of 75 percent of all living species.

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

Can such an event happen in modern times? Since Earth is actually orbiting the Sun through a swarm of solar system debris, the answer has to be yes. In fact, in 1908 there was an enormous atmospheric explosion above Tunguska, Siberia. The resulting blast leveled 2,000 square kilometers (770 square miles) of forest, and the shock wave circled the globe. Such an event is predicted to happen once every few hundred years or so. As recently as 1947, the Sikhote-Alin meteorite crashing north of Vladivostok, Russia, made an array of craters, some of which were one-fourth the size of a football field.

Asteroids Turned Meteorites

Tens of thousands of small bodies called asteroids are found in the asteroid belt, with the largest one, Ceres, discovered in 1801, being about 930 kilometers (575 miles) in diameter. Most of these are in stable orbits around the Sun and are really just small planets, or planetoids. From time to time, these asteroids crash into one another, sending their fragments in all directions. But there are some empty zones in the asteroid belt, known as Kirkwood gaps (after American astronomer Daniel Kirkwood), which are caused by a special gravitational relationship with Jupiter. If some asteroid fragments from a collision are thrown into one of these gaps, Jupiter's enormous gravity has the effect of sending them into a more elliptically shaped orbit (as seen in the figure on page 104) that can intersect Earth's orbit. That is how fragments of the asteroid belt can end up crashing into Earth as meteorites.

wavelength the distance from crest to crest on a wave at an instant in time

spectra representations of the brightness of objects as a function of the wavelength of the emitted radiation

One way to study asteroids is to measure the intensity of sunlight at different **wavelengths** reflecting off their surfaces. This is then compared to the light reflected off pulverized meteorites in the laboratory. Reflectance **spectra** from various asteroids can be matched with different types of meteorites, further strengthening the connection between asteroids and meteorites.

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

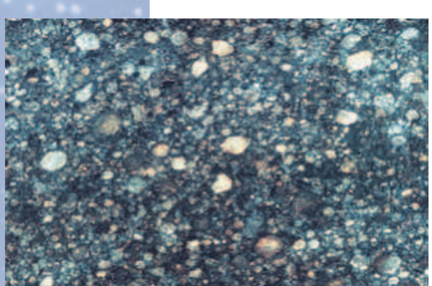
There are three basic types of meteorites: stones, stony-irons, and irons. Stones are divided into two main subcategories: chondrites and achondrites. Chondrites are the main type of stony meteorite, constituting 84 percent of all witnessed meteorite falls. Most chondrites are characterized by small spherical globules of silicate, known as chondrules. Interestingly, carbonaceous chondrites also contain organic compounds such as amino acids, which may have contributed to the origin of life on Earth. Chondrites are the most primitive of the meteorites, suffering little change since their origin. Achondrites, on the other hand, come from chondritic parent bodies that have been heated to the melting point, destroying their chondrules and separating heavy and light **minerals** into a core and mantle. These are known as differentiated meteorites. Early volcanism occurred on the surface of their parent bodies forming a thin crust. A subcategory of achondrites called SNC achondrites are believed to have come from Mars.

Stony-irons are a metal-silicate mixture. Meteorites from one subcategory, the pallasites, contain large crystals of the mineral olivine imbedded in a matrix of metal. These are thought to form at the boundary of the molten metal core of an asteroid and its olivine-bearing silicate mantle.

Irons are actually alloys of mostly iron with a small percentage of nickel. As the liquid metal core of an asteroid slowly cools over a period of millions of years, the different alloys of nickel-iron (kamacite and taenite) form an intertwining growth pattern known as a Widmanstätten pattern, which is indicative of extraterrestrial iron meteorites.

Meteorites are true extraterrestrials, valuable not only to science but also to the discoverer. If you happen to find a piece of the Moon lying on the ground (as some people have), you can plan your retirement from that day onward. Today, a thriving market exists as an increasing number of new meteorites are being discovered yearly, many finding their way to the marketplace. A growing number of aficionados eagerly await these new discoveries. SEE ALSO Asteroids (volume 2); Comets (volume 2); Close Encounters (volume 2); Impacts (volume 4); Mars (volume 2); Moon (volume 2).

Joel L. Schiff



A cut slab of a typical ordinary chondrite showing a field of chondrules.

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Microgravity

Gravity is an omnipresent force in our lives. Without it, water from a drinking fountain would simply shoot up from the spout without arcing into the fountain again. Chocolate syrup on a sundae would stay put without dripping down a scoop of ice cream. In fact, gravity, the force of attraction that draws one object to another, is so powerful on Earth that scientists sometimes have to get away from its influence—if only for a short while—to better understand other forces at work in the universe. To do this, they must be in a microgravity environment.

While it may appear that these astronauts are floating, they are actually in a state known as "freefall."

Microgravity, where the effects of gravity are minimized (approximating one millionth that of Earth's normal gravity), is achieved during freefall. At first glance, astronauts working on the International Space Station may appear to be floating. In fact, they are in freefall inside the spacecraft, which is also in freefall. To understand this phenomenon, it may help to think through a mental experiment by English physicist and mathematician Isaac Newton (1642–1727). He understood that the force that causes apples and other objects to fall to the ground is the same force that holds celestial bodies such as the Moon in orbit. If a cannon is fired from atop a high hill, the cannonball will fall to Earth, landing some distance away. If more force is used, the cannonball travels farther before hitting the ground. If the cannonball is propelled with enough force, it will fall all the way around Earth, orbiting the planet, just as the Space Station or any space shuttle does.

Scientists who have conducted experiments in microgravity have discovered countless phenomenon that they would not see in normal gravity. For example, during space shuttle flight STS-95, which carried Senator John Glenn back into orbit in 1998, scientists saw ordered crystals of two different sizes of particles form together in one solution. On Earth, where metals (such as copper and zinc) are melted together to form alloys (such as brass), materials scientists contend with buoyant convection, which is fluid flow that causes denser particles to sink and less dense particles to rise. **Convection** makes it more difficult to blend uniform alloys and other materials.

convection the movement of heated fluid caused by a variation in density; hot fluid rises while cool fluid sinks

Convection also affects how a flame burns. On Earth, gravity pulls cooler, denser air closer to the planet, causing soot and hot, less dense flame gases to rise. This can lead to an unsteady, flickering flame. In microgravity, a candle flame produces minimal soot for a brief time then appears spherical and blue. American combustion researchers found on the Russian space station Mir in 1998 that while a flame in microgravity does need airflow to burn, as it does on Earth, that flow is only a fraction of a centimeter per second, so small one would not feel it. The findings confirmed that materials considered to be flame-resistant on Earth might burn in low-gravity conditions in space.

As astronauts learn how physical phenomena are affected in microgravity, they are also finding out how the microgravity environment affects their own bodies. For example, during long-duration flights, such as on the International Space Station, human muscles begin to **atrophy** and bones can become more **porous** as they do in someone with **osteoporosis**. Scientists are researching methods of exercise and bone-replacement therapy that will help astronauts stay in top condition as they continue their discoveries of how forces behave with—or without—gravity. SEE ALSO GRAVITY (VOLUME 2);

atrophy to wither, shrink, or waste away

porous allowing the passage of a fluid or gas through holes or passages in the substance

osteoporosis the loss of bone density; can occur after extended stays in space

NEWTON, ISAAC (VOLUME 2); LIVING IN SPACE (VOLUME 3); LIVING ON OTHER WORLDS (VOLUME 4); LONG-DURATION SPACEFLIGHT (VOLUME 3); ZERO GRAVITY (VOLUME 3).

Julie A. Moberly

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Military Exploration

An Atlas II rocket takes off from the Cape Canaveral Air Force Station carrying a communications satellite for the United States Navy. The satellite is part of the Navy's global communications network.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

Among the different reasons for sending space probes and satellites into orbit is the use of the space environment for defensive purposes. Military equipment such as missiles, rockets, and communications systems were among the first hardware used in the early space programs. Gradually, civil and commercial space projects developed their own purpose-built spacecraft. But the military continues to have a dominant place in the space programs of the United States, China, and Russia. The principal launching sites for rockets in all three countries are military bases, and military ships and planes are used for tracking and communications during rocket launches.

The French commercial launching site in Kourou, French Guiana, had its origins as a French military base in the 1950s. The military forces of Israel, Brazil, India, and North Korea have also been major influences in the origins and evolution of these nations' scientific and commercial space programs.

In the United States, the rockets used in the civil, commercial, and military space programs had their origins as **ballistic** missiles and later were first used for space purposes by the military. The first U.S. space rockets, derived from German V-2 rockets captured by the military following the end of World War II (1939–1945), were tested and flown by the U.S. Army from a military base at White Sands, New Mexico. The rocket that carried the first attempted launch of a U.S. satellite, the Vanguard, was developed by the U.S. Navy. The U.S. Air Force developed subsequent intercontinental ballistic missiles. The R-7 ballistic missile developed by the Soviet military has been adapted as a launching rocket and is still flying today.

Military forces have developed several different types of satellites in various types of orbits in space. These include communications satellites such as the Defense Space Communication System and Milstar, navigation satellites such as the Global Positioning System (GPS), early warning satellites such as the Defense Support Program satellites, and weather satellites such as the Defense Meteorological Satellite Program. During the Gulf

War in 1991, space satellites, including secret **reconnaissance** and surveillance craft, were used by coalition-deployed forces for communicating among force locations and for tracking Scud missiles fired by the Iraqi government.

reconnaissance a survey or preliminary exploration of a region of interest

In 1983 President Ronald Reagan proposed a major expansion of the military use of space in his Strategic Defense Initiative. The project called for the development of a space-based warning, tracking, and intercept system to destroy missiles attacking the United States. The program lasted from 1983 to 1993 and was discontinued following the collapse of the Soviet Union.

The administration of President George H. W. Bush proposed a limited space defense system in 1989 called Global Protection against Limited Strike. This system was to feature a fleet of orbiting attack craft called Brilliant Pebbles. The "Pebbles" carried no explosive equipment but would destroy incoming missiles by colliding with them as they entered space. This project was also canceled when President Bill Clinton entered office in 1993.

A more limited space-based tracking and laser attack system is being researched by the administration of George W. Bush to defend the continental United States from a limited ballistic missile attack from Third World nations. The first test flight of a prototype antimissile space laser is set for 2012. SEE ALSO GOVERNMENT SPACE PROGRAMS (VOLUME 2); MILITARY CUSTOMERS (VOLUME 1); MILITARY USES OF SPACE (VOLUME 4); RECONNAISSANCE (VOLUME 1); SATELLITES, TYPES OF (VOLUME 1).

Frank Sietzen, Jr.

Internet Resources

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Moon

Our solitary and prominent Moon orbits Earth at a mean distance of only 382,000 kilometers (236,840 miles). The nearest planet, Venus, is never closer than 40 million kilometers (25 million miles). The Moon's mass is just under one-eightieth that of Earth, its volume just over one-fiftieth; the difference mainly stems from the Moon lacking a large metallic iron core and therefore having a much lower overall density than Earth. Its low mass is responsible for the low surface gravity (one-sixth that at Earth's surface), popularly recognized in the jumping, bouncing gait of Apollo astronauts. The mass is much too low for the Moon to hold any significant atmosphere—it is essentially in a **vacuum**—or for its surface to have liquid water.

vacuum an environment where air and all other molecules and atoms of matter have been removed

The surface area of the Moon is only about four times that of the land area of the United States. The Moon is not as large as any planet other than distant little Pluto but is of the same scale as the Galilean satellites of Jupiter. These moons are much smaller in comparison with the planet they orbit.

Basins formed on the Moon 4 billion years ago, and were subsequently filled with basaltic lava flows. The Orientale basin, 600 miles across, is near the center, while the area at the upper right is the large, dark Oceanus Procellarum.

Earth's Moon is very different in chemical composition and structure—and probably origin—from any other body in the solar system.

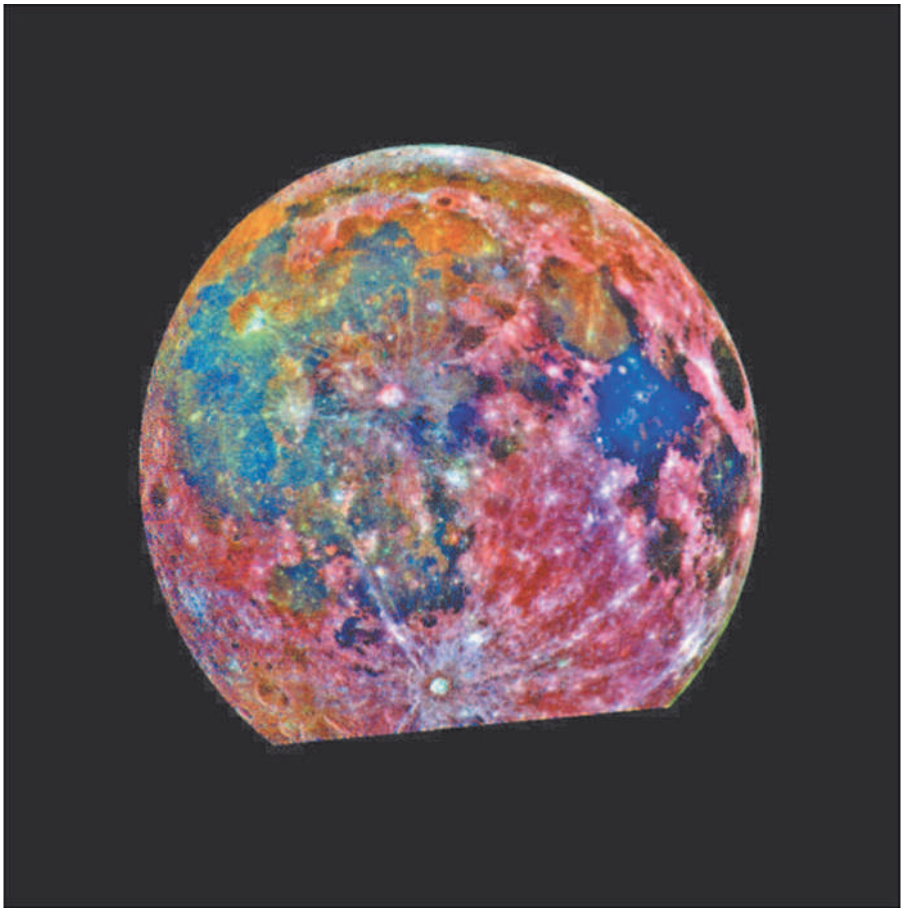
Orbit and Rotation

ecliptic the plane of Earth's orbit

The 29.53-day orbit provides us with the lunar phases, as well as the occasional eclipses of the Sun and the more frequent eclipses of the Moon. The orbit is tilted only slightly (5.1°) from the plane of the **ecliptic**, but because Earth itself has a tilted axis of rotation (23.5°), the Moon's orbit is tilted substantially with respect to Earth's equator. The Moon's own axial rotation period is exactly the same as its orbital period, and so it shows almost the same face to Earth continuously. It is not exactly the same face because of the tilt of the Moon's rotational axis (1.5°) to its orbital plane around Earth, and the slight ellipticity of that orbit (the position of the observer on Earth also has a slight effect). Altogether, only 41 percent of the Moon's surface is permanently invisible to observers on Earth.

angular momentum the angular equivalent of linear momentum; the product of angular velocity and moment of inertia (moment of inertia = mass × radius^2)

The gravitational pull of the Moon provides the twice-daily tides on Earth as Earth spins under the Moon. The Moon is gradually receding because of the tidal effects. As the Moon recedes, its **angular momentum** increases, compensated by a decrease in the spin rate of Earth. Thus, Earth's day is increasing in length; 600 million years ago it was only about eighteen hours long. The Moon stabilizes the tilt of Earth's own axis of rotation over long periods of time, and this has been important for stabilizing climate and thus life habitats.



This is a false-color composite image of the Moon, photographed through three color filters by the Galileo spacecraft. The colors aid in the interpretation of the satellite's surface soil composition: red areas typically correspond to lunar highlands; orange to blue shades suggest ancient volcanic lava flow or lunar sea; and purple sections indicate pyroclastic deposits.

The Exploration of the Moon

Even to the naked eye the Moon's face has darker and lighter patches. Italian mathematician and astronomer Galileo Galilei used a telescope in 1610 to discover its rugged, varied, and essentially unchanging features. He distinguished the brighter areas as higher and more rugged, the darker as lower, flatter, and smoother. He called the former "terra" (meaning "land"; pl. "terrae") and the latter "mare" (meaning "sea"; pl. "maria"), although that is not what they are.

For three centuries the Moon remained an object of astronomical study, with the collection of data about its shape, size, movements, and surface physical properties, as well as mapping. Not until the middle of the twentieth century were observations and a combination of natural and terrestrial analogs advanced enough that the volcanic origin of its dark plains and the impact origin of its craters and basins could be considered as settled. In the 1960s, a program of geological mapping, using techniques such as crater counting and overlapping relationships, confirmed and elucidated the nature of geological units and the order in which they were produced.

The study of the Moon reached peak activity in the space age, when spacecraft sent back detailed information from orbiters, **hard-landers**, and **soft-landers** (mainly from 1959 to 1970), and Apollo astronauts conducted experiments and made observations from **equatorial orbit** and at the surface (from 1968 to 1972). Six Apollo missions and three robotic sample-

hard-lander a spacecraft that collides with the planet or satellite, making no attempt to slow its descent; also called crash-landers

soft-lander spacecraft that uses braking by engines or other techniques (e.g., parachutes, airbags) such that its landing is gentle enough that the spacecraft and its instruments are not damaged, and observations at the surface can be made

equatorial orbit an orbit parallel to a body's geographic equator

BASIC DATA ABOUT THE MOON

Greatest distance from Earth	406,697 km
Shortest distance from Earth	356,410 km
Eccentricity of orbit	0.0549
Rotation period (synodic month)	29.53 Earth days
Rotation period (sidereal month)	27.32 Earth days
Mean orbital inclination to ecliptic	5° 08' 43"
Inclination of rotation axis to orbit plane	1° 32'
Mean orbital velocity	1.68 km/s
Period of revolution of perigee	3,232 Earth days
Regression of the nodes	18.60 years
Mass	7.35×10^{22} kg
Mean Density	3.34 g/cc
Surface gravity	1.62 m/s^2
Escape velocity	2.38 km/s
Mean diameter	3,476 km
Mean circumference	10,930 km
Surface area	37,900,000 km^2
Albedo (fraction light reflected) terrae	0.11–0.18
Albedo (fraction light reflected) mare	0.07–0.10
Mean surface temperature day	107°C
Mean surface temperature night	−153°C
Mean surface temperature at poles: light	−40°C
Mean surface temperature at poles: dark	−230°C

return vehicles collected samples of the Moon (from 1970 to 1976). Samples are particularly useful for understanding the processes that created the rocks and for the dating of events using **radiogenic isotope techniques**. Two **flybys** by the Galileo mission✶ to Jupiter (in 1990 and 1992), the Clementine lunar polar orbiter (in 1994) and the Lunar Prospector polar orbiter (in 1998) have provided substantially more global imaging, topographic, chemical, and mineralogical data.

radiogenic isotope techniques use of the ratio between various isotopes produced by radioactive decay to determine age or place of origin of an object in geology, archaeology, and other areas

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

✶The Galileo mission successfully used robots to explore the outer solar system. This mission used gravity assists from Venus and Earth to reach Jupiter, where it dropped a probe into the atmosphere and studied the planet for nearly seven years.

Global and Interior Characteristics

The Moon is nearly homogeneous, as shown by its motions in space, and by the fact that rocks near the surface are not much different in density from the Moon as a whole. Nonetheless, samples show that the Moon was thoroughly heated at its birth about 4.5 billion years ago, possibly to the point of total melting, and then quickly solidified to produce a comparatively thin (60 to 100 kilometers [37 to 62 miles]) crust of slightly lighter material. This structure was confirmed by seismic experiments performed on the early Apollo missions. There may be an iron core, but if so it is very tiny, and there is no significant magnetic field.

Samples show that the Moon is very depleted in volatile elements (those that form gases and low-temperature boiling-point liquids), to the extent that it lacks any water of its own at all, even bonded into rocks. Water delivered to the Moon by cometary impact might exist, frozen in crater floors near the poles. The Moon is very reduced chemically, such that iron metal exists, but rust (oxidized, ferric iron) does not. The Moon is very depleted in the siderophile elements ("iron-loving") that go with metallic iron into a core, except for the surface rubble to which such elements have been delivered by eons of meteorite impact.

The Uppermost Surface of the Moon

The Moon has been bombarded by meteorites ranging in size from numerous tiny dust particles to rare objects hundreds of kilometers in diame-

Astronaut and geologist Harrison H. Schmitt working at the Taurus-Littrow landing site, where he first spotted orange soil. The lunar surface is covered everywhere with a thin fragmental layer ("regolith") that consists mainly of ground-up and remelted rocks.

ter. The surface is covered everywhere with a thin fragmental layer (known as soil, or "regolith") that consists mainly of ground-up and remelted lunar rocks, with an average grain size of less than 0.1 millimeters (0.004 inch). This soil contains pebbles, cobbles, and even boulders of lunar rocks. A small percentage of the regolith consists of the meteoritic material that did the bombarding. The regolith is about 5 meters (16.5 feet) thick on **basalts** that were poured out about 3 billion years ago, while older surfaces have even

basalts dark, volcanic rock with abundant iron and magnesium and relatively low silica common on all of the terrestrial planets

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

thicker regoliths. This regolith layer, exposed to **cosmic radiation** and the **solar wind**, contains materials, such as hydrogen, that do not reach the surface of Earth because of its protection by both a magnetic field and an atmosphere.

The Older Crust of the Moon

Much of the crust consists of material that formed within a few tens of millions of years of the Moon's origin, partly by the floating of light (in both density and color) feldspar **minerals**, which crystallized from a vast ocean of silicate magma. The magma formed because of the Moon's rapid formation, and because of the generation of radioactive heat, which was greater then than now. Continued melting and remelting added to the crust, and the final dregs of the crystallizing magma ocean, richer in those elements that do not easily fit into common crystallizing minerals (feldspar, pyroxene, and olivine), also ended up in the crust. The rocks from the dregs are commonly called "KREEP"-rich because they are richer in potassium (K), rare Earth elements (REE) such as lanthanum, and phosphorus (P) than are typical rocks. Most, though not all, of this crust was in place by 4.3 billion years ago.

At its birth and at about 3.9 billion years ago (what happened in the time between remains somewhat unknown) the Moon was subjected to enormous bombardments that created deep basins as well as numerous small craters, partly disrupting the crust. This crust is somewhat thinner on the front side (about 60 kilometers [37 miles]) than on the farside (about 100 kilometers [62 miles]).

The Younger Crust of the Moon

mare dark-colored plains of solidified lava that mainly fill the large impact basins and other low-lying regions on the Moon

spherules tiny glass spheres found in and among lunar rocks

Impacts decreased substantially after 3.8 billion years ago, to a level close to that of today by about 3.2 billion years ago. The Moon's deep basins, partly filled with overlapping thin flows of **mare** basalt, formed from the melting of small amounts of the lunar interior. These basins (150 kilometers [93 miles] to perhaps 500 kilometers [310 miles] deep) are prominent as the dark plains—the maria—of the Moon and show many signs of volcanic flow. Some of the volcanic lava erupted as fiery fountains, forming heaps of glass **spherules**. These lavas comprise only about 1 percent of the crust, but as the latest, topmost rocks, least affected by impacts, they remain clearly visible. They are much less abundant on the lunar farside, and everywhere their formation had ceased by 2 billion years ago. The Moon is now magmatically dead, and its uppermost crust is being continually gardened and converted into regolith.

The Origin of the Moon

isotope ratios the naturally occurring proportions between isotopes of an element

Earth and the Moon show an identical relationship of oxygen **isotope ratios** (oxygen being the most common element in both planets), a relationship that is different from all other measured solar system objects (including Mars) except yEH chondrites. This indicates that Earth and the Moon formed in the same part of the solar system and gives credence to ideas that the Moon formed from Earth materials.

The pre-Apollo ideas of either capture, fission from Earth (by rapid spinning), or formation together as a double planet are not consistent with what scientists now know from geological or sample studies, nor with the orbital and angular momentum constraints. Thus a new concept was developed in the 1980s: Earth collided during its growth with an approximately Mars-sized object, producing an Earth-orbiting disk of material that accumulated to form the Moon. This idea can account for many features, including the chemistry of the Moon, its magma ocean, and even the tilt of Earth's axis. It is compatible with concepts of how planets develop by accumulation of solid objects. One of the implications of this theory is that the Moon actually must have accumulated very rapidly, on the order of days to years, rather than older ideas of tens of millions of years, and this explains the early melting of the Moon. SEE ALSO APOLLO (VOLUME 3); APOLLO LUNAR LANDING SITES (VOLUME 3); EXPLORATION PROGRAMS (VOLUME 2); GALILEI, GALILEO (VOLUME 2); LUNAR BASES (VOLUME 4); LUNAR OUTPOSTS (VOLUME 3); LUNAR ROVERS (VOLUME 3); NASA (VOLUME 3); PLANETARY EXPLORATION, FUTURE OF (VOLUME 2); ROBOTIC EXPLORATION OF SPACE (VOLUME 2); SHOEMAKER, EUGENE (VOLUME 2).

Graham Ryder

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National Aeronautics and Space Administration

See NASA (Volume 3).

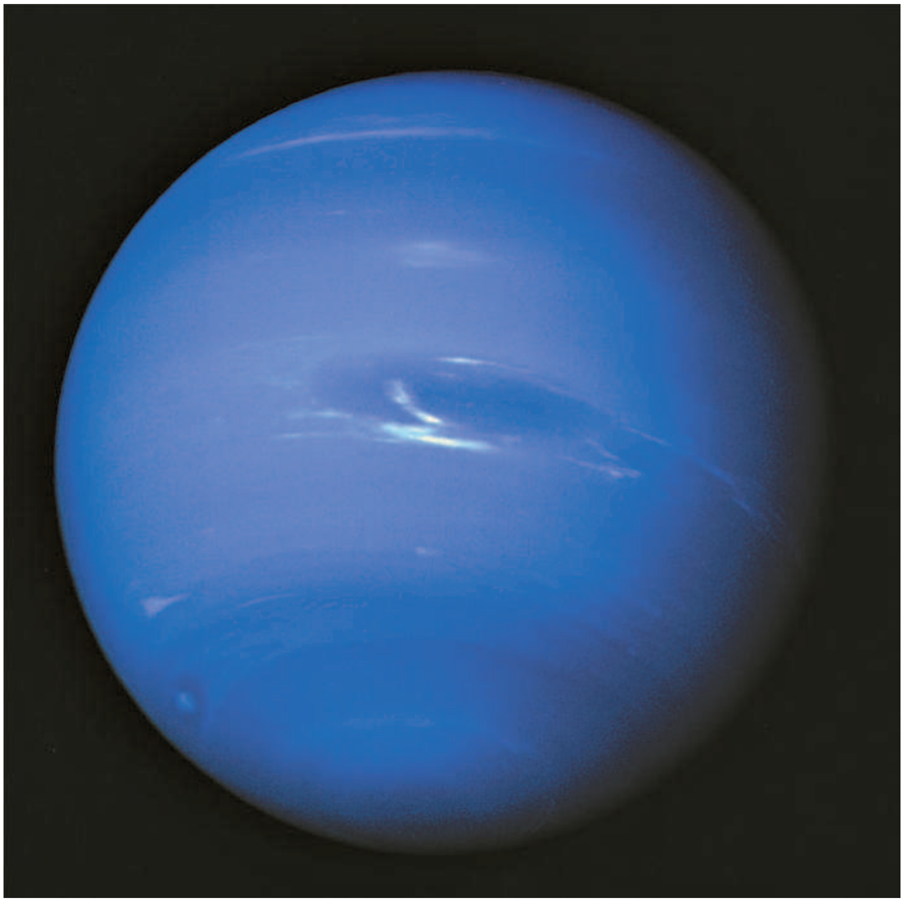
N

Neptune

Neptune is the most distant giant planet, circling the Sun at an average distance of almost 6 billion kilometers (3.7 billion miles; thirty-nine times the distance from Earth to the Sun). Neptune is a near twin to Uranus in size (with a radius of 24,764 kilometers [15,354 miles] at the equator), in composition (about 80 percent hydrogen, 15 percent helium, and 3 percent methane, with other trace elements), and in internal structure (a rocky core surrounded by a methane- and ammonia-rich watery mantle topped by a thick atmosphere).

The icy particles in the upper cloud decks of Neptune differ slightly from those of Uranus. Their color, combined with the atmospheric methane that absorbs red light, gives Neptune a rich sky-blue tint compared with the more greenish Uranus. Neptune has the strongest internal heat source of all the giant planets, radiating almost three times more heat than one would expect. Like Jupiter and Saturn, which radiate about twice as much energy than expected, Neptune is thought to have excess heat from the time of the

Neptune as seen through green and orange camera filters from a Voyager 2 flyby. Visible planetary features include: the Great Dark Spot (planet center); the bright, fast moving feature Scooter (to the west); and the little dark spot (below).



gravitational contraction the collapse of a cloud of gas and dust due to the mutual gravitational attraction of the parts of the cloud; a possible source of excess heat radiated by some Jovian planets

planet's formation and from continued **gravitational contraction**. Neptune's rotational axis is inclined only 29 degrees, compared with Uranus's more than 90 degrees.

A Saga of Discovery

The discovery of Neptune was a mathematical triumph and a political nightmare. After Uranus was discovered in 1781, astronomers inferred the presence of another planet from the shape of the Uranian orbit. In England, astronomer John Adams made meticulous but unpublished calculations of the planet's likely position in 1845. Shortly thereafter, French astronomer Urbain Leverrier independently determined the suspected planet's position, which nearly matched Adams's prediction. After Leverrier's work was published in 1846, English astronomers realized that Adams's work warranted a more serious look. But by then, the French astronomer had sent his prediction to observers in Berlin. Almost immediately, German astronomer Johann Galle discovered Neptune near the predicted location. For years, debates raged across national boundaries over who deserved credit for the discovery of Neptune. We now credit both Leverrier and Adams for the prediction and recognize Galle for the actual observation.

Unusual Cloud Features

In 1989, Voyager 2 flew by Neptune and detected numerous cloud features. The biggest was the Great Dark Spot, a hurricane-like storm that was about half the size of Earth. The next to be discovered was a small white spot, which appeared to race rapidly around the planet when compared with the lumbering Great Dark Spot. It was named the "Scooter." Many more spots were found, many of which were rotating even faster than Scooter. A small dark spot in the south developed a bright core, and a bright clump near the south pole was observed to be composed of many fast-moving bright patches.

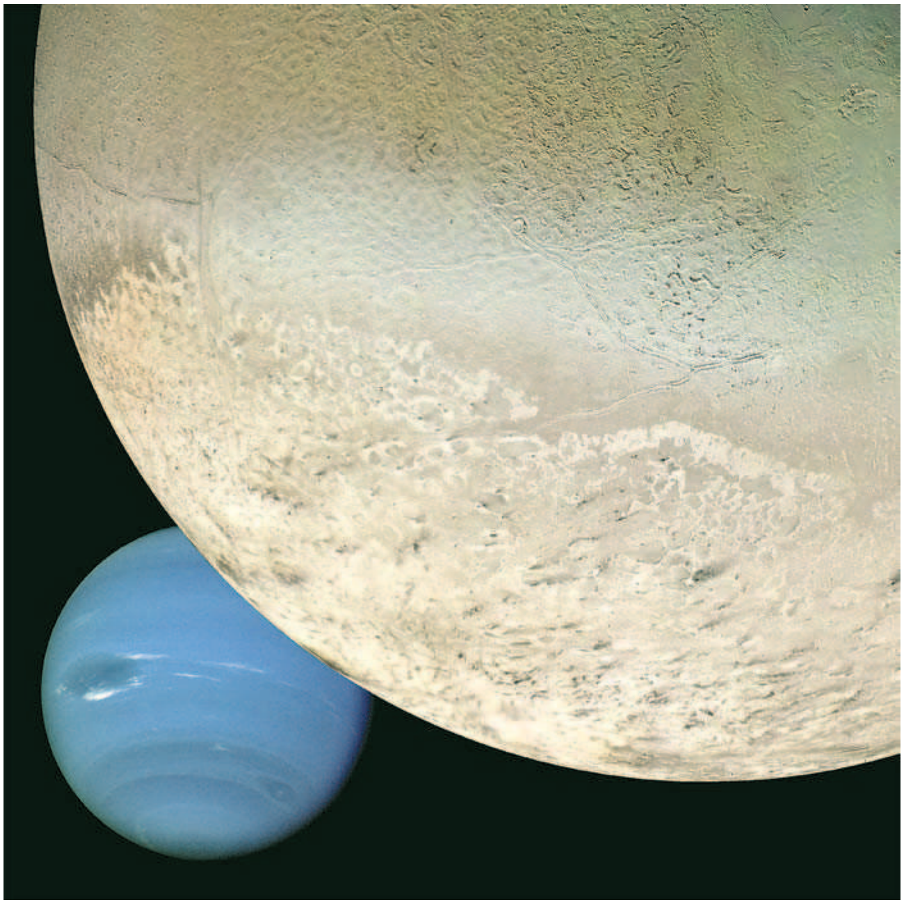
Rotation and Magnetic Field

Voyager 2 measured Neptune's 16.11-hour internal rotation period by monitoring the planet's magnetic field. The atmosphere rotates with periods ranging from over 18 hours near the equator to faster than 13 hours near the poles. In fact, the winds of Neptune are among the fastest in the solar system; only Saturn's high-speed equatorial jet is faster. Like the Uranian magnetic field, Neptune's magnetic field is also offset from the planet's center and significantly tilted with respect to the planet's rotation axis. Neptune's field is about 60 percent weaker than that of Uranus.

The Moons of Neptune

Neptune's largest moon, Triton, has a **retrograde** and highly inclined orbit. This suggests the moon may have been captured rather than formed around Neptune. Triton has a thin atmosphere of primarily nitrogen gas, thought to be in equilibrium with the nitrogen ice covering Triton's surface. Because of Triton's unusual orbit, however, the surface ice is thought

retrograde having the opposite general sense of motion or rotation as the rest of the solar system; that is, clockwise as seen from above Earth's north pole



Triton partially obscures Neptune during this Voyager 2 flyby from August 1989. Triton, at 2,706 kilometers (1,683 miles) in diameter, is Neptune's largest moon.

to change with time, leading to the possibility that Triton's atmosphere also varies. Recent occultations (observations of stars glimmering through Triton's tenuous atmosphere) suggest that Triton's atmosphere may have expanded by nearly a factor of two since the Voyager 2 encounter. Triton's northern hemisphere looks much like the surface of a cantaloupe. The southern hemisphere is dominated by a polar ice cap, probably composed of nitrogen. In the highest resolution images, active geysers (ice volcanoes) were seen spewing columns of dark material many kilometers into the thin atmosphere. Triton's surface has relatively few **impact craters**, suggesting that it is young.

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

elliptical having an oval shape

prograde having the same general sense of motion or rotation as the rest of the solar system, that is counterclockwise as seen from above Earth's north pole

Nereid (the only other Neptune moon known prior to the Voyager 2 mission) also has an unusual orbit that is highly **elliptical** and tilted nearly 30 degrees, again suggesting a capture origin. Little is known about it other than its irregular shape. Voyager 2 discovered six additional moons around Neptune. These are all in circular **prograde** orbits near Neptune's equatorial plane, and they probably formed in place. One of these, Proteus, is larger than Nereid; it had not been discovered prior to the Voyager 2 encounter because it is so close to Neptune. Proteus is irregular in shape. A particularly large impact crater suggests that it came close to destruction in an earlier collision.

The Rings of Neptune

Astronomers used occultations to search for rings around Neptune, because that technique had been successful for discovering the rings of Uranus. The results were odd: some events seemed to clearly show rings, but others clearly did not. The Voyager 2 encounter solved the puzzle. There were three complete rings, but the rings were variable in their thicknesses (the three distinct rings were named Adams, Leverrier, and Galle, after the astronomers who were involved in the discovery saga). The thickest parts—dubbed rings arcs—were seen during occultations; the other parts of the rings were too thin to be detected. Scientists are not sure what causes Neptune's rings arcs. Some of the smallest moons appear to "shepherd" the inner edges of two of the rings, but no moons were found at locations that would explain the clumps through a **shepherding** mechanism. Despite their clumpiness, Neptune's rings are very circular, unlike the rings of Uranus.

shepherding small satellites exerting their gravitational influence to cause or maintain structure in the rings of the outer planets

Recent Hubble Space Telescope images have continued to show remarkable changes in Neptune's atmosphere: the Great Dark Spot discovered by Voyager 2 in 1989 had disappeared, and a new Great Dark Spot developed in the northern hemisphere. From the dynamics of Neptune's clouds, to the expanding Triton atmosphere, to the forces creating the clumpy rings, many interesting puzzles remain to be solved in the Neptune system. SEE ALSO Exploration Programs (volume 2); NASA (volume 3); Robotic Exploration of Space (volume 2); Uranus (volume 2).

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Newton, Isaac

British Physicist and Mathematician
1642–1727

Sir Isaac Newton formulated a single law of gravitation based on Kepler's three laws of planetary motion.

Considered one of the greatest scientists of all time, Isaac Newton was a British physicist and mathematician. Born in 1642, the year Italian mathematician and astronomer Galileo Galilei died, Newton's astounding list of contributions include discovering the law of gravity, designing a novel type of reflecting telescope, and writing the landmark work, *The Mathematical Principles of Natural Philosophy* (1687). This seminal volume spelled out the law of gravity, the laws of motion, and the universality of the gravitational force. It was Newton who first realized that white light is made up of the colors of the rainbow, made visible through the prism.

Newton's brilliance is very much in evidence today. For instance, the newton is a unit for force named after him. The Newtonian telescope is a type of reflecting telescope still in popular use. Newton's law of gravity and his laws of motion are at work, evidenced by the trajectory of a spacecraft circling Earth and by the behavior of all astronomical objects, such as the planets within the solar system. Newton's first law of motion is called the law of inertia; a second law concerns acceleration; while a third law states that for every action there is an equal and opposite reaction. Newton died in 1727, receiving recognition at the time for his brilliance. SEE ALSO EINSTEIN, ALBERT (VOLUME 2); GALILEI, GALILEO (VOLUME 2); GRAVITY (VOLUME 2).

Leonard David

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Observatories, Ground

O

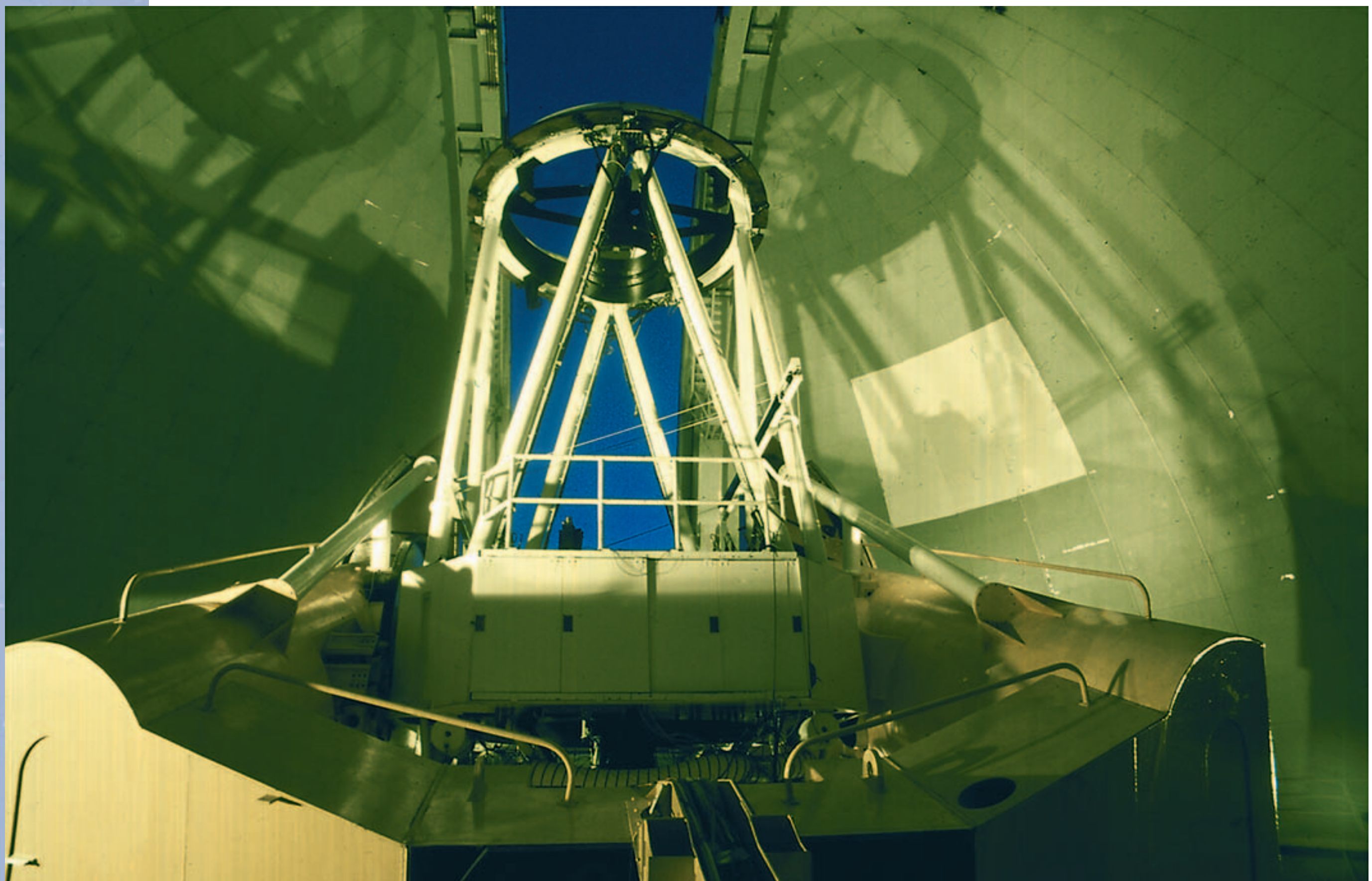
Astronomers study the universe by measuring electromagnetic radiation—**gamma rays**, **X rays**, optical and **infrared radiation**, and radio waves—emitted by planets, stars, galaxies, and other distant objects. Because Earth's atmosphere is transparent to optical and infrared radiation and to radio waves, these types of radiation can be studied from ground-based observatories. Astronomers must launch telescopes into space in order to study X rays, gamma rays, and other radiation that is blocked by absorption in Earth's atmosphere.

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

infrared radiation radiation whose wavelength is slightly longer than the wavelength of light

X rays a form of high-energy radiation just beyond the ultraviolet portion of the spectrum

Astronomers make use of ground-based observatories whenever they can. It is about 1,000 times cheaper to build a telescope of a given size on the ground than to launch it into space, so it is much more economical to operate on the surface of Earth.



This telescope is housed inside the interior dome of the Mauna Kea Observatory, Hawaii. Situated on a volcano, Mauna Kea is considered one of the world's best sites for optical and infrared astronomy.

A telescope can be thought of as a bucket that collects light or radio waves and brings them to a focus. More light can be gathered with a larger bucket. Since most astronomical sources of light are very faint, it is desirable to build telescopes as large as possible. Given current technology, we can build much larger telescopes on the ground than we can in space, which is another reason that ground-based observatories remain very important.

The Locations of Ground-Based Observatories

The best ground-based sites for optical and infrared astronomy are Mauna Kea, a volcano on the Big Island of Hawaii that is 4,205 meters (13,796 feet) high, and mountain peaks in the desert in northern Chile. Other good sites are in the Canary Islands and the southwestern United States. The following are the characteristics that astronomers look for when they select a site for an optical/infrared telescope:

1. *Clear skies.* The best sites in the world are clear about 75 percent of the time. Most types of astronomical observations cannot be carried out when clouds are present.
2. *Dark skies.* The atmosphere scatters city lights, making it impossible to see faint objects. The best sites are therefore located far away from large cities. (Even with the naked eye, one can see quite clearly the difference between what can be seen in the night sky in a city and in the country.)

MAJOR RADIO OBSERVATORIES OF THE WORLD

Observatory	Location	Description	Web Site
Individual Radio Dishes			
Arecibo Telescope (National Astron. & Ionospheric Center)	Arecibo, Puerto Rico	305-m fixed dish	www.naic.edu
Greenbank Telescope (National Radio Astron. Observ.)	Green Bank, West Virginia	100- x 110-m steerable dish	www.gb.nrao.edu/GBT/GBT.html
Effelsberg Telescope (Max Planck Institute für Radioastronomie)	Bonn, Germany	100-m steerable dish	www.mpifr-bonn.mpg.de/effberg.html
Lovell Telescope (Jodrell Bank Radio Observat.)	Manchester, England	76-m steerable dish	www.jb.man.ac.uk/
Goldstone Tracking Station (NASA/JPL)	Barstow, California	70-m steerable dish	gts.gdscc.nasa.gov/
Australia Tracking Station (NASA/JPL)	Tidbinbilla, Australia	70-m steerable dish	tid.cdscc.nasa.gov/
Parkes Radio Observatory	Parkes, Australia	64-m steerable dish	www.parkes.atnf.csiro.au/
Arrays of Radio Dishes			
Australia Telescope	Several sites in Australia	8-element array (seven 22-m dishes plus Parkes 64-m)	www.atnf.csiro.au/
MERLIN	Cambridge, England and other British sites	Network of 7 dishes (the largest of which is 32 m)	www.jb.man.ac.uk/merlin/
Westerbork Radio Observatory	Westerbork, the Netherlands	12-element array of 25-m dishes (1.6-km baseline)	www.nfra.nl/wsrt
Very Large Array (NRAO)	Socorro, New Mexico	27-element array of 25-m dishes (36-km baseline)	www.nrao.edu/doc/vla/html/VLAhome.shtml
Very Long Baseline Array (NRAO)	Ten U.S. sites, Hawaii to Virgin Islands	10-element array of 25-m dishes (9000)-km baseline	www.nrao.edu/doc/vlba/html/VLBA.html
Very–Long–Baseline–Interferom. Space Observ. Program (VSOP)	Connect a satellite to network on Earth	Japanese HALCA 8-m dish in orbit and ≈ 40 dishes on Earth	sgra.jpl.nasa.gov/
Millimeter-Wave Telescopes			
IRAM	Granada, Spain	30-m steerable mm-wave dish	iram.fr/
James Clerk Maxwell Telescope	Mauna Kea, Hawaii	15-m steerable mm-wave dish	www.jach.hawaii.edu/JCMT/pages/intro.html
Nobeyama Cosmic Radio Observatory	Minamimaki-Mura, Japan	6-element array of 10-m mm-wave dishes	www.nro.nao.ac.jp/~nma/index-e.html
Hat Creek Radio Observatory (University of California)	Cassel, California	6-element array of 5-m mm-wave dishes	bima.astro.umd.edu/bima

3. *High and dry.* Water vapor in Earth's atmosphere absorbs infrared radiation. Fortunately, water vapor is concentrated at low altitudes, and so infrared observatories are best located at high altitudes.
4. *Stable air.* Light rays are distorted when they pass through turbulent air, with the result that the image seen through a telescope is distorted and blurred. The most stable air occurs over large bodies of water such as oceans, which have a very uniform temperature. Therefore, the best sites are located in coastal mountain ranges (e.g., in northern Chile or California) or on isolated volcanic peaks in the middle of oceans (e.g., Mauna Kea).

The Hubble Space Telescope is above Earth's atmosphere, so its images are much clearer and sharper than the distorted images that are ob-

Stephen Hinman, Mirror Lab manager at the Steward Observatory Mirror Laboratory at the University of Arizona, examines a spun cast telescopic mirror.

adaptive optics the use of computers to adjust the shape of a telescope's optical system to compensate for gravity or temperature variations

ultraviolet radiation electromagnetic radiation with a shorter wavelength and higher energy than visible light

served from the ground. Astronomers are, however, devising techniques called **adaptive optics** that can correct atmospheric distortions by changing the shapes of small mirrors hundreds of times each second to compensate precisely for the effects of Earth's atmosphere. Even when this technique is perfected, space observatories will still be needed to observe gamma rays, X rays, **ultraviolet radiation**, and other wavelengths that are absorbed by Earth's atmosphere before they reach the ground.

The requirements for radio observatories are not nearly so stringent as for optical/infrared telescopes, and many types of radio observations can be made through clouds. Therefore, countries that do not have good optical/

infrared sites, such as Great Britain, Japan, the Netherlands, and Germany, have concentrated on radio astronomy.

While they are not bothered much by clouds or city lights, radio telescopes are affected by electrical interference generated by cell phones, radio transmitters, and other artifacts of civilization. Therefore, radio telescopes are often located far away from large population centers in special radio-quiet zones. Also, certain radio wavelengths are reserved for the use of radio astronomy and cannot be used to transmit human signals.

Optical and Infrared Telescopes

There are two main types of telescopes: refracting telescopes, which use lenses to gather the light and form an image; and reflecting telescopes, which use mirrors to accomplish the same purpose. Telescopes are described by the size of the largest lens or mirror that they contain. The largest refracting telescope ever built is the Yerkes 40-inch (1-meter) telescope, which is located in southeastern Wisconsin. Refractors are limited to fairly small sizes for two reasons. First, since the light must pass through a lens to be focused, the lens must be supported around its outside edge, not from behind. Large lenses tend to sag and distort in shape because of the effects of gravity, and the focused image is not as sharp as it should be. Second, because the light passes through the lens, the glass must be entirely free of bubbles or other defects that would distort the image. It is difficult and costly to make large pieces of perfect glass.

Reflecting telescopes make use of mirrors. Since the light is reflected from the front surface, mirrors can be supported from behind and can therefore be made as large as several meters in diameter. The front surface is coated with highly reflective (shiny) aluminum or silver. Since the light in a reflector never passes through the mirror, the glass can contain a few bubbles or other flaws. For these reasons the largest telescopes in the world are reflectors.

Reflecting telescopes are used for both infrared and optical astronomy. Because glass does not transmit infrared radiation very efficiently, refracting telescopes are unsuitable for most kinds of infrared astronomy.

New Technology Telescopes

For about forty years after its completion in 1948, the Palomar 5-meter (16.7 feet) reflector in southern California was the largest telescope in the world. The 5-meter Palomar mirror is very thick and is therefore rigid enough not to change shape when the telescope tracks stars as they rise in the east and set in the west. The Palomar mirror weighs about 20 tons, and a very large steel structure (weighing about 530 tons) is required to hold it. The Palomar telescope is near the limit in size of what can be built for a reasonable cost with a massive, rigid mirror.

In the 1990s, many countries took advantage of developments in technology to build telescopes with diameters of 6.5 to 10 meters (21 to 33 feet). It is now possible to use thin telescope mirrors, which do change shape when they are pointed in different directions. High-speed computers calculate the forces that must be applied to the flexible mirrors to produce the correct shape. These restoring forces can be adjusted many times each second if

LARGE OPTICAL TELESCOPES BEING BUILT OR IN OPERATION

Aperture (m)	Telescope Name	Location	Status	Web Address
16.4	Very Large Telescope (four 8.2–m telescopes)	Cerro Paranal, Chile*	First telescope completed 1998	www.eso.org/vlt/
11.8	Large Binocular Telescope (two 8.4–m telescopes)	Mount Graham, Arizona	First light 2002–2003	medusa.as.arizona.edu/btwww/tech/lbtbook.html
10.0	Keck I	Mauna Kea, Hawaii	Completed 1993	astro.caltech.edu/mirror/keck/index.html
10.0	Keck II	Mauna Kea, Hawaii	Completed 1996	astro.caltech.edu/mirror/keck/index.html
9.9	Hobby–Eberly (HET)	Mount Locke, Texas	Completed 1997	www.astro.psu.edu/het/overview.html
8.3	Subaru (Pleiades)	Mauna Kea, Hawaii	First light 1998	www.naoj.org/
8.0	Gemini (North)	Mauna Kea, Hawaii†	First light 1999	www.gemini.edu
8.0	Gemini (South)	Cerro Pachon, Chile†	First light 2000	www.gemini.edu
6.5	Multi-Mirror (MMT)	Mount Hopkins, Arizona	First light 1998	sculptor.as.arizona.edu.edu/foltz/www/
6.5	Magellan	Las Campanas, Chile	First light 1997	www.ociw.edu/~johns/magellan.html
6.0	Large Alt-Azimuth	Mount Pastukhov, Russia	Completed 1976	—
5.0	Hale	Palomar Mountain, California	Completed 1948	astro.caltech.edu/observatories/palomar/public/index.html
4.2	William Herschel	Canary Islands, Spain	Completed 1987	www.ast.cam.ac.uk/ING/PR/pr.html
4.2	SOAR	Cerro Pachon, Chile	First light 2002	www.noao.edu/
4.0	Blanco Telescope (NOAO)	Cerro Tololo, Chile†	Completed 1974	www.ctio.noao.edu/ctio/html
3.9	Anglo-Australian (AAT)	Siding Spring, Australia	Completed 1975	www.aao.gov.au/index.html
3.8	NOAO Mayall	Kitt Peak, Arizona†	Completed 1973	www.noao.edu/noao.html
3.8	United Kingdom Infrared (UKIRT)	Mauna Kea, Hawaii	Completed 1979	www.jach.hawaii.edu/UKIRT/home.html
3.6	Canada-France-Hawaii (CFHT)	Mauna Kea, Hawaii	Completed 1979	www.cfht.hawaii.edu/
3.6	ESO	Cerro La Silla, Chile*	Completed 1976	www.ls.eso.org/
3.6	ESO New Technology	Cerro La Silla, Chile*	Completed 1989	www.ls.eso.org/
3.5	Max Planck Institut	Calar Alto, Spain	Completed 1983	www.mpia-hd.mpg.de/CAHA/
3.5	WIYN	Kitt Peak, Arizona†	Completed 1993	www.noao.edu/wiyn/wiyn.html
3.5	Astrophysical Research Corp.	Apache Point, New Mexico	Completed 1993	www.apo.nmsu.edu/
3.0	Shane (Lick Observatory)	Mount Hamilton, California	Completed 1959	www.ucolick.org/
3.0	NASA Infrared (IRTF)	Mauna Kea, Hawaii	Completed 1979	irtf.ifa.hawaii.edu

*Part of the European Southern Observatory (ESO).
†Part of the U.S. National Optical Astronomy Observatories (NOAO).

necessary. A lightweight thin mirror can be supported by a lightweight steel structure, and telescopes double the size of the Palomar telescope are affordable with this new technology.

At the dawn of the twenty-first century, the largest single mirror that has been manufactured to date is 8.4 meters (27.5 feet) in diameter, and it is scheduled to be installed in a telescope in southern Arizona in 2003. This is probably about the largest single mirror that is feasible. Given the width of highways and tunnels, it would be impossible to transport a much larger mirror from where it was manufactured to a distant mountaintop.

Currently the largest telescopes in the world are the twin 10-meter (33-foot) Keck telescopes on Mauna Kea. These telescopes do not contain a single mirror that is 10 meters in diameter. Rather, each consists of thirty-six separate hexagonal-shaped mirrors that are 1.8 meters (6 feet) in diameter. These mirrors are positioned so precisely relative to one another that they can collect and focus the light as efficiently as a continuous single mirror.

Radio Telescopes

Radio astronomy is a young field relative to optical astronomy. Italian mathematician and astronomer Galileo Galilei used the first optical telescope, a refractor, in 1610. By contrast, American electrical engineer Karl Jansky first detected astronomical radio waves in 1931. Astronomical radio waves cannot be heard. Like light, radio waves are a form of electromagnetic radiation. Unlike light, however, we cannot sense radio waves directly but must use electronic equipment. Radio waves are reflected by surfaces that conduct electricity, just as light is reflected by a shiny aluminum or silver surface. Accordingly, a radio telescope consists of a concave metal reflector that focuses the radio waves on a receiver.

Interferometry

Resolution refers to the fineness of detail that can be seen in an image. The larger the telescope, the finer the detail that can be observed. One way to see finer detail is to build a larger single telescope. Unfortunately, there are practical limits to the size of a single telescope—currently about 10 meters (33 feet) for optical/infrared telescopes and about 100 meters (330 feet) for radio telescopes. If, however, astronomers combine the signals from two or more widely separated telescopes, they can see the fineness of detail that would be observed if they had a single telescope of that same diameter. Telescopes working in combination in this way are called **interferometers**. For example, infrared radiation falling on the two 10-meter Keck telescopes, which are about 85 meters (279 feet) apart, has been combined, allowing astronomers to obtain the kind of detailed image that they would observe if they had a single telescope 85 meters in diameter.

interferometers devices that use two or more telescopes to observe the same object at the same time in the same wavelength to increase angular resolution

Radio interferometry is easier than optical and infrared interferometry because radio waves have much longer wavelengths than optical or infrared radiation. The equipment used to measure radio waves need not be built to the same precision as optical telescopes, and radio waves are not distorted very much by turbulence in Earth's atmosphere. For these reasons, radio astronomers have been able to build whole arrays of telescopes separated by thousands of kilometers to conduct interferometry. For example, U.S. astronomers operate the Very Long Baseline Array, which consists of ten telescopes located across the United States and in the Virgin Islands and Hawaii. When combined with a telescope in Japan, this array of radio telescopes has the same resolution as a telescope with the diameter of Earth.

The Future of Ground-Based Observatories

By 2003, fourteen mirrors with diameters larger than 6.5 meters (21.3 feet) will have been installed in optical/infrared telescopes. During the early twenty-first century, these telescopes are likely to produce many impressive discoveries. But astronomers are already planning for the next generation of large telescopes. These will truly be "world" telescopes. The costs, which are estimated to be several hundred million dollars each, are beyond the reach of any single country. Therefore, the new, very large telescopes will be built through international consortia involving many countries.

Astronomers in Europe are exploring the feasibility of building an optical/infrared telescope that is 100 meters (330 feet) in diameter—about the length of a football field. This telescope is called the OWL telescope, which stands for Overwhelmingly Large Telescope. The mirror would be built in the same way as the Keck mirrors, that is, by combining literally thousands of smaller mirrors to form a single continuous surface. This telescope would be powerful enough to study objects present when the universe was only a few million years old. The current age of the universe is about 14 billion years, and so with a telescope such as OWL astronomers could observe directly the evolution of the universe throughout nearly all of its history.

In radio astronomy, the next major project is likely to be the Atacama Large Millimeter Array (ALMA). The project will be an interferometer that detects radio radiation with wavelengths between 0.350 and 10 millimeters (0.014 and 0.4 inches). The facility will consist of sixty-four radio antennas, each 12 meters (39 feet) in diameter, with the separations between antennas varying from 150 meters (490 feet) to 10 kilometers (6.2 miles). ALMA will be located at one of the driest spots on Earth—a large plateau at an altitude of 5,000 meters (16,400 feet) in the Atacama Desert in northern Chile. Water vapor in Earth's atmosphere absorbs much of the millimeter wavelength radiation that astronomers would like to detect, and so it is important to select an extremely dry site. The facility will be particularly useful for studying how stars and planets form and what galaxies were like when the universe was very young. SEE ALSO Astronomer (Volume 2); Astronomy, History of (Volume 2); Astronomy, Kinds of (Volume 2); Careers in Astronomy (Volume 2); Hubble Space Telescope (Volume 2); Observatories, Space-Based (Volume 2).

Sidney C. Wolff

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Observatories, Space-Based

Space-based observatories are telescopes located beyond Earth, either in orbit around the planet or in deep space. Such observatories allow astronomers to observe the universe in ways not possible from the surface of Earth, usually because of interference from our planet's atmosphere. Space-based observatories, however, are typically more complicated and expensive than Earth-based telescopes. The National Aeronautics and Space Administration (NASA) and other space agencies have been flying space observatories of one type or another since the late 1960s. While the Hubble Space Telescope is the most famous of the space observatories, it is just one of many

The Hubble Space Telescope (HST) is lifted into position by the Remote Manipulator System (RMS) from its berth in the cargo bay of the Earth-orbiting space shuttle Discovery.

that have provided astronomers with new insights about the solar system, the Milky Way galaxy, and the universe.

The Advantages and Disadvantages of Space-Based Telescopes

Observatories in space have a number of key advantages. Telescopes in space are able to operate twenty-four hours a day, free of both Earth's day-night cycle as well as clouds and other weather conditions that can hamper observing. Telescopes above the atmosphere can also observe portions of the **electromagnetic spectrum** of light, such as **ultraviolet radiation**, **X rays**, and **gamma rays**, which are blocked by Earth's atmosphere and never reach the surface. Telescopes in space are also free of the distortions in the atmosphere that blur images. These factors increase the probability that space telescopes will be more productive and useful than their ground-based counterparts.

Space-based observatories also have some disadvantages. Unlike most ground-based telescopes, space observatories operate completely automatically, without any humans on-site to fix faulty equipment or deal with other problems. There are also limitations on the size and mass of objects that can be launched, as well as the need to use special materials and designs that can withstand the harsh environment of space, creating limitations on the types of observatories that can be flown in space. These factors, as well as current high launch costs, make space observatories very expensive: the

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

ultraviolet radiation electromagnetic radiation with a shorter wavelength and higher energy than visible light

X rays a form of high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

With the Earth as a backdrop, astronauts John M. Grunsfeld and Steven L. Smith replace gyroscopes inside the Hubble Space Telescope during extravehicular activity.

largest observatories, such as the Hubble Space Telescope, cost over $1 billion, whereas world-class ground-based telescopes cost less than $100 million. In many cases, though, there is no option other than to fly a space observatory, because ground-based telescopes cannot accomplish the required work.

The History of Space-Based Telescopes

The first serious study of observatories in space was conducted in 1946 by astronomer Lyman Spitzer, who proposed orbiting a small telescope. In the late 1960s and early 1970s NASA launched four small observatories under the name Orbiting Astronomical Observatories (OAO). Two of the OAO missions were successful and conducted observations, primarily in ultraviolet light, for several years. NASA followed this up with a number of other small observatories, including the International Ultraviolet Explorer in 1978 and the Infrared Astronomy Satellite in 1983.

While NASA was developing and launching these early missions, it was working on something much larger. In the 1960s it started studying a proposal to launch a much larger observatory to study the universe at visible, ultraviolet, and infrared **wavelengths**. This observatory was originally known simply as the Large Space Telescope, but over time evolved into what became known as the Hubble Space Telescope. Hubble was finally launched by the space shuttle Discovery in April 1990. After astronauts corrected a problem with the telescope's optics in 1993, Hubble emerged as

wavelength the distance from crest to crest on a wave at an instant in time one of the best telescopes in the world. Hubble is scheduled to operate at least through 2010.

The Great Observatories

While the Hubble Space Telescope may be the most famous space observatory, it is far from the only major one. NASA planned for Hubble to be the first of four "Great Observatories" studying the universe from space, each focusing on a different portion of the spectrum. The second of the four Great Observatories, the Compton Gamma Ray Observatory (CGRO), was launched by the space shuttle Atlantis on mission STS-37 in April 1991. The telescope was named after Arthur Holly Compton, a physicist who won the Nobel Prize in 1927 for his experimental efforts confirming that light had characteristics of both waves and particles.

The purpose of CGRO, also known as Compton, was to study the universe at the wavelengths of gamma rays, the most energetic form of light. CGRO carried four instruments that carried out these observations. Data from these instruments led to a number of scientific breakthroughs. Astronomers discovered through CGRO data that the center of our galaxy glows in gamma rays created by the annihilation of matter and **antimatter**. Observations by CGRO of hundreds of mysterious gamma-ray bursts showed that the bursts are spread out evenly over the entire sky and thus likely originate from far outside our own galaxy. Astronomers used CGRO to discover a new class of objects, known as blazars: **quasars** that generate gamma rays and jets of particles oriented in our direction.

antimatter matter composed of antiparticles, such as positrons and antiprotons

quasars luminous objects that appear starlike but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

CGRO was intended to operate for five years but continued to work for several years beyond that period. In early 2000 one of Compton's three gyroscopes, used to orient the spacecraft, failed. Because the spacecraft was so heavy—at 17 tons it weighed more than even Hubble—NASA was concerned that if the other gyroscopes failed the spacecraft could reenter Earth's atmosphere uncontrolled and crash, causing damage and injury. To prevent this, NASA deliberately reentered Compton over the South Pacific on June 4, 2000, scattering debris over an empty region of ocean and ending the spacecraft's nine-year mission.

The third spacecraft in NASA's Great Observatories program is the Chandra X-Ray Observatory. The spacecraft, originally called the Advanced X-Ray Astrophysics Facility but today known simply as Chandra, was launched by the space shuttle Columbia on mission STS-93 in July 1999. Chandra was the largest spacecraft ever launched by the space shuttle. The spacecraft is named after Subrahmanyan Chandrasekhar, an Indian-American astrophysicist who won the Nobel Prize for physics in 1983 for his studies of the structure and evolution of stars.

Chandra carries four instruments to study the universe at X-ray wavelengths, which are slightly less energetic than gamma rays, at up to twenty-five times better detail than previous spacecraft missions. To carry out these observations Chandra is in an unusual orbit: Rather than a circular orbit close to Earth, as used by Hubble and Compton, it is in an **eccentric** orbit that goes between 10,000 and 140,000 kilometers (6,200 and 86,800 miles) from Earth. This **elliptical** orbit allows Chandra to spend as much time as possible above the charged particles in the **Van Allen radiation belts** that would interfere with the observations.

eccentric the term that describes how oval the orbit of a planet is

elliptical having an oval shape

Van Allen radiation belts two belts of high energy charged particles captured from the solar wind by Earth's magnetic field

The Chandra X-Ray Observatory, just prior to deployment from space shuttle Columbia's payload bay. The 50,162 pound observatory is named after astrophysicist Subrahmanyan Chandrasekhar, who won the Nobel Prize for physics in 1983 for his studies of the structure and evolution of stars.

Although Chandra has been in orbit only a relatively short time, it has provided astronomers with a wealth of data. Astronomers have used Chandra to learn more about the **dark matter** that may make up most of the mass of the universe, study **black holes** in great detail, witness the results of **supernova** explosions, and observe the birth of new stars. Chandra's mission is officially scheduled to last for five years but will likely continue so long as the spacecraft continues to operate well.

dark matter matter that interacts with ordinary matter by gravity but does not emit electromagnetic radiation; its composition is unknown

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

supernova an explosion ending the life of a massive star; caused by core collapse or the sudden onset of nuclear fusion

brown dwarfs star-like objects less massive than 0.08 times the mass of the Sun, which cannot undergo thermonuclear process to generate their own luminosity

The final spacecraft of the Great Observatories program is the Space Infrared Telescope Facility (SIRTF). SIRTF will probe the universe at infrared wavelengths of light, which are longer and less energetic than visible light. SIRTF is scheduled for launch in January 2003 on an unpiloted Delta rocket. Rather than go into Earth orbit, SIRTF will be placed in an orbit around the Sun that gradually trails away from Earth; this will make it easier for the spacecraft to perform observations without interference from Earth's own infrared light. Astronomers plan to use SIRTF to study planets, comets, and asteroids in our own solar system and look for evidence of giant planets and **brown dwarfs** around other stars. SIRTF will also be used to study star formation and various types of galaxies during its five-year mission.

Other Space Observatories

Besides NASA's Great Observatories, there have been many smaller, space-based observatories that have focused on particular objects or sections of the electromagnetic spectrum. A number of these missions have made major contributions. NASA's Cosmic Background Explorer (COBE) spacecraft was launched in 1989 on a mission to observe **cosmic microwave background** radiation, light left over from shortly after the **Big Bang**. COBE's instruments were able to measure small variations in the background, providing key proof for the Big Bang model of the universe. NASA launched a new mission, the Microwave Anisotropy Probe (MAP), in June 2000 to measure the variations in the microwave background in even greater detail.

cosmic microwave background ubiquitous, diffuse, uniform, thermal radiation created during the earliest hot phases of the universe

Big Bang name given by astronomers to the event marking the beginning of the universe, when all matter and energy came into being

NASA is not the only space agency to launch space observatories. The European Space Agency (ESA) has launched a number of its own observatories to study the universe. The Infrared Space Observatory provided astronomers with unprecedented views of the universe at infrared wavelengths in the mid- and late 1990s. In 1999 ESA launched XMM-Newton, an orbiting X-ray observatory similar to NASA's Chandra spacecraft. XMM-Newton and Chandra serve complementary purposes: Whereas Chandra is designed to take detailed X-ray images of objects, XMM-Newton focuses on measuring the **spectra** of those objects at X-ray wavelengths.

spectra representations of the brightness of objects as a function of the wavelength of the emitted radiation

Japan has also contributed a number of small space observatories. The Advanced Satellite for Cosmology and Astrophysics spacecraft was launched in 1993 and continues to operate in the early twenty-first century, studying the universe at X-ray wavelengths. The Yohkoh spacecraft was launched in 1991 to study the Sun in X rays. The Halca spacecraft, launched in 1997, conducts joint observations with radio telescopes on Earth. The Soviet Union also flew several space observatories, including the Gamma gamma-ray observatory and the Granat X-ray observatory. Since the collapse of the Soviet Union, however, Russia has been unable to afford the development of any new orbiting telescopes.

Future Space Observatories

The success of past and present space observatories has led NASA, ESA, and other space agencies to plan a new series of larger, more complex spacecraft that will be able to see deeper into the universe and in more detail than their predecessors. Leading these future observatories is the Next Generation Space Telescope (NGST), the successor to the Hubble Space Telescope. Scheduled for launch in 2009, NGST will use a telescope up to 6.5 meters (21.3 feet) in diameter (Hubble's is 2.4 meters [7.9 feet] across), which will allow it to observe dimmer and more distant objects. The telescope will be located at the Earth-Sun L-2 point, 1.5 million kilometers (930,000 miles) away, to shield it from Earth's infrared radiation. NASA is also supporting the development of other new space observatories, including GLAST, a gamma-ray observatory scheduled for launch in 2006.

ESA is developing several space observatories that will observe the universe at different wavelengths. Integral is a gamma-ray observatory scheduled for launch in 2002. Planck, scheduled for launch in 2007, will build upon the observations of the cosmic microwave background made by COBE and MAP. Herschel, also scheduled for launch in 2007, will observe the universe at far-infrared wavelengths. ESA is also collaborating with NASA on development of the NGST.

In the future, space observatories may consist of several spacecraft working together. Such orbiting arrays of telescopes could allow astronomers to get better images without the need to build extremely large and expensive single telescopes. One such mission, called Terrestrial Planet Finder (TPF), would combine images from several telescopes, each somewhat larger than Hubble, to create a single image. A system of this type would make it possible for astronomers to directly observe planets the size of Earth orbiting other stars. TPF is tentatively scheduled for launch no sooner than 2011. NASA is also studying a similar proposal, called Constellation-X, which would use several X-ray telescopes to create a virtual telescope 100 times more powerful than existing ones.

In the more distant future, astronomers have proposed developing large telescopes, and arrays of telescopes, on the surface of the Moon. The farside of the Moon is an ideal location for a radio telescope, because it would be shielded from the growing artificial radio noise from Earth. However, there are as of yet no detailed plans for lunar observatories. SEE ALSO Astronomer (volume 2); Astronomy, History of (volume 2); Astronomy, Kinds of (volume 2); Hubble Space Telescope (volume 2); Observatories, Ground (volume 2).

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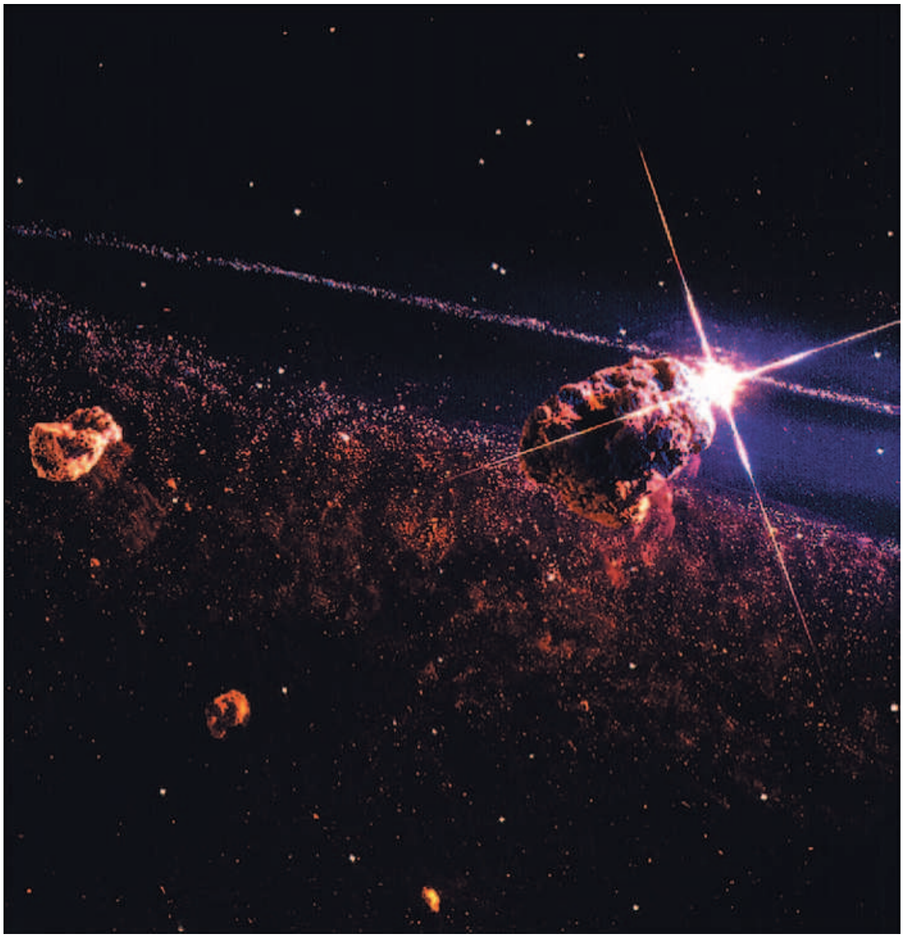
Oort Cloud

The Oort cloud is a vast swarm of some 2 trillion comets orbiting our star in the most distant reaches of our solar system, extending from beyond the orbits of Neptune and Pluto out to 100,000 times the Earth-Sun distance—nearly one-third the distance to the nearest star. While the planets are confined to a flattened disk in the solar system, the Oort cloud forms a spherical shell centered on the Sun, which gradually flattens down to an extended disk in the inner region, called the Kuiper belt. Bright comets observed through telescopes or with the unaided eye get perturbed out of the Oort cloud or Kuiper belt, and become visible when they get close to enough so that the Sun's energy can transform the surface ices into gases. These gases drag off the embedded dust, and we see the light reflected from the dust as a tail.

Comets are the leftover icy building blocks from the time of planet formation, which formed in the region of the outer planets. Essentially these



The Oort Cloud, which may contain as many as two trillion comets, orbits the outer reaches of the solar system.

comets are dirty snowballs, composed primarily of water ice, with some carbon monoxide and other ices, in addition to **interstellar** dust. When their orbits passed close enough to the giant planets to be affected, some were thrown toward the Sun and some were tossed outward toward the distant reaches of the solar system, the spherical swarm we now call the Oort cloud. Some of the comets sent inward hit the inner rocky planets, and probably contributed a significant amount of ocean water and organic material, the building blocks of life, to Earth. Comets that live in the Oort cloud are especially important scientifically because they have been kept in a perpetual deep freeze since the formation of our solar system 4.6 billion years ago. This means that they preserve, nearly intact, a record of the chemical conditions during the first few million years of the solar system's history, and can be used to unravel our solar system's origins much like an archaeologist uses artifacts to decipher an ancient civilization.

interstellar between the stars

The Oort cloud was "discovered" by Dutch astronomer Jan Hendrik Oort in 1950, not through telescopic observations, but through a theoretical study of the orbits of long-period comets (comets with periods greater than 200 years). Long-period comets can have orbits ranging from **eccentric** ellipses to parabolas to even modest hyperbolas. While trying to explain the distribution of these orbits (which were mostly nearly parabolic or hyperbolic), Oort concluded that the only explanation was that the source of these comets had to be a massive cloud of comets surrounding the solar

eccentric the term that describes how oval the orbit of a planet is system. These comets would be fed into the region of the planets as the motion of the solar system through the galaxy caused the solar system to pass relatively close to stars. The slight change in the gravitational acceleration from these stars was enough to send some distant comets into orbits that brought them into the inner solar system.

Oort's remarkable discovery was made with only a few handfuls of comet observations. Since then, precise observations of comet orbits and new modern computer models have shown not only that his ideas were correct but also that the Oort cloud can be divided into different regions: the outer Oort cloud, acted upon by passing stars; the inner Oort cloud, which is close enough to the Sun (perhaps 2,000 to 15,000 Earth-Sun distances) that the comets are not affected by gravitational interactions, and finally the flattened innermost region—the Kuiper belt. Kuiper belt comet orbits can be perturbed through interactions with the outer planets, and these comets then become observable as short-period comets. Because the Kuiper belt is much closer to the Sun, the world's largest telescopes began directly observing these comets in the late-twentieth century. The first Kuiper belt object was discovered in 1993, and by 2002 more than 500 such objects were discovered. SEE ALSO Comets (volume 2); Kuiper Belt (volume 2); Orbits (volume 2); Planetesimals (volume 2); Small Bodies (volume 2).

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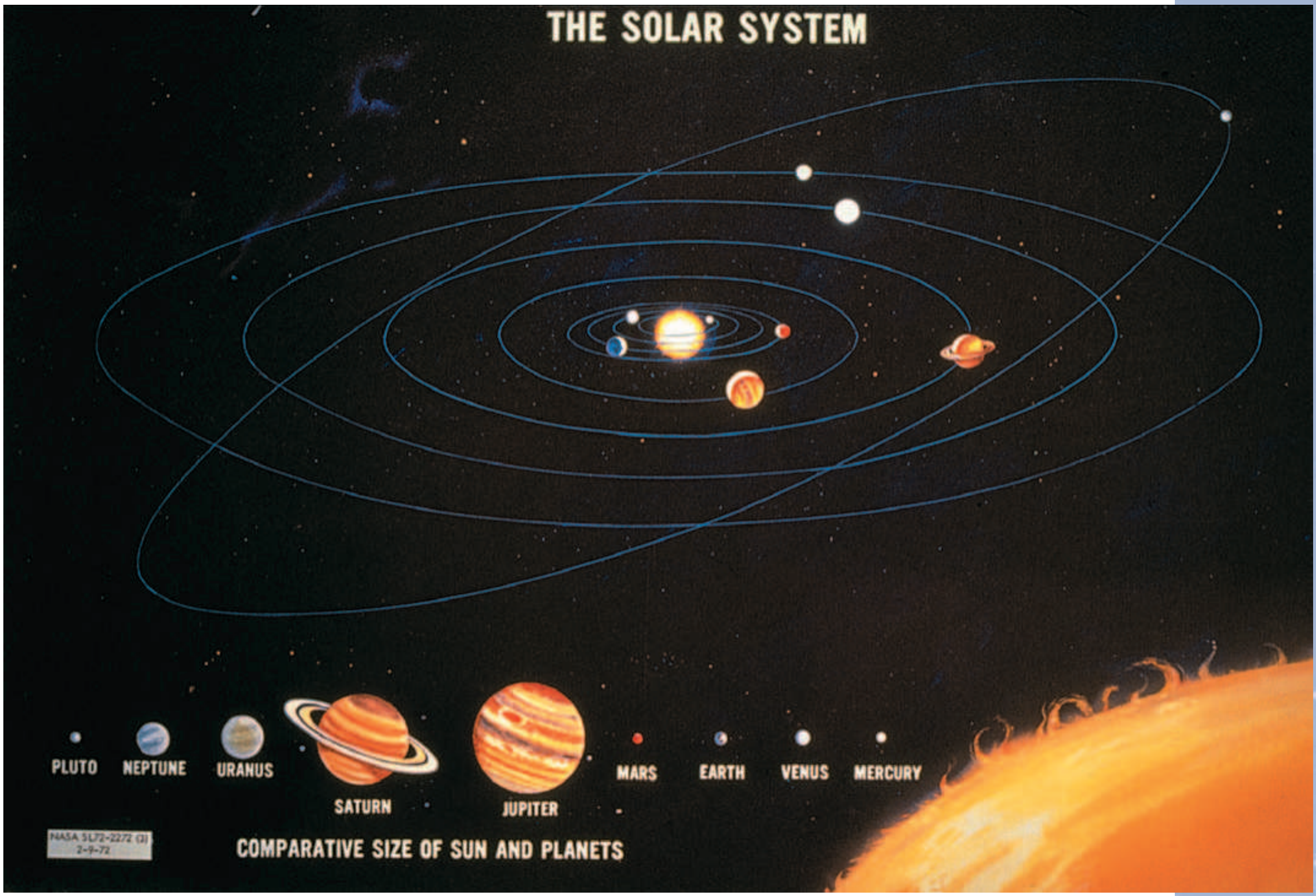
Orbits

Orbits are the pathways taken by objects under the influence of the gravity of another object. These **trajectories** are governed by the fundamental laws of gravity and the motion of the object. The ability to calculate the orbit of an object, be it a planet, moon, asteroid, or spacecraft, makes it possible to predict where it will be in the future. Both solar system objects and spacecraft can be found in a wide range of orbits, including specific types of Earth orbits that are particularly useful for some types of spacecraft.

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

All objects in space are attracted to all other objects by the force of gravity. In the case of an object orbiting a planet or other celestial body, where the mass of the object is much less than the mass of the planet, the object will fall towards the planet. However, if the object has some initial **velocity**, it will not fall straight towards the planet, as its trajectory will be altered by gravity. If the object is going fast enough, it will not hit the planet, because the planet's surface is curving away underneath it. Instead, it will keep "falling" around the planet in a trajectory known as an orbit. Orbits require a specific range of speeds. If the object slows down below a mini-

velocity speed and direction of a moving object; a vector quantity



A graphical diagram of the solar system showing the nine planets and their comparative sizes, as well as each planet's orbital track around the Sun.

mum orbital velocity, it will hit the planet; if it speeds up beyond a maximum escape velocity, it will move away from the planet permanently.

Orbital Elements

The shape of an orbit around a planet (or another body) can be defined by several key factors, known as orbital elements. One is the orbit's mean radius, also known as the semimajor axis. The second is the eccentricity of the orbit, or the degree by which the orbit differs from a circle. The third factor is the inclination of the orbit, or the angle between the plane of the orbit and the plane of Earth's orbit. An inclination of 0 degrees would mean the orbit is perfectly aligned with Earth's orbital plane. Three other factors, known as the right ascension of the ascending node, argument of periapsis, and true anomaly, further refine the orientation of the orbit as well as the position of the object in orbit at a given time.

Calculating these orbital elements requires a minimum of three measurements of the position of the object at different times. Additional observations help refine the calculation of the orbit and reduce errors. Once the orbital elements are known, other key parameters of the orbit can be computed, such as its period, and the closest and farthest the object is in its orbit (known respectively as periapsis and apoapsis). For objects orbiting Earth, periapsis and apoapsis are known as perigee and apogee; for

The Moon's orbit around Earth is slightly tilted and moves around Earth counterclockwise as seen from above the North Pole.

perihelion the point in an object's orbit that is closest to the Sun

aphelion the point in an object's orbit that is farthest from the Sun.

objects orbiting the Sun, these locations are known as **perihelion** and **aphelion**.

Types of Orbits

Solar system objects travel in a wide variety of orbits. Most planets go around the Sun in nearly circular, low-inclination orbits. The exception is Pluto, which has an inclined orbit that is so eccentric that it is closer to the Sun than Neptune is for twenty years out of each 248-year orbit. Asteroid orbits can be more eccentric, particularly for those objects whose orbits have been altered by the gravity of Jupiter or another planet. Comet orbits, however, can be extremely eccentric, especially for long-period comets that pass through the inner solar system only once every hundreds, or thousands, of years.

Spacecraft orbiting Earth can be found in several different types of orbits based on their altitude and orientation. Many spacecraft, including the space shuttle and International Space Station, are in low Earth orbit, flying a few hundred kilometers above Earth and completing one orbit in about ninety minutes. These orbits are the easiest to get into and are particularly useful for spacecraft that observe Earth. Higher orbits, extending out to altitudes of tens of thousands of kilometers, are used by specific types of communications, navigation, and other spacecraft. At these higher orbits it can take many hours to complete a single orbit.

Special Classes of Orbits

There are several special classes of orbits of particular interest. The best-known special orbit is geostationary orbit, a circular orbit 36,000 kilometers (22,320 miles) above Earth. At this altitude it takes a satellite twenty-four hours to complete one orbit. To an observer on the ground a satellite in this orbit would appear motionless in the sky, hence the name geostationary. Geostationary orbit is also known as a Clarke orbit, after science fiction writer Arthur C. Clarke, who first proposed the concept in 1945. This orbit is used today by hundreds of communications and weather satellites.

Satellites in geostationary orbit do not work well for people in high latitudes, because the satellites appear near the horizon. To get around this limitation, the Soviet Union placed communications satellites in highly inclined, **elliptical** orbits, so that they appeared to hang nearly motionlessly high in the sky for hours at a time. Such orbits are known as Molniya orbits, after the class of spacecraft that launched them.

elliptical having an oval shape

Another special type of orbit is Sun-synchronous orbit. This nearly polar orbit is designed such that the spacecraft's orbital path moves at the same apparent rate as the Sun. This allows the spacecraft to pass over different regions of Earth at the same local time. Sun-synchronous orbits are used primarily by **remote sensing** satellites that study Earth because these orbits make comparisons between different regions of Earth and different times of the year easier. The Mars Global Surveyor and Mars Odyssey spacecraft orbiting Mars also use versions of Sun-synchronous orbit. SEE ALSO Asteroids (volume 2); Comets (volume 2); Gravity (volume 2); Satellites, Types of (volume 1); Trajectories (volume 2).

remote sensing the act of observing from orbit what may be seen or sensed below Earth

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Planet X

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Ever since the discovery of the ninth planet, Pluto, astronomers have speculated about whether a still more distant, tenth planet may exist. This thinking was initially based on two lines of reasoning. First, astronomers had been successful at discovering Uranus, and then Neptune, and then Pluto. This led them to believe that additional planets might await discovery farther out, if they only searched hard enough for them. Second, the search for Pluto, like the search for Neptune before it, had been based on the apparent tug of a giant, unseen world affecting the orbit of its predecessor. Yet after Pluto's discovery, it became clear that the newly found planet was very small, smaller than the United States. Such a small world could not have tugged significantly on Neptune.

Not long after the discovery of Pluto, however, it was discovered that the discrepancies in the orbit of Neptune that led astronomers to search for Pluto had been fictitious—they were simply measurement errors made by old telescopes. Pluto's discovery had been a lucky accident. With this finding, most astronomers concluded in the early 1980s that the train of logic leading to suspicions of a "Planet X" was faulty, and that it was unlikely a large Planet X existed beyond Pluto.

More recently, however, the tide has begun to swing back to a general consensus that there may indeed be planets orbiting the Sun beyond Pluto. Indeed, there may be not just one (i.e., Planet X), but many. Why this change? For one thing, astronomers discovered the Kuiper belt, a teeming ensemble of miniature worlds within which Pluto orbits. Objects half as large as Pluto have already been discovered among the hundreds of Kuiper belt objects found since 1992, and most astronomers expect that still larger objects, probably including some larger than Pluto itself, will eventually be identified.

Moreover, it has become clear from computer-generated solar system formation models that during the final stage of the formation of giant planets, a significant number of larger, "runner-up" objects to the giant planets (some perhaps even larger than Earth) may have been ejected to orbits in the Oort cloud of comets lying far beyond Pluto.

Do such objects actually exist? We will not know until observational searches either find them or rule them out. Such a search is difficult. Because such objects will be farther out than Pluto, and therefore dimmer, locating them will be rather akin to finding a needle in a haystack. Searches now underway and planned for the first decade of the twenty-first century may well settle the question. Until then, however, the subject of Planet X (and planets Y, Z, and so forth) will remain a subject of ongoing scientific debate. SEE ALSO Extrasolar Planets (volume 2); Kuiper Belt (volume 2); Oort Cloud (volume 2).

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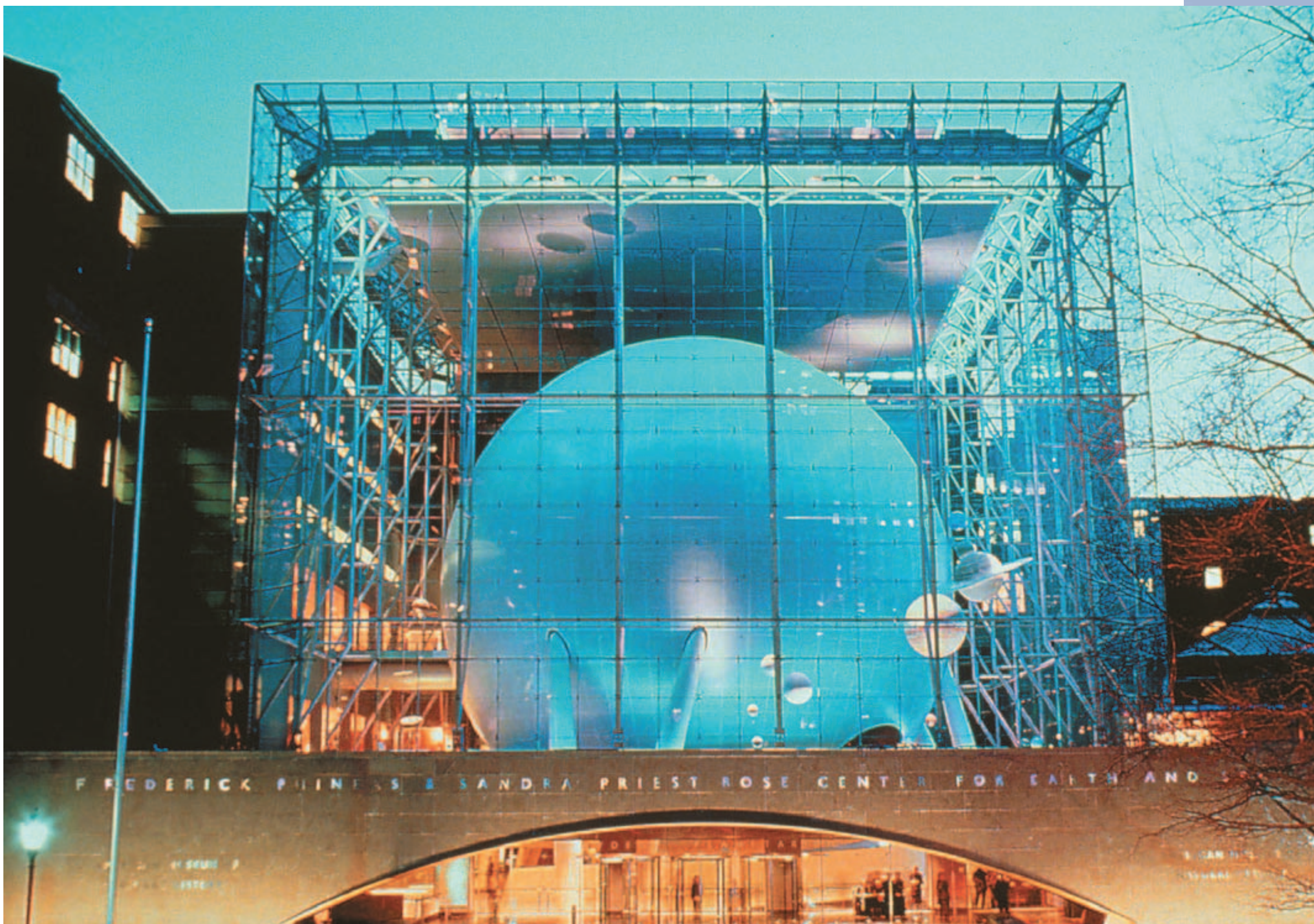
Planetariums and Science Centers

Planetariums, museums, and science centers can be found in most major cities around the world. Science centers are an outgrowth of the original planetarium theaters, which, at their inception in the 1930s, were the only



The sphere of the Hayden Planetarium is part of the Rose Center for Earth and Science at New York City's American Museum of National History. The planetarium contains the largest and most powerful virtual reality simulator in the world.

places the general public could learn about science in general and astronomy in particular.

A planetarium consists of a hemispherical-domed theater in which a specialized star projector can display the night sky at any time of the year. Central to the experience is the planetarium projector. There are two principle types of star projectors: opto-mechanical and digital.

Traditional Planetarium Projectors

Opto-mechanical planetarium projectors typically have two spheres incorporating carefully drilled metal plates that, when illuminated, reproduce the constellation patterns on the reflective dome surface. In addition, the positions of planets hundreds of years into the past or future can be displayed. There are four principle manufacturers of this kind of projector: Zeiss (Germany), Minolta (Japan), Gotoh (Japan), and Spitz, Inc. (United States). Walther Bauersfeld of the Zeiss company built the first opto-mechanical star projector in 1923.

Digital Planetarium Projectors

A digital projector called "Digistar®," short for digital stars, was introduced in 1980 by Evans and Sutherland, Inc. Because of its low profile, the projector

The entrance to the Omnimax theater of the Henry Crown Space Center, at the Museum of Science and Industry in Chicago.

is effectively hidden in the center of the theater. Digistar® is built around a cathode-ray tube with a large fish-eye lens. A computer database of 9,000 stars can be projected onto the dome. Since the system is computer-based, it can recreate the night sky as seen from other nearby stars in addition to the view from Earth. Constellations can be "flown around," and the solar system becomes a dynamic projection that can be rotated as if the audience were in space. The system can also be used to draw any three-dimensional object as a "wire-frame," such as an architectural model, a mathematical shape, or a spacecraft.

The Spread of Planetariums

Since the invention of the planetarium projector, many major cities have built planetarium theaters. The first theaters were built in Vienna, Rome, and Moscow, all prior to 1930. The first planetarium in the United States was the Adler Planetarium in Chicago, which opened in 1930.

During the late 1960s and early 1970s many new planetariums were built. Installations in schools and colleges were encouraged by the introduction of cheaper star projectors by Spitz, based in Pennsylvania. This expansion reflected a growth in the teaching of science during a time of great exploration of space, which culminated in humans landing on the Moon in 1969.

Evolution of Science Centers

As an outgrowth of the tremendous interest in science generated by planetariums, and responding to a greater public desire to learn more, the concept of a science center developed. Science centers provide hands-on activities that engage people in science. Some science centers combine locally built exhibits that match local interests with traveling exhibits that focus on particular issues or subjects, such as "Missions to Mars" or "Global Warming." Science centers develop their own educational programs. Today, most cities have a science center or a planetarium. People working in various departments, such as education, marketing, technical support, administration and presentations, staff these large informal science learning centers. The larger science centers often incorporate a large-format film theater in addition to the popular planetarium theaters.

Planetariums of the Twenty-First Century

Planetarium theaters come in many shapes and sizes. Some serve as unique classrooms and belong to schools or colleges. Classes held in planetariums teach the basics of astronomy, the night sky, the seasons, and other topics related to the science curriculum. Larger theaters, such as the Adler Planetarium in Chicago, are stand-alone facilities. Others are part of larger science centers. For example, the Buhl Planetarium is part of the Carnegie Science Center in Pittsburgh, Pennsylvania. These larger facilities play to a general public audience, and their goals are very different from school-based theaters. They encourage the spark that may ignite a child's interest in science, and strive to develop public's understanding of space and astronomy.

At the dawn of the twenty-first century, traditional planetarium projectors are being replaced with modern digital projectors. Planetariums are changing from places to view the night sky as seen from Earth, into amazing domed theaters where audiences are immersed in three-dimensional digital images and can be transported to a new universe full of realism. Elaborate productions using synchronized sound and narration elevate the planetarium theater to new heights. The changes have been reflected in the role of the audiences. Previously, passive audiences watched a show from beneath the dome as if in a glorified lecture theater. Now, audiences are transported to places they previously could imagine only in their dreams. Faster and more powerful computers and real-time image generation have added new capabilities to the modern planetarium theater, allowing audience interaction and making the visitor an integral part of the show.

A modern planetarium theater combines full-color video-graphics with stars. Recent advances in video technology allow full-dome, full-motion video scenes to be created. The most modern advance consists of a real-time image generator that creates images that can fill the whole dome, and five-button keypads at each seat that allow the audience to control part of the show, meaning that audience members are no longer passive participants in the immersive experience. The first two facilities in the world to house this system were Adler Planetarium in Chicago and the Boeing CyberDome at Exploration Place in Wichita, Kansas.

Career Options

The options for a career in the planetarium and science center industry are wide and varied. Staffing requirements include educators, scientists, computer graphic artists, teachers, exhibit designers, writers, marketing staff, and administrators.

International Planetarium Society

The International Planetarium Society, founded in 1970, is the organization for planetarium professionals. Representatives from regional planetarium associations from around the world form its council, and biennial conferences provide opportunities for exchanging ideas and experiences.

Association of Science and Technology Centers

Founded in 1973, the Association of Science and Technology Centers now numbers more than 550 members in forty countries. Members include not only science and technology centers and science museums but also nature centers, aquariums, planetariums, zoos, botanical gardens, space theaters, and natural history and children's museums. SEE ALSO Astronomy, Kinds of (volume 2); Careers in Astronomy (volume 2); Careers in Space Science (volume 2).

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Planetary Exploration, Future of

The first artificial satellites launched into Earth orbit were part of an international scientific program called the International Geophysical Year. They returned data on Earth and its space environment. Before long, the United States and the Soviet Union began sending spacecraft to study the Moon and, later, other planets.

Sending Spacecraft to the Planets

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

The U.S. Ranger spacecraft (1961–1965) were designed to crash into the Moon, transmitting television images right up to the moment of impact. The Surveyor spacecraft (1966–1968) soft-landed on the Moon, verifying that the lunar surface would support an **Apollo** lander, taking pictures of the surface surroundings, and performing the first crude geochemical analyses of lunar rocks. A series of Lunar Orbiter spacecraft photographed the Moon, developed the film onboard, scanned the developed images, and transmitted the scans to Earth. The Orbiter photographs constituted the primary database for planning the Apollo landings and comprised the only global set of pictures available to scientists for over twenty-five years.

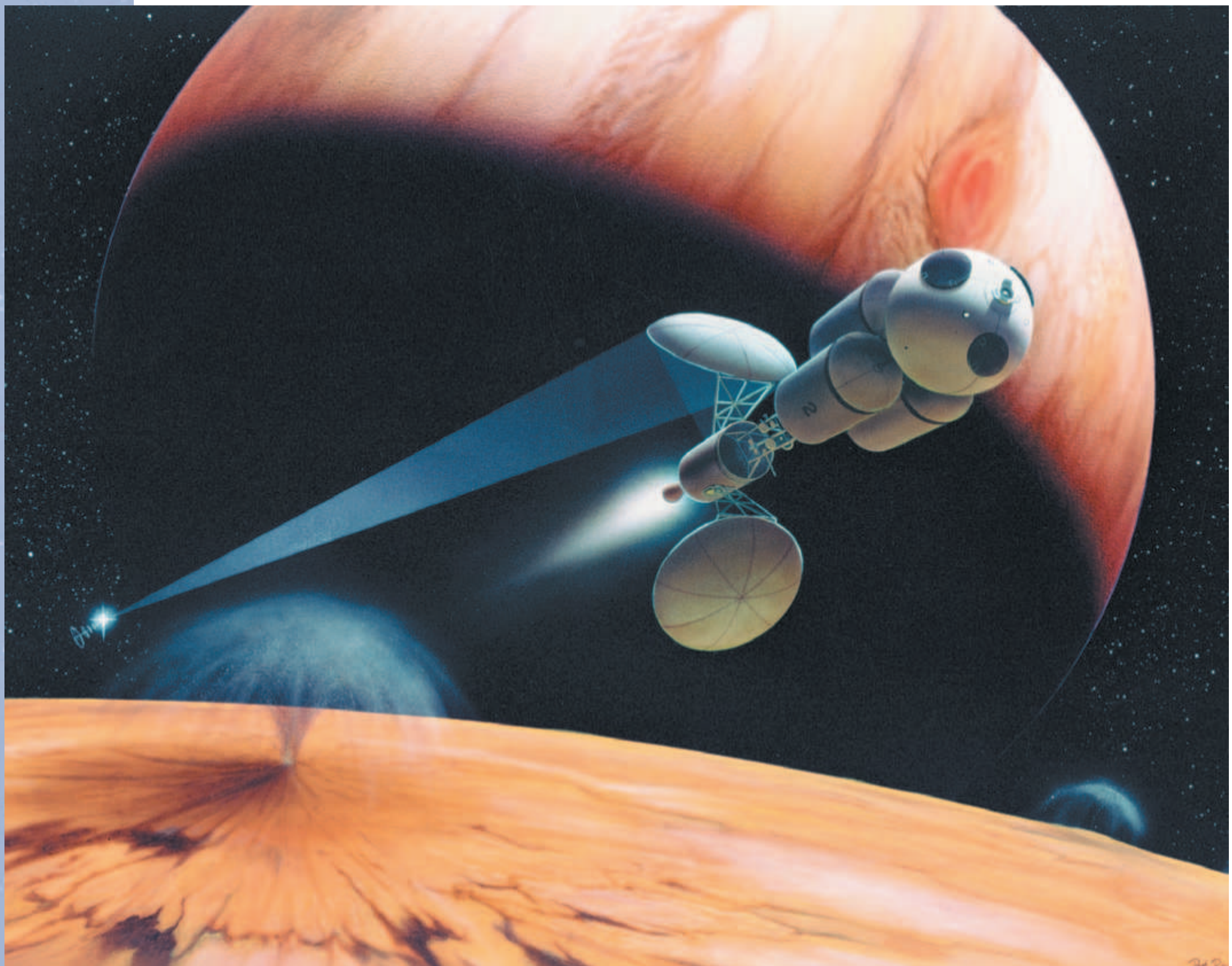
A Soviet Zond spacecraft (1965) returned the first pictures of the farside of the Moon, the side that always faces away from Earth. Although of poor quality, the pictures showed features that the Soviets were allowed to name through international agreements. Thus, there are names such as

Lunar Orbiter I launched September 6, 1966. The mission went on to gather data on the Moon's surface features.

Gagarin and Tsiolkovsky for craters on the farside. The Soviet Luna series of spacecraft performed several landings on the Moon, returning pictures and other data. Three of those spacecraft, Luna 16 (1970), Luna 20 (1972), and Luna 24 (1976), acquired lunar surface material by drilling and returned the samples to Earth. No other robotic spacecraft has ever collected extraterrestrial material and returned it to Earth.

The United States explored the inner planets (sometimes called the terrestrial planets) with the Mariner series of spacecraft (1962–1973). The tiny Pioneers 10 (1973) and 11 (1974) were sent hurtling past Jupiter and Saturn, taking crude pictures and measuring magnetic fields and charged particles. These Lilliputian explorers are still flying far beyond the planets, returning data on the farthest reaches of the Sun's influence over **interstellar** space.

interstellar between the stars



An artist's rendition of a laser power station that might one day propel spacecraft through the solar system by tapping the energy stores of the local environment.

Following Pioneer were the larger and more capable Voyagers 1 (September, 1977) and 2 (August, 1977), which completed remarkable journeys, passing all of the large outer planets—Jupiter, Saturn, Uranus, and Neptune. The Voyager mission took advantage of a rare alignment of the outer planets that allowed the spacecraft to receive gravitational boosts at each planet, which were necessary to complete the journey to the next planet.

Until recently, the Soviet Union was the only other nation to attempt planetary exploration. Although all Soviet missions to Mars have failed, the Soviets achieved a unique and amazing success by landing two Venera spacecraft (1981) on the surface of Venus. These landers survived the hellish surface environment long enough to return pictures and send back geochemical data on surrounding rocks.

Exploring a Planet in Stages

reconnaissance a survey or preliminary exploration of a region of interest

The exploration of a planet by spacecraft can be characterized in terms of several stages or levels of completeness: **reconnaissance**, orbital survey, surface investigation, sample return, and human exploration. The first stage, reconnaissance, is accomplished through a **flyby** of the planet. As the spacecraft passes, pictures are taken, measurements of the environment are made, and navigation data is accumulated for future missions.

In the second stage, orbital survey, a spacecraft is placed in orbit around the planet. A planetary photographic database is accumulated and **remote sensing** observations are conducted. Depending on the sensors aboard the spacecraft, data may be collected on planetary surface composition; atmospheric composition, structure, and dynamics; the nature of the gravity field, which can yield information about the internal structure of the planet; and the nature of the magnetic field. A series of orbiters may be flown over time, observing different phenomena or improving the level of detail and resolution of the data.

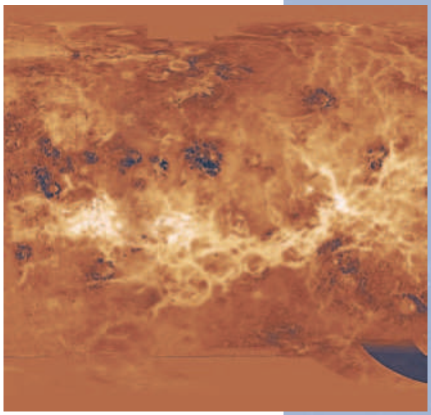
Eventually, a landing is made on the planet for surface investigation. Two Viking landers settled onto the surface of Mars in 1976 to test for signs of biological activity in the Martian soil. Actual soil samples were placed in special chambers on the lander. Similarly, certain geochemical or geological measurements cannot be made remotely. A lander can also observe the planet at small scales that cannot be imaged from orbit. In some cases, a **rover** can leave the lander and explore the surroundings. Such was the case of the small rover named Sojourner on the Pathfinder mission to Mars (1996).

As scientists accumulate knowledge about a planet, they seek answers to questions of increasing complexity. At some point, the measurements required are too complex and demanding to be carried out on a robotic spacecraft of limited capability. A sample return mission can bring pieces of the planet to laboratories on Earth, where the most qualified experts using equipment of the highest sophistication can examine them. Preservation of the scientific integrity of the sample has the highest priority—during collection on the planet, during transit to Earth, and after delivery to a special facility for curation. If the samples are cared for appropriately, they become treasures for future scientists with ever more advanced analytic techniques.

The final stage of study is human exploration. Astronaut explorers, aided by robotic assistants, can observe, experiment, innovate, and adapt to changing conditions in ways that cannot be duplicated by machines. Besides, why should robots have all the fun?

Future Exploration of the Solar System

By the beginning of the twenty-first century, reconnaissance had been completed for the inner solar system and for the giant planets of the outer solar system. Orbital surveys have been accomplished at the Moon (Lunar Orbiters, Clementine, Lunar Prospector), Venus (Magellan), Mars (Mariner 9, Viking, Mars Global Surveyor), and Jupiter (Galileo). The Cassini spacecraft was en route to Saturn, with exploration of that planet expected to begin in 2004. Some asteroids have been photographed by passing spacecraft, and the NEAR Shoemaker spacecraft engaged in a rendezvous with the asteroid Eros. Samples have been returned only from the Moon. **Meteorites** collected on Earth are samples from (unknown) asteroids, from the Moon, and from Mars. Human exploration has occurred briefly and only on the Moon.



Lava flows on the surface of Venus, as viewed from the spacecraft Magellan (1990–1994). The Magellan mapped 98 percent of Venus' surface, thus revolutionizing our understanding of the planet, particularly its geology.

flyby flight path that takes a spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

remote sensing the act of observing from orbit what may be seen or sensed below Earth

rover name of a vehicle used to move about on a surface

meteorite any part of a meteoroid that survives passage through Earth's atmosphere

The National Aeronautics and Space Administration (NASA) has future plans for more orbital surveys of Mars as well as landings and sample return missions. Human exploration of Mars is being discussed, as is further human exploration of the Moon, without definite commitments. The European Space Agency (ESA), as well as individual European nations, will join NASA in exploring Mars. European and Japanese spacecraft will visit the Moon. India and China are discussing possible Moon missions. Some private companies have plans to land on the Moon through profit-seeking ventures. ESA is planning an orbital survey of Mercury. The Japanese space agency, the Institute of Space and Aeronautical Science, is working on a sample return from an asteroid.

Planetary exploration is becoming an international activity. Equally exciting is the prospect of planetary missions sponsored by institutions other than the traditional government agencies. The future may hold surprises for all of us. SEE ALSO Apollo (volume 3); Apollo Lunar Landing Sites (volume 3); Earth—Why Leave? (volume 4); Exploration Programs (volume 2); Mars Missions (volume 4); Reconnaissance (volume 1); Robotic Exploration of Space (volume 2).

Wendell Mendell

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Planetary Protection *See Planetary Protection (Volume 4).*

Planetesimals

Planetesimals are the fundamental building blocks of the planets as well as the ancestors of asteroids and comets. To understand them and their importance, one must first understand how planets form.

The solar system formed 4.6 billion years ago from an interstellar cloud of gas and dust. When this gaseous cloud became unstable, it collapsed under the force of its own gravity and became a flattened, spinning disk of hot material. The region with the greatest concentration of mass became the Sun. The rest of the mass, perhaps only a little more than the mass of the Sun, eventually cooled enough to allow solid grains to condense, with rocky ones close to the Sun and icy ones farther away. The grains settled near the midplane of the disk, where mutual collisions allowed them to slowly grow into pebble-sized objects. At this point, the story is less clear. Some astronomers claim particle velocities in the disk remained low enough to allow the pebbles to stick to one another. Others argue that pebbles are generally not very sticky, and gravitational forces alone could cause concentrated swarms of pebbles to coalesce. In either case, the process eventually produced planetesimals, which measured a few kilometers across.

Models of planetesimal disks suggest that low relative velocities between the bodies produce accretion (objects hit and stay together) rather than fragmentation (objects break up and disperse). As planetesimals grow still larger, their gravitational attraction increases, allowing them to become even more effective at accreting nearby planetesimals. This process, called runaway growth, allows some planetesimals to reach the size of the Moon or even Mars. These so-called protoplanets were the precursors of the current planets of the solar system. For reference, 2 billion planetesimals, each one being 10 kilometers (6 miles) in diameter, are needed to make an Earth-sized planet.

Planetesimal clouds formed in the Helix Nebula.

At this point in solar system evolution, the disk mass is dominated by protoplanets, planetesimals, and gas. Mutual gravitational interactions force most protoplanets to collide and merge, eventually producing small planets such as Earth. If a protoplanet grows large enough, however, it can also gravitationally capture enormous amounts of the remaining gas. This explains why Jupiter and Saturn are so much larger than Earth.

The same interactions that cause protoplanets to collide also stir up the remaining planetesimals. Most of these objects end up impacting existing protoplanets or are thrown out of the solar system. The leftovers that managed to stay in the stable regions of the solar system until planet formation ended are now called asteroids and comets. The asteroid belt is a population of rocky planetesimals located between the orbits of Mars and Jupiter. The Kuiper belt and Oort cloud are populations of icy planetesimals located beyond the orbit of Neptune. Even now, mutual collisions between and among asteroids and comets as well as planetary interactions cause pieces of the survivors to escape their small body reservoirs. A few of these multikilometer or smaller objects strike Earth. Small impactors deliver meteorites, while large ones infrequently wreak global devastation. SEE ALSO Asteroids (volume 2); Comets (volume 2); Gravity (volume 2); Impacts (volume 4); Kuiper Belt (volume 2); Meteorites (volume 2); Oort Cloud (volume 2); Orbits (volume 2); Small Bodies (volume 2).

William Bottke

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Pluto

Pluto is the only planet in the solar system still unvisited by a spacecraft. Its status as the only planet in our Sun's family still studied purely by telescope is unique—and frustrating—to planetary scientists trying to uncover its secrets.

Pluto's Strange Orbit

eccentric the term that describes how oval the orbit of a planet is

American astronomer Clyde Tombaugh discovered Pluto in 1930. Despite astronomers' best efforts, Pluto's faintness and star-like appearance allowed the planet to keep most of its secrets. For twenty-five years, we could only refine our knowledge of its strange orbit, finding it on old photographs and taking new ones. Pluto's orbit is more **eccentric** and more tilted (inclined) than any other planet, taking 248.8 years to make one trip around the Sun. At perihelion (closest approach, which last occurred in 1996), it is only 60 percent as far from the Sun as at aphelion (farthest approach). So at perihelion, Pluto is closer to the Sun than Neptune ever gets. Yet, Pluto and Neptune cannot collide for two reasons. First, the relative inclination of the two orbits means their paths do not intersect. Second, Pluto is in a 2:3 orbit-orbit resonance with Neptune. This means that for every two trips Pluto makes around the Sun, Neptune makes exactly three. When Pluto is at perihelion, Neptune is on the other side of the Sun.

The Significance of Brightness Measurements

amplitude the height of a wave or other oscillation; the range or extent of a process or phenomenon

subsolar point the point on a planet that receives direct rays from the Sun

In 1955, photometry (brightness measurements) of Pluto showed a repetition of 6.38 days—the length of Pluto's day. Two trends in the evolution of the brightness have since been found. First, its **amplitude** has increased from about 10 percent to a current value of 30 percent. This tells us that the **subsolar point** has been moving equatorward, and that the planet's spin axis must be severely tilted. Second, the average brightness has faded over the years, evidence that Pluto's poles are likely brighter than its equator. Decades of photometry have been interpreted to derive maps of Pluto's surface reflectance, or albedo. These are comparable in detail with what the Hubble Space Telescope has been able to reveal.

The Size and Composition of Pluto and Its Moon

retrograde having the opposite general sense of motion or rotation as the rest of the solar system, clockwise as seen from above Earth's north pole

occultations phenomena that occurs when one astronomical object passes in front of another

Little regarding Pluto's size or composition was known until recently. In 1976 the absorption of methane was discovered in Pluto's spectrum. This implied a bright, icy planet, and therefore a small radius. In 1978 James Christy, then an astronomer at the United States Naval Observatory, discovered Pluto's satellite, which was named Charon. Orbiting Pluto with the same 6.38726-day period as Pluto's spin, Charon was the key to unlocking Pluto's secrets. By timing the orbital period and measuring the estimated separation between the two, astronomers could compute the total mass of the system—about 0.002 Earth masses. Charon orbits **retrograde**, and Pluto spins backwards (just like Venus and Uranus).

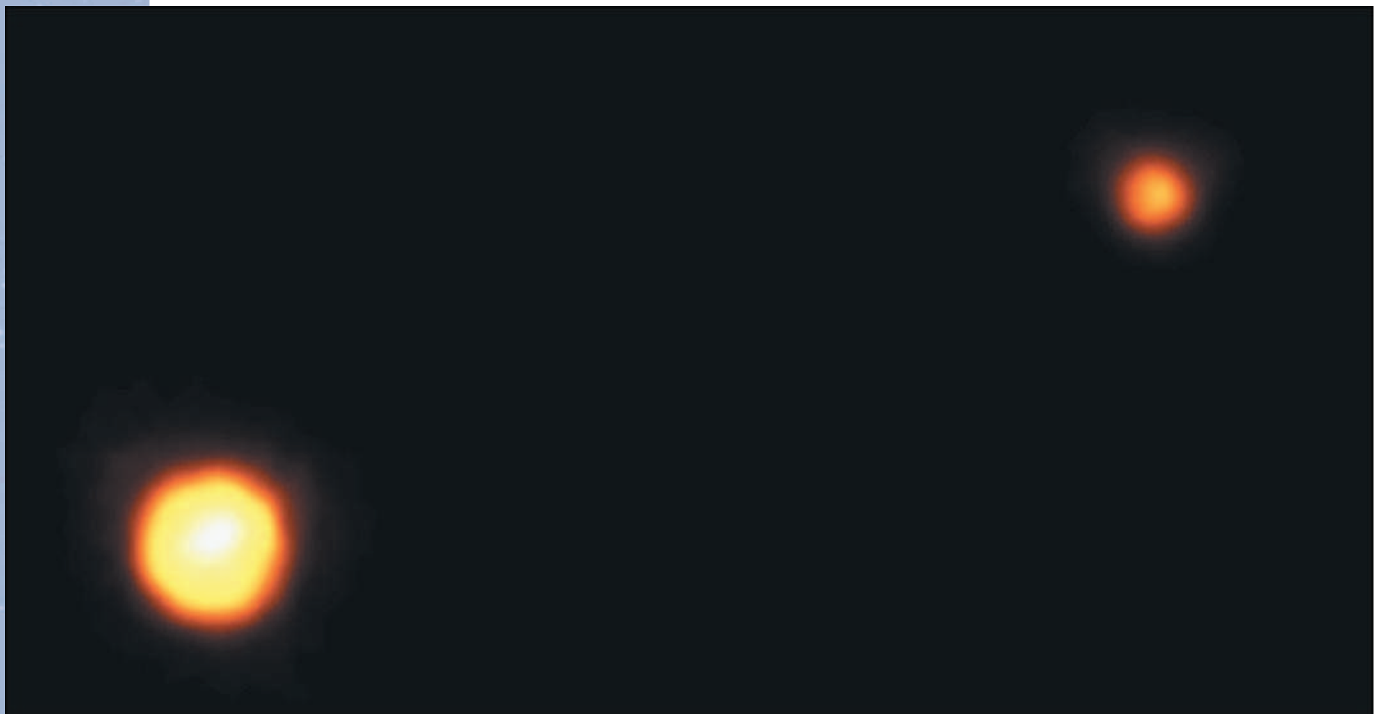
Charon's orbital plane above Pluto's equator was seen edge-on in 1988. This produced a series of **occultations** and eclipses of and by the satellite, each half-orbit, from 1985 to 1992. Timing these "mutual events" allows calculation of the radii for both bodies—approximately 1,153 kilometers (715 miles) for Pluto and 640 kilometers (397 miles) for Charon. The sum is about the radius of the Moon. When Charon hid behind the planet, Pluto's spectrum could be observed uncontaminated by its moon. This spectrum, when subtracted from a combined spectrum of the pair taken a few hours before or after, yields the spectrum of Charon. Pluto's spectrum showed methane frost: the gas we use for cooking is frozen solid on its surface! Charon's spectrum revealed nothing but dirty water ice. (Independent mea-

An artist's rendering of Pluto, partially obscured by its satellite, Charon. Pluto is the only planet in the solar system still unvisited by a spacecraft.

surements show the amount of methane on Pluto varies with longitude. Bright regions have more methane than dark regions.) When Charon passed between Pluto and Earth, it (and its shadow) selectively hid different portions of its **primary**. Interpretation of these measurements is complicated but has allowed refined albedo (or reflectivity) maps of one hemisphere of Pluto to be extracted.

Surface and Atmospheric Readings

The surface temperature of Pluto is currently under debate. Two results have been published: about 40°K (−233°C; −388°F) and about 55°K (−218°C; −361°F). The first value is similar to the temperature on Triton, Neptune's largest moon; the latter is more consistent with Pluto's lower albedo. In either case, it is very cold. Water ice on Pluto is harder than steel is at room temperature! Misconceptions exist about how dark it would seem for an astronaut on Pluto. Despite the planet's remote distance, the Sun would appear to have the brightness of about 70 full Moons on Earth. Combine this with the bright, icy surface and one would have no problems navigating the surface.



Pluto (lower left) and its moon, Charon (top right), as seen through the Hubble Space Telescope, February 21, 1994. At the time this image was taken, Pluto was 4.4 billion kilometers (2.6 billion miles) from Earth.

On June 9, 1985, Pluto passed in front of a star. Rather than blinking out, the starlight gradually dimmed due to refraction by an atmosphere. Too dense to be methane alone, the atmosphere was suspected to contain nitrogen and carbon monoxide. Both have since been identified on Pluto's surface, with nitrogen comprising about 97 percent of the ground material. From details of precisely how the starlight faded, scientists believe there is a temperature increase close to the surface, much like on Earth. Pluto's atmospheric pressure is only a few millionths that of Earth, and the atmosphere actually may "frost out" with increasing distance from the Sun.

primary the body (planet) about which a satellite orbits

The Hubble Space Telescope has been used to measure the size of Charon's orbital radius, about 19,500 kilometers (12,090 miles, or approximately 1.5 Earth diameters). Densities have also been calculated: 1.8 to 2.0 grams per cubic centimeter (112 to 125 pounds per cubit foot) for Pluto and 1.6 to 1.8 grams per cubic centimeter (100 to 112 pounds per cubit foot) for Charon. From the density, scientists can infer the internal composition, a roughly 50-50 mix of rock and ice.

Future Spacecraft Visit?

adaptive optics the use of computers to adjust the shape of a telescope's optical system to compensate for gravity or temperature variations

Efforts to learn more continue. New large Earth-based telescopes equipped with **adaptive optics** and fast computers will allow the blurring effects of our atmosphere to be nullified, surpassing the resolution of Hubble's rather small 2.4-meter (4.9-foot) mirror. In contrast, the "faster, better, cheaper" policy of the National Aeronautics and Space Administration (NASA) has led to a halt of the Pluto–Kuiper Express spacecraft. A new mission profile, called the New Horizons Pluto–Kuiper Belt Mission, was approved by Congress in 2001. However, funding for this mission is not in the President's proposed budget for 2002. Launch must happen by 2006 or Jupiter will no longer be in position to slingshot the craft towards Pluto with a **gravity assist**, and the trip to Pluto will take years longer. We will have to wait the better part of a Jupiter orbit (11.8 years) until the geometry repeats itself. By then, Pluto's atmosphere may have frozen out. Until the task is taken seriously, Pluto will remain the only planet unvisited by a spacecraft. SEE ALSO HUBBLE SPACE TELESCOPE (VOLUME 2); KUIPER BELT (VOLUME 2); NASA (VOLUME 3); ORBITS (VOLUME 2); PLANET X (VOLUME 2); PLANETARY EXPLORATION, FUTURE OF (VOLUME 2); TOMBAUGH, CLYDE (VOLUME 2).

Robert L. Marcialis

gravity assist using the gravitational field of a planet during a close encounter to add energy to the motion of a spacecraft

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Pulsars

The discovery of pulsars in 1967 was a complete surprise. Antony Hewish and his student Jocelyn Bell (later Bell Burnell) were operating a large radio antenna in Cambridge, England, when they detected a celestial source of radio waves that pulsed every 1.3373 seconds. Never before had a star or **galaxy**, or any other astronomical phenomenon, been observed to tick like a clock.

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

Hewish and Bell considered a number of exotic explanations for the speed and regularity of the pulsing radio source, including the possibility that it was a beacon from an extraterrestrial civilization. Within a few years, the correct explanation emerged, which is no less exotic. A pulsar is a city-sized spinning ball of ultradense material that emits beams of radiation, which flash Earth-like lighthouse beams, as it spins.

How Pulsars Are Created

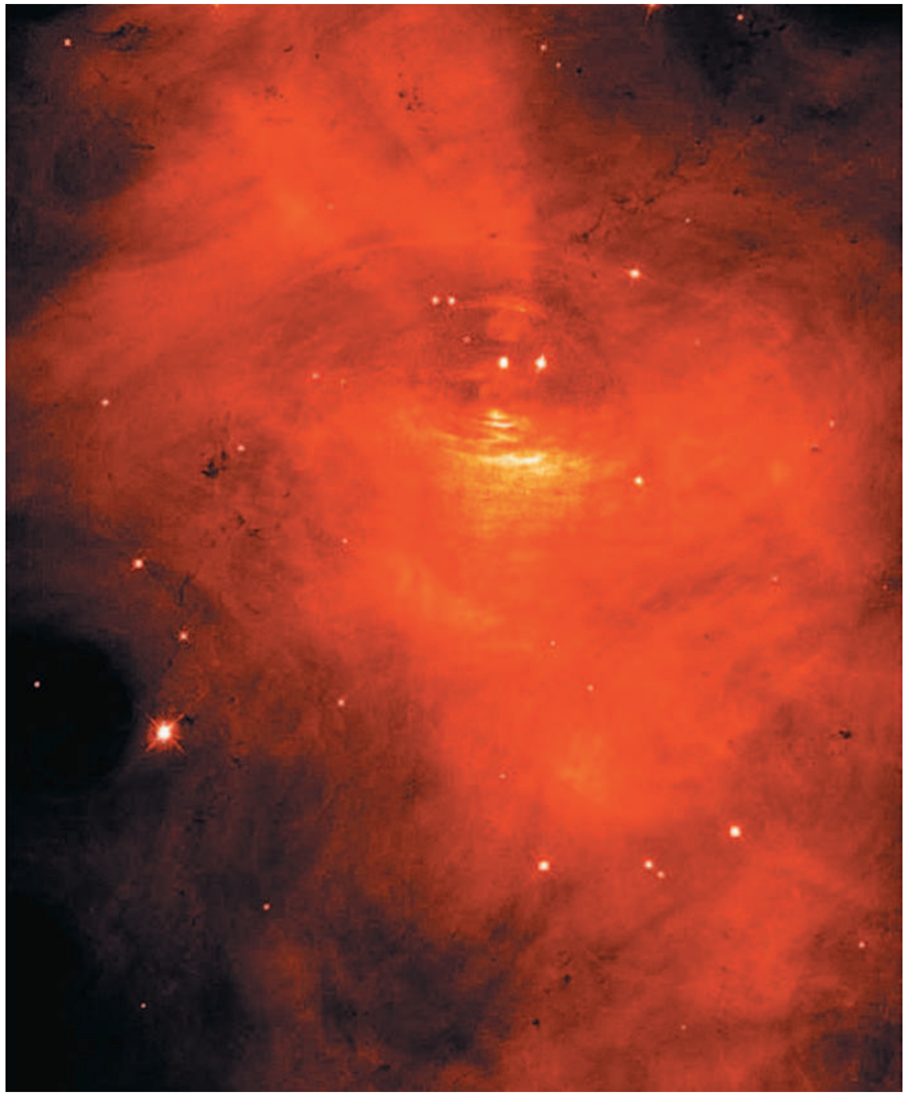
Pulsars are produced when certain types of stars stop producing energy and collapse. The attractive force of gravity is always trying to contract the material of a star into an ever-smaller ball, but a star can maintain its size for billions of years because of the heat and pressure produced by nuclear reactions within it. When a star finally exhausts its supply of nuclear fuel, it collapses. An ordinary star (such as the Sun) will quietly contract into an Earth-sized glowing ember called a white dwarf. A more massive star will explode violently in an event called a supernova. It is within the detritus of such explosions that pulsars are born.

The reason for the explosion is that when the star collapses all the way down to a diameter of about 20 kilometers (12 miles), its atoms are packed so closely that their **protons** and **electrons** merge to form **neutrons**, which repel each other by nuclear forces and oppose further shrinkage. The collapsing material suddenly rebounds, producing a huge expanding fireball. In

protons positively charged subatomic particles

electrons negatively charged subatomic particles

neutrons subatomic particles with no electrical charge



Interior view of the Crab Nebula showing the Crab Pulsar, formed from a supernova explosion over 900 years ago.

some cases, the neutron matter is obliterated by the blast, or it keeps shrinking all the way down to a single point, forming a black hole. Sometimes, however, the dense nugget of neutrons survives the explosion, in which case it becomes what is called a neutron star.

Pulsars and Neutron Stars

Neutron stars are unfathomably dense. A marble with the same density as a neutron star would weigh as much as a boulder 400 meters (0.25 mile) across. Because the rotation of the star is amplified during its collapse (much as an ice-skater spins faster by pulling in her arms), neutron stars are born spinning quickly, as fast as 100 revolutions per second. They also have the most intense magnetic fields known in the universe. If Earth had a magnetic field as strong, it would erase credit cards as far away as the Moon. This powerful magnetism causes intense beams of radio waves to be launched from both magnetic poles of at least some neutron stars; the poles swing around as the star rotates and may flash Earth if they happen to be oriented in the right direction.

In 1934, just two years after the discovery of the neutron, astronomers Walter Baade and Fritz Zwicky predicted that neutron stars should exist. Five years later, Robert Oppenheimer and George Volkoff published a detailed theory of neutron stars. But none of these scientists knew whether neutron stars could ever be observed with telescopes. They were expected to be so dim as to be invisible; nobody predicted they would emit focused beams of radiation. Even now that more than 1,500 pulsars have been discovered, nobody understands the details of how the radiation beams are produced.

Whatever the mechanism, a pulsar keeps pulsing for millions of years. Although the pulse rate is remarkably steady, it does slow down by a tiny but measurable amount. For example, the pulsar at the center of the Crab **Nebula** (the site of a supernova that occurred in 1054 C.E. in the constellation Taurus) blips once every 33 milliseconds, but this pulse period is slowing by 0.013 milliseconds every year. Eons from now, the pulsar will spin too slowly to produce radiation beams bright enough to observe, and will spend the rest of eternity as a quiet neutron star.

nebula clouds of interstellar gas and/or dust

X-ray Pulsars

A neutron star can be rescued from this oblivion, and resume its identity as a pulsar, if it happens to have a companion star. Stars are often found in pairs (or even triplets or quadruplets) and when one star explodes in a supernova, the other may survive. Eventually the intense gravity of the pulsar may rip material away from the giant star. As the material swirls down to the pulsar's surface, it heats up to millions of degrees and glows brightly in **X rays**. The swirling matter may be funneled by the neutron star's magnetic field onto a hot spot on the neutron star's surface; as this spot rotates with the neutron star, astronomers see pulses of X rays, and the neutron star regains the limelight as an "X-ray pulsar."

X rays a form of high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

Millisecond Pulsars

It is also possible that the swirling matter will cause the neutron star to spin faster and faster, like a top being spun up. The rotation period can become as short as a few thousandths of a second, which is enough to reactivate the radio pulses, and the neutron star is reborn as a "millisecond pulsar." The fastest known millisecond pulsar spins 642 times per second, which is impressive for something bigger than London and more massive than the Sun.

Areas of Future Research

Despite all of this knowledge, the life cycles of pulsars are still a subject of research. Many of the unanswered questions are about young pulsars: How often do supernovas produce them? Can they be created in other ways? Are they always born spinning quickly?

In particular, due to recent advances in X-ray astronomy, a new category of young pulsars has been discovered consisting of objects that spin relatively slowly and emit X rays rather than radio waves, even though they do not have a stellar companion. A consensus is developing that these unusual pulsars should be called "magnetars," because they seem to have magnetic fields hundreds of times larger than the already enormous fields of "ordinary" pulsars. If proven to be accurate, this would be yet another surprising development in the history of pulsar science. SEE ALSO Astronomy, Kinds of (volume 2); Black Holes (volume 2); Einstein, Albert (volume 2); Gravity (volume 2); Stars (volume 2); Supernova (volume 2).

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Robotic Exploration of Space

In January 1959, only a little more than a year after the launching of Sputnik 1, the Soviet Union's Luna 1 flew 5,955 kilometers (3,692 miles) above the surface of the Moon, thus quickly heralding the age of planetary exploration. Since then, nearly 100 successful robotic missions to obtain closer looks at the planets, their moons, and asteroids have been launched, mainly by the United States and the Soviet Union. Among the planets, only Pluto, so far away that a signal from it would take five hours to reach Earth, has not had a spacecraft fly at least close by it. During the more than four decades of planetary exploration, continued improvements and miniaturization in electronics and computers, and in rocketry and instrument techniques in general, have been used to gain scientific knowledge.

The term "robotic" is used for any spacecraft without a human pilot. In addition to the obvious method of sending instructions directly from Earth, control of robotic spacecraft can also be programmed precisely in advance or programmed to react to the environment. Missions have included **flybys**, **crash-landers**, **orbiters**, **atmospheric probes**, and **soft-landers**. Some robotic spacecraft have multiple components, for instance an orbiter that released a lander (Viking 1 and Viking 2, at Mars) or an atmospheric probe (Galileo, at Jupiter). Robotic spacecraft have so far been essentially in the business of sending information or data about other planetary bodies back to Earth. Only spacecraft to the Moon have returned samples; in addition to the crewed Apollo missions, three Soviet spacecraft also brought back samples.

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

crash-lander or hard-lander: a spacecraft that collides with the planet, making no (or little) attempt to slow down; after collision, the spacecraft ceases to function because of the (intentional) catastrophic failure

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling the planet indefinitely

atmospheric probe a separate piece of a spacecraft that is launched from it and separately enters the atmosphere of a planet on a one-way trip, making measurements until it hits a surface, burns up, or otherwise ends its mission

The Challenge of Robotic Planetary Exploration

Lunar and planetary exploration is a proposition far different from orbiting Earth. A launch vehicle can throw only about one-fifth as much mass out of Earth's gravitational field as it is capable of putting into Earth orbit. Time becomes more and more a factor with distance: To send a signal to and then from the Moon takes only two seconds. For Mars it takes between eighteen and forty-five minutes, depending on the relative positions of Mars and Earth. Everything has to be planned and programmed, well in advance.

An artist's rendition of the Mars Rover Sojourner (foreground) and the Pathfinder Lander in operation on the Martian surface. These robots work in environments that may be harmful to humans or in situations where sending a human crew would be too costly.

Interplanetary spacecraft must last for years in space. It takes a few minutes to reach Earth orbit but almost a year to get to Mars. Galileo was launched in October 1989, and arrived at Jupiter through a complex route more than six years later. Once there, it began orbiting and sending back data, continuing to do so into the early twenty-first century. Spacecraft have to be remarkably reliable, because there is no means of replacing or repairing parts. Interplanetary space has dangers from solar and **cosmic radiation**, and there is the potential for damage from **solar wind**, dust, and even larger chunks of material. Spacecraft have to be resilient to the range of cold and hot temperatures, and the uneven temperatures, to which they are exposed.

soft-lander spacecraft that uses braking by engines or other techniques (e.g., parachutes, airbags) such that its landing is gentle enough that the spacecraft and its instruments are not damaged, and observations at the surface can be made

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

Spacecraft: Getting There

The first lunar probe, Luna 1, went on to become the first artificial object to orbit the Sun. It was equipped to measure solar and cosmic radiation, interplanetary magnetic fields, the **micrometeoroid flux**, and the composition of gases. During the same year, Luna 2 became the first artificial object

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

micrometeoroid flux the total mass of micrometeoroids falling into an atmosphere or on a surface per unit of time

aerobraking the technique of using a planet's atmosphere to slow down an incoming spacecraft; its use requires the spacecraft to have a heat shield, because the friction that slows the craft is turned into intense heat

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

parking orbit placing a spacecraft temporarily into Earth orbit, with the engines shut down, until it has been checked out or is in the correct location for the main burn that sends it away from Earth

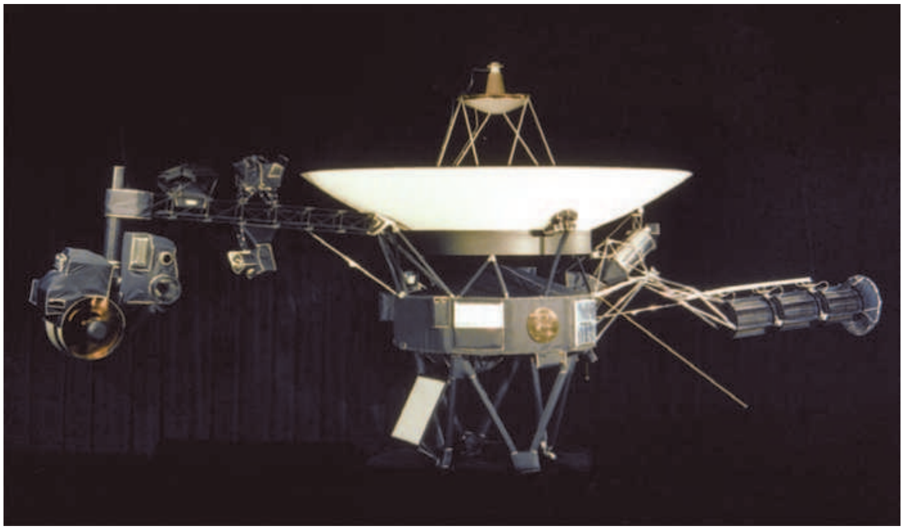
to crash into the Moon, and Luna 3 the first to circle behind the Moon. Luna 3 also sent back the first human glimpses of the farside of the Moon. These earliest missions illustrate most of the basic needs of robotic spacecraft: launch vehicle, power, communications, and scientific instruments. What they lacked that most subsequent missions (apart from the Ranger series) had was a propulsion system or a navigation system; they were just thrown at the Moon.

The earliest missions to any planets have been flybys, with some impacts. A flyby has the advantage of seeing more of the planet; an impact allows a closer look but there is then an immediate loss of the spacecraft. An orbiter allows for a longer, more complete look at a planet but requires an engine and fuel to slow the spacecraft and insert it into orbit. These engines have to be controllable and thus cannot be solid fuel rockets that cannot be turned off. If the planet has an atmosphere, it can be used for **aerobraking** to slow down the spacecraft, and this has been done at Mars. In many cases the engine is used several times to change the orbit. A controllable engine is also used for midcourse corrections, which are necessary to reach exactly the required destination.

An engine is needed for soft-landings, and in rare cases, for taking off again. Soft-landing techniques depend on whether the planet has an atmosphere or not. If it does, then parachutes, air bags, and other devices can be used to get hardware safely to the surface, after first slowing the spacecraft with engines and aerobraking. If there is no atmosphere, descent must be under the control of rocket engines.

The smallest spacecraft have weighed a little over 200 kilograms (440 pounds), the largest nearly 6,000 kilograms (13,230 pounds), as they left Earth orbit. For comparison, the mass of the Mercury spacecraft in orbit was about 1,400 kilograms (3,080 pounds), whereas a **Gemini** spacecraft weighed about 3,800 kilograms (8,370 pounds). A huge amount of mass on the launch pad is needed to get a few kilograms of scientific instruments to their destination. An Atlas-Agena space rocket and its load on the launch pad weighed about 125,000 kilograms (275,575 pounds)—about 90 percent of which was fuel—and at its destination the Ranger spacecraft was less than 400 kilograms (880 pounds). On the launch pad, the Luna 16 launch vehicle and its **payload** had a mass of about 1 million kilograms (2.2 million pounds). The spacecraft on the way to the Moon was about 5,600 kilograms (12,345 pounds); the empty lander, 1,900 kilograms (4,185 pounds); and the little sphere that eventually was parachuted back to Earth containing its precious cargo of only about 100 grams (3.5 ounces) of lunar soil, less than 40 kilograms (88 pounds).

Generally a spacecraft is first placed in an Earth **parking orbit**, and from there is given another boost to give it the appropriate interplanetary trajectory. In some cases, such as the Magellan mission to Venus and the **Galileo mission** to Jupiter, the spacecraft was carried first to **low Earth orbit** on a space shuttle. While early lunar **trajectories** were fairly direct, many later missions had more complex journeys. Mariner 2 to Venus was launched in the direction opposite of Earth's orbit, then gradually fell in towards the Sun, overtaking Earth, and catching up with its target. Voyager 2 used **gravitational assists** consecutively to fly past Jupiter, Saturn, Uranus, and Neptune, with ten years between the first and last encounters. Galileo,



The spacecraft Voyager was developed in the late 1970s, when NASA mission designers realized that the giant outer planets—Jupiter, Saturn, Uranus and Neptune—would soon align in such a way that single spacecraft could theoretically use gravity assists to hop from one planet to the next.

now in orbit around Jupiter, flew by Venus and twice by Earth to obtain gravitational assists, and also flew by two asteroids on its journey. Most of a spacecraft's flight is **ballistic**, that is, it is not powered but is pulled by gravity, with engines needed for course corrections.

All spacecraft must have power, to run instruments and controls, and communications systems, to receive and send information. In the inner solar system, including Mars, at least some of the power can be obtained from solar panels. At the outer planets there is insufficient sunlight for solar panels. For these, spacecraft are designed around large-dish antennae powered with **radioisotope thermoelectric generators**, which generate heat by natural radioactive decay. Spacecraft have been designed to operate on very little power. Cassini's generators produced 815 watts at launch and will still be producing over 600 watts at the end of its mission at Saturn (by comparison, a typical household light bulb is 100 watts).

Missions and Scientific Instruments

Spacecraft instruments have used much of the **electromagnetic spectrum** to observe the planets and their surroundings, including low-energy radar waves, **infrared**, visible light (with which we are most familiar), **ultraviolet**, and high-energy **X rays**. Most instruments are passive but some are active, including **laser-pulsing** to measure distance (and hence topography) and radar sounding. Particles and dust have also been measured directly. A wide variety of instruments have been carried on the nearly 100 missions undertaken through the early twenty-first century, but some have been more commonly used than others.

All spacecraft carry a radio transmitter, used for transmitting both data about the spacecraft itself and about the scientific measurements. As a spacecraft goes behind a planet with an atmosphere, the changes in the radio signal provide information on the atmosphere, such as its density and thickness.

Galileo mission successful robot exploration of the outer solar system; this mission used gravity assists from Venus and Earth to reach Jupiter, where it dropped a probe into the atmosphere and studied the planet for nearly seven years

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

gravitational assist the technique of flying by a planet to use its energy to "catapult" a spacecraft on its way, thus saving fuel, and thus mass and cost of a mission; gravitational assists typically make the total mission duration longer, but they also make things possible that otherwise would not be possible

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

radioisotope thermoelectric generator device using solid state electronics and the heat produced by radioactive decay to generate electricity

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

X rays a form of high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

laser-pulsing firing periodic pulses from a powerful laser at a surface and measuring the length of time for return to determine topography

Lunar Orbiter a series of five unmanned missions in 1966 and 1967 that photographed much of the Moon at medium to high resolution from orbit

magnetometer an instrument used to measure the strength and direction of a magnetic field

wavelength the distance from crest to crest on a wave at an instant in time

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

The signal is used to track the spacecraft, and variations in the spacecraft motion are informative. The overall gravitational tug provides information about the mass of the planet. Tiny measurable changes in the motion of the spacecraft tell about variation in the gravity field, which in turn tell about how mass is distributed in the planet. This standard technique of planetary study was used in the analysis of **Lunar Orbiter** tracking to determine mass concentrations beneath many of the large circular basins on the Moon.

A **magnetometer** has been carried on many spacecraft because they are small, reliable, and useful instruments. Even Luna 1 carried a magnetometer and found that the Moon produces no significant magnetic field, quite unlike Earth. The magnetic fields around planets and asteroids are informative, like gravity, about what the interior is like at the present time. They also provide information about what things may have been like in the past. The magnetometer carried on the Mars Global Surveyor has shown areas that were magnetized at some time in the past. Magnetometers discovered the powerful magnetic fields produced by Jupiter.

Many spacecraft carry a camera providing images that approximate what human eyes see. These come in many different varieties, some providing wide views, some having very high resolutions. The Ranger missions to the Moon carried cameras as the prime instrument, to see what the Moon was like as we saw it from closer and closer. With cameras we have seen the volcanoes, craters, and valleys of Mars, the cratered Moonlike surface of Mercury, the smooth but cratered surfaces of some asteroids, and the cracked icy crusts of some of Jupiter's moons. Images have provided huge amounts of geological information about the planets. Geologists are still using images from the Moon collected in the 1960s. For Venus, which has a thick atmosphere, such images are no good for surface studies, and instead radar techniques have been used to map and understand the surface features.

Chemical and mineralogical data about both surfaces and atmospheres have been obtained from orbit. Natural X-ray and gamma-ray sources provide direct chemical information but are blocked by thick atmospheres. They have been used extensively for the Moon, however, and relevant instruments are part of a planned mission to Mercury. The Martian atmosphere is thin enough that such instruments can be used there, but the spacecraft carrying them, Mars Observer, failed. X-ray fluorescence (carrying their own X-ray sources) or other chemistry instruments were carried by the Viking landers on Mars, the Surveyor landers on the Moon, and the Venera landers on Venus, to measure the composition of rocks and soils, as well as to search for traces of life. Spectral reflectance observations, in the ultraviolet through visible through infrared **wavelengths**, have been used extensively to understand mineralogy. Specific **minerals** absorb particular wavelengths, so measurements are made that show these absorptions, and in this way the mineralogy can be inferred. Such absorptions also show the presence of phases, such as water, in atmospheres.

Some missions are much more complicated, involving different kinds of instrumentation. Galileo is not only observing Jupiter and its moons from orbit, but it also launched a probe into Jupiter's atmosphere, to measure its chemical composition and physical properties (e.g., density). Atmospheric probes have also been used at Venus, and the Cassini mission to Saturn is carrying a probe to be launched into the atmosphere of Titan, that planet's largest moon. While the Soviet Union used primitive rovers on two lunar missions in the 1960s, the only other **rover** yet used to add to our knowledge of planets was flown on Mars Pathfinder. Its rover Sojourner made small forays to investigate rocks and soils near the lander.

rover name of a vehicle used to move about on a surface

Spacecraft: The Future

Spacecraft have flown by every major planet, and most of their important moons, in the solar system. We can hardly say that we know enough about any of them as yet, both from the point of view of types of mission or of instruments flown, or of how much has been seen before a mission ends. Mercury has only been flown by, as have Saturn and the more distant planets. Cassini is on a mission to orbit Saturn, while a Discovery-class mission will orbit Mercury. We have barely looked at comets; the small Discovery mission Stardust is on its way to comet Wild 2. It will meet its coma at 20,000 kilometers per hour (12,400 miles per hour), six times faster than a speeding bullet, collect small particles, and bring them to Earth. Because of the potential relationship with understanding the origin of life, many people think it highly desirable to find out more about the properties of Europa, one of Jupiter's large moons, and its potential sub-ice ocean.

Two types of mission are likely to become more common in the future. One is a sample return, particularly from Mars. These missions are inherently complex. The other category consists of rover missions. A fixed lander obviously has limited capabilities, and the extension of its senses by adding mobility has tremendous advantages. Sojourner demonstrated the usefulness of such machines, but in both a real as well as a metaphorical sense, it only scratched the surface. SEE ALSO Exploration Programs (volume 2); Government Space Programs (volume 2); NASA (volume 3); Pluto (volume 2); Robotics Technology (volume 2).

Graham Ryder

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Robotics Technology

The word "robot" was coined in 1934 by the Czech playwright Karel Čapek from the Czech word *robota*, meaning "compulsory labor." While this original meaning still applies to most Earth-bound robots, robots in space have broken through the tedium to become great explorers. They work in environments that may be harmful to humans or in situations where sending a human crew would be too costly. They have been sent as advanced guards to measure the temperature, evaluate the atmosphere, and analyze the soil of other worlds to determine what human explorers can expect to find.

What, exactly, is a robot? A broad definition considers any mechanism guided by automatic controls to be a robot; a very narrow definition requires a robot to be a humanoid mechanical device capable of performing complex human tasks automatically. Robots in space have fallen somewhere in between these extremes. They generally involve a mechanical arm—resembling part of a human, at least—attached to a stationary planetary landing module or to a mobile rover that must perform complex tasks, such as recognizing and avoiding dangerous obstacles in its path. But the evolution to humanoid robots is well under way with the Robonaut being developed by the National Aeronautics and Space Administration (NASA).

Early Space Robots

The first robot in space was a motor-driven mechanical arm equipped with a scoop on the Surveyor 3, which landed on the Moon on April 20, 1967. Acting on signals sent from engineers on Earth, the arm extended and the scoop dug four trenches in the lunar soil, up to 18 centimeters (7 inches) deep. It then placed the samples in front of a camera for scientists on Earth to see. Later Surveyor missions carried analytical instrumentation to determine the chemical composition of the soil samples.

Following the successful human Moon landings that began in 1969 with Apollo 11, NASA began to prepare for piloted missions to Mars. They launched two spacecraft called Viking 1 and Viking 2, which landed on Mars in 1976 on July 20 and September 3, respectively. The Viking landers transmitted pictures of the rock-strewn, rusty-red landscape of Mars back to Earth for the first time. Because there had long been speculation about life on Mars, the Viking landers carried three biological experiments onboard. When the robotic arm of Viking 1 put a sample of the Martian soil into one of the experimental chambers, an excessive amount of oxygen was generated—a possible indication of some form of plant life in the soil. But, to the dismay of the scientists, when the same experiment was performed by Viking 2, no signs of life were found. The question of whether there is life on Mars remains unanswered.

A different type of robot called an "aerobot" was used by Soviet and French scientists to analyze the atmosphere of Venus as part of the Vega balloon mission in 1985. Two Teflon-coated balloons (aerobots) carrying scientific instrumentation floated through the thick Venusian atmosphere for forty-eight hours while researchers recorded temperature, pressure, vertical wind **velocity**, and visibility measurements. Separate landing modules carried analytical instrumentation to determine the composition of the atmosphere and of the surface on landing. More advanced aerobot technol-

velocity speed and direction of a moving object; a vector quantity

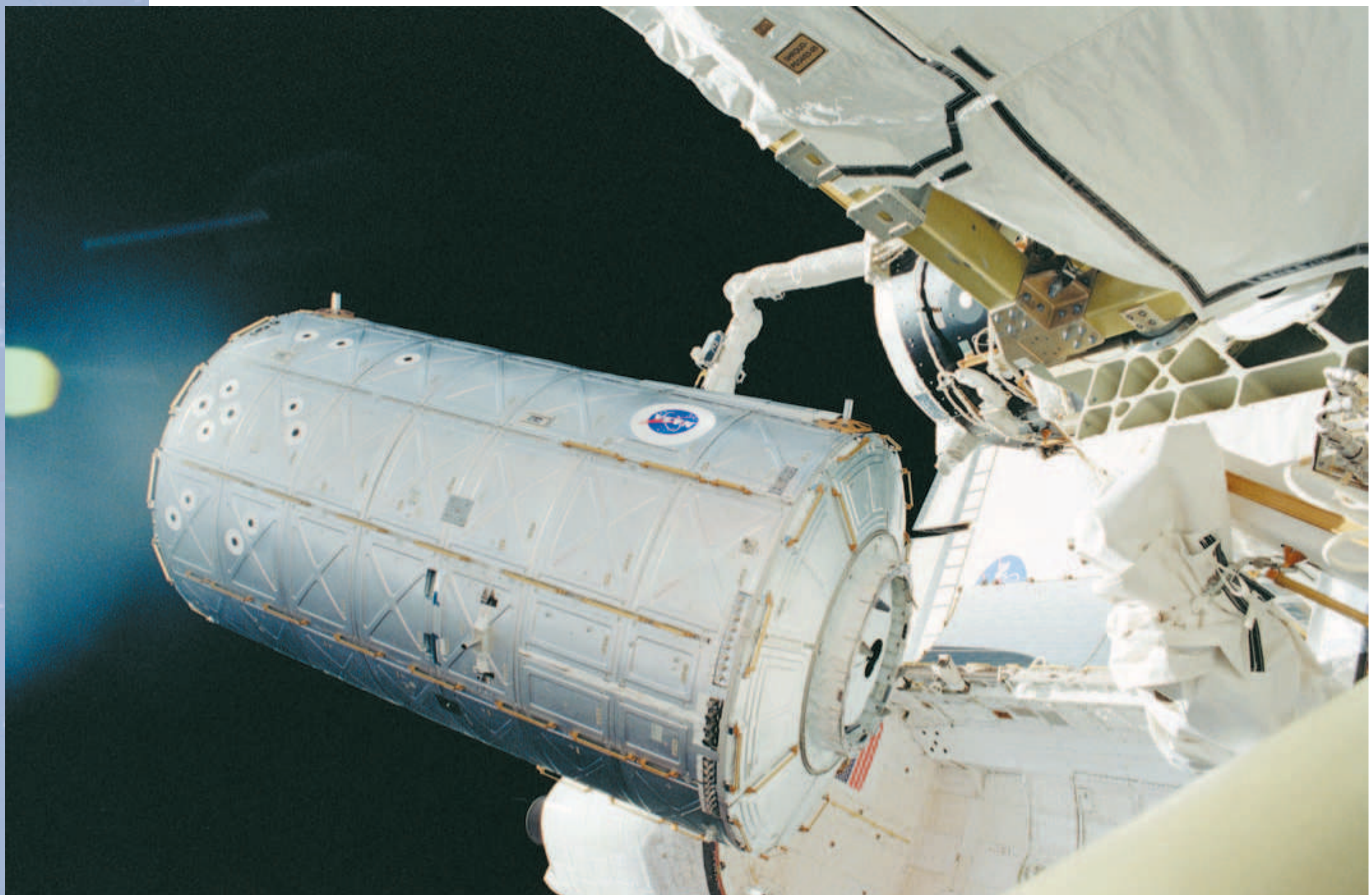
Technicians examine the Microrover Sojourner, the first robotic roving vehicle sent to Mars. Made with a six-wheel chassis and a rotating joint suspension system instead of springs, the design of Sojourner provides greater obstacle-crossing reliability with full unit stability.

ogy is being developed for NASA's Mars Aerobot Technology Experiment, scheduled for April 2003.

Space Shuttle–Era Robots

The space shuttle was developed as a reusable spacecraft to replace the costly one-time-use-only vehicles that marked the Apollo era. On its second mission in November 1981, astronauts aboard the space shuttle Columbia tested the Remote Manipulator System (RMS), a robotic arm located in the cargo bay. The RMS is 15 meters (50 feet) long 38 centimeters (15 inches) in diameter and weighs 411 kilograms (905 pounds). It has a shoulder (attached to the cargo bay), a lightweight boom that serves as the upper arm, an elbow joint, a lower arm boom, a wrist, and an "end effector" (a gripping tool that serves as a hand) that can grab onto a **payload**. The RMS was designed to lift a satellite weighing up to 29,500 kilograms (65,000 pounds) from the payload bay of the shuttle and release it into space. It can also retrieve defective satellites in orbit for the astronauts to repair. Perhaps the greatest achievement of the RMS has been the retrieval and repair of the Hubble Space Telescope (HST), whose initially flawed primary mirror produced blurry pictures. After it was hauled in by the RMS and repaired using corrective optics in 1993, the HST began delivering the high-quality photographs that astronomers had long awaited.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle



The Remote Manipulator System (RMS) of the space shuttle Atlantis moves the Destiny laboratory from its storage bay for future mission use.

rover a vehicle used to move about on a surface

alpha proton X-ray spectrometer analytical instrument that bombards a sample with alpha particles (consisting of two protons and two neutrons); the X rays are generated through the interaction of the alpha particles and the sample

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

After two decades of debate about the need to explore Earth's nearest neighbor in the solar system, the Mars Pathfinder landed on the Red Planet on July 4, 1997, and deployed a six-wheeled robotic **rover** called Sojourner to explore the terrain. Standing only 30 centimeters (1 foot) tall and resembling a rolling table with its flat solar panels facing skyward to soak up energy from the Sun, Sojourner roamed short distances to take pictures of interesting rock formations. It used two stereoscopic cameras mounted on its front to see the terrain in three dimensions, just like we do with our slightly separated stereoscopic eyes. A laser beam continuously scanned the area immediately in front of Sojourner to avoid collisions with objects the cameras might have missed. Sojourner analyzed the chemical composition of fifteen rocks using its **alpha proton X-ray spectrometer**. NASA plans to land a pair of advanced rovers on Mars in 2003.

Robonaut and Beyond

Engineers are starting to think of robots on a more human scale again. Since the space shuttle and the International Space Station are designed on a human scale, having robots built to the same scale would be advantageous in working on these spacecraft. NASA is currently developing the Robonaut, a humanoid robotic astronaut about the size of a human astronaut, with a head mounted on a torso, a primitive electronic brain that allows it to make decisions relating to its work, four cameras for eyes, a nose with an **infrared** thermometer to determine an object's temperature, two arms containing 150 sensors each, and two five-fingered hands for dexterous manipulation of objects. It will work alone or alongside human astronauts on space walks to build or repair equipment.

Robotics engineers are also working on a personal satellite assistant, which is a softball-size sphere that would hover near an astronaut in a spacecraft, monitoring the environment for oxygen and carbon monoxide concentrations, bacterial growth, and air temperature and pressure. It will also provide additional audio and video capabilities, giving the astronaut another set of eyes and ears. SEE ALSO Exploration Programs (volume 2); Robotic Exploration of Space (volume 2).

Tim Palucka

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S

Sagan, Carl

American Astronomer, Author, and Educator
1934–1996

Carl Sagan was a Pulitzer-prize winning author, visionary educator, and devoted scientist. He worked to extend humankind's reach into the solar system, and to help people understand the importance and meaning of the scientific method. Born on November 9, 1934, Sagan conducted his undergraduate work at Harvard University, and earned doctorates in astronomy and astrophysics at the University of Chicago. He was named a professor at Cornell University in Ithaca, New York, in 1971. Sagan's academic research concentrated on biology, evolution, astrophysics, planetary science, and anthropology.

Sagan was the author of more than 600 academic papers, twenty books, and a television miniseries called *Cosmos.* His novel about contact with an extraterrestrial civilization, *Contact*, was made into a popular Hollywood film in 1997. Much of Sagan's life was devoted to debunking scientific

Carl Sagan pioneered the study of exobiology—the study of possible alien life forms and biochemistry.

misconceptions and advocating clear thinking and better appreciation for the basics of science and its importance in everyday life. He was also a strong advocate for space exploration, especially robotic exploration of the solar system and beyond. Sagan also supported nuclear disarmament and urged the United States and the then–Soviet Union to undertake a joint mission to explore Mars.

Sagan was cofounder of the Planetary Society, a nonprofit organization supporting the exploration of space. He died on December 20, 1996, in Seattle, Washington, at the age of sixty-two. SEE ALSO Astronomy, Kinds of (volume 2); Literature (volume 1).

Frank Sietzen, Jr.

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Saturn

Saturn, the sixth planet from the Sun, revolves around the Sun in a slightly **elliptical** orbit at a mean distance of 1.4294 billion kilometers (888,188,000 miles) in 29.42 years. Perhaps best known for its rings, Saturn also has a large collection of moons orbiting around it.

elliptical having an oval shape

Physical and Orbital Properties

One of four gas giant outer planets (along with Jupiter, Uranus, and Neptune), Saturn is the second most massive planet in the solar system. It has a mass equivalent to 95.159 times Earth's and possesses an atmosphere composed primarily of the gases hydrogen and helium (by mass, comprising approximately 78 percent and 22 percent of the atmosphere, respectively).

It is the trace elements and their compounds that give the planet its golden color and the faint banded structure of the cloud tops in its lowermost **stratosphere**. Methane, ethane, other carbon compounds, and ammonia are observed in the atmosphere. Winds can exceed 450 meters per second (1,000 miles per hour). There is no solid surface beneath the clouds. With depth, the atmosphere slowly thickens from gas to liquid. At very great depths, liquid hydrogen may be compressed enough to become metallic. Saturn has a molten core of heavy elements including nickel, iron, silicon, sulfur, and oxygen, which totals as much as three Earth-masses.

stratosphere a middle portion of a planet's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

Saturn's magnetic field is much like the field of a simple bar magnet and similar to the planetary magnetic fields of Earth, Jupiter, Uranus, and Neptune. But its near-perfect alignment with the planet's rotation axis makes its origin mysterious. The magnetic field governs Saturn's huge, tadpole-shaped **magnetosphere**, the volume of space controlled by Saturn rather than by the interplanetary magnetic field.

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

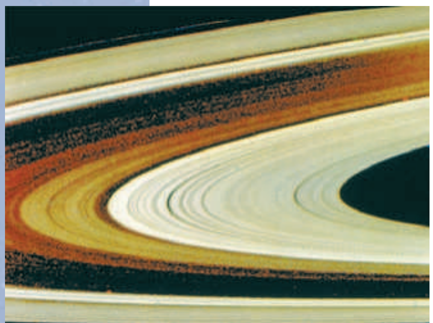
Saturn is the second largest planet in the solar system. Its equatorial diameter is 120,660 kilometers (74,975 miles). Saturn rotates rapidly, having

This picture of the Saturnian system was prepared from a collection of images taken by Voyager 1 and 2 spacecraft. The orbit of Saturn's moons and their distinctly different compositions make the Saturnian satellites a small-scale version of the solar system.

a day lasting only 10 hours and 39.9 minutes. The **centrifugal** force of this rapid rotation forces the planet to look slightly squashed: its polar diameter is 108,831 kilometers (67,624 miles). Saturn's axis of rotation is inclined to the plane of its orbit by 25.2 degrees, much like Earth's inclination of 23.4 degrees. Like Earth, Saturn has seasons and it constantly changes its presentation to Earth over its long orbit. Weather on Saturn is controlled not by its seasons or the Sun but by the flow of heat from inside the planet. This outward heat flow exceeds the heat received from the Sun by a factor of about three. Its origin is still being investigated.

centrifugal directed away from the center through spinning

The combination of Saturn's mass and volume leads to an average density unique in the solar system: at 0.70 grams per cubic centimeter it is less dense than water (1 gram per cubic centimeter). Because of the planet's large size, the force of gravity at Saturn's cloud tops is only 1.06 times Earth's. Nevertheless, to escape from Saturn, a rocket launched from its cloud tops would have to achieve a speed of 35.5 kilometers per second (22 miles per second), more than three times Earth's escape velocity of 11.2 kilometers per second (7 miles per second).



Saturn's rings are composed primarily of water ice particles, and range in size from micrometers to meters.

The Rings of Saturn

Italian mathematician and astronomer Galileo Galilei noted Saturn's odd telescopic appearance in 1610, but Dutch astronomer Christiaan Huygens, who had discovered Saturn's largest moon, Titan, in 1655, was the first to identify it as a ring in 1659. Huygens also demonstrated how the ring plane was tilted, explaining the odd behavior seen over the previous decades.

Italian-born French astronomer Giovanni Domenico Cassini noted a gap within Huygens's single ring in 1675. Now called the Cassini division, this gap separates the outer A ring from the inner B ring. The C ring, inside the others, was discovered in 1850. More than a century later, hints of the D ring were found (and then confirmed by the spacecraft Voyager 1 in 1980), and in 1966 the E ring was observed. The Pioneer 11 spacecraft discovered the F and G rings in 1979. In order outward from the planet, the rings are D, C, B, A, F, G, E. (See table below.)

While Saturn's main rings span a huge distance, they are less than 1 kilometer (0.6 mile) thick and their plane is slightly warped. Ring particles in the main rings range in size from a few tens of meters across down to the size of smoke particles, about 1 micrometer (10^{-6} meter). The E ring is different, being composed of small particles that orbit within a much thicker volume.

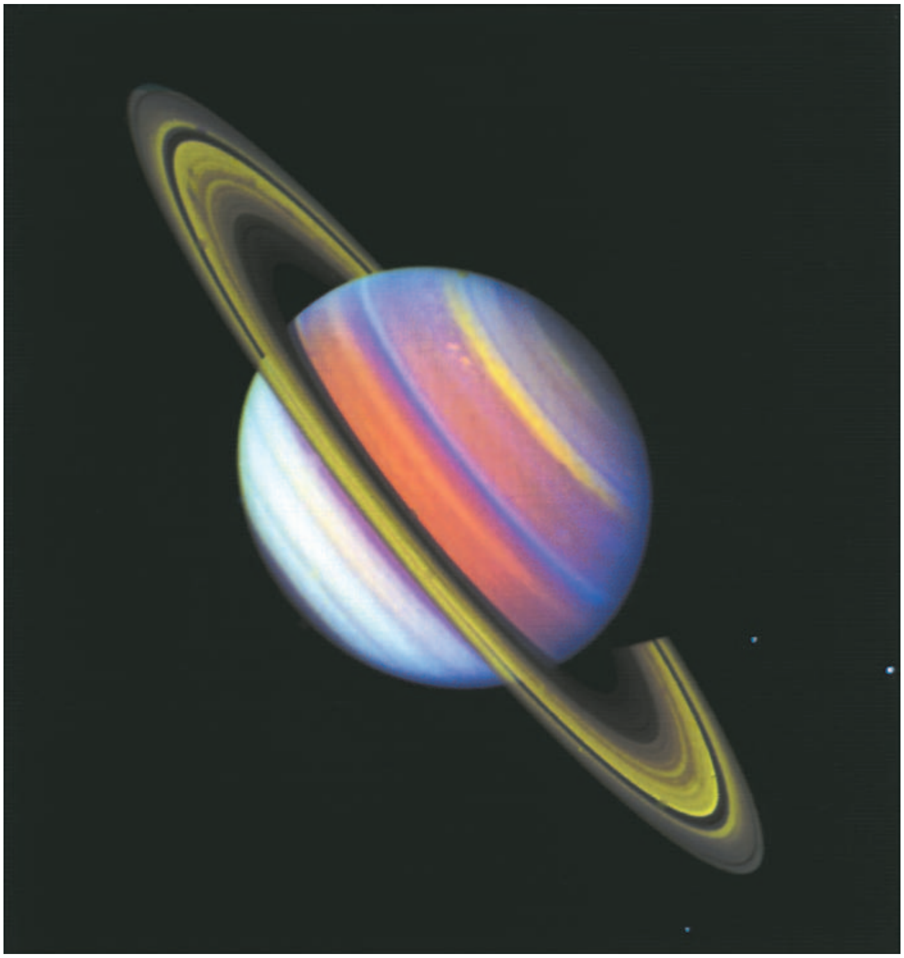
The Satellite System of Saturn

Saturn's system of satellites (moons) is notable, ranging from inside the A ring to almost 13 million kilometers (about 8 million miles) from the planet. The classical nine largest moons were discovered between 1655 (Titan) and 1898 (Phoebe). With the rings nearly invisible during the ring plane crossing of 1966, two additional co-orbital (sharing an orbit) moons were discovered, situated between the F and G rings.

Observations in 1980–1981 by the Voyager spacecraft added more moons. Besides an A-ring shepherd moon (which limits the outer edge of the ring) and one in the A ring's Encke gap, small moons trapped in grav-

THE RINGS OF SATURN

Ring Designation	Distance from Saturn km	R_S	
Saturn Radius, R_S	60,330	1.00	
D (inner edge)	66,970	1.11	
C (inner edge)	74,510	1.24	
B (inner edge)	92,000	1.53	
B (outer edge) (Cassini Division)	117,580	1.95	
A (inner edge)	122,170	2.03	
A (ring gap center)	133,400	2.21	
A (outer edge)	136,780	2.27	
F (center)	140,180	2.32	(width 50 km)
G (center)	170,180	2.82	(width variable)
E (inner edge)	~181,000	~3	
E (outer edge)	~483,000	~8	



Green, violet and ultraviolet filtered images were combined to create this image of Saturn, July 12, 1981. This image was taken by Voyager 2 at a distance of 43 million kilometers from Saturn.

itationally stable points (called Lagrangian points, L4 and L5) in the orbits of two of the larger moons were discovered. By 1990 Saturn's satellite count had reached eighteen.

State-of-the-art telescopes and techniques increased Saturn's moon count during the last half of 2000. Twelve additional, tiny outlying satellites were discovered, with additional ones awaiting confirmation. Saturn's total moon count thus reached thirty and was likely to increase further. Some of these small, distant, outer moons orbit Saturn backwards compared to its rotation direction, as Phoebe does, whereas others move in the same direction as the rotation but have orbits highly inclined to Saturn's equator.

Among the classical set of icy satellites, Enceladus and Iapetus are particularly noteworthy. Enceladus, with a diameter of only 498 kilometers (310 miles), is the most reflective solid body in the solar system. Surprisingly for a small, cold moon, the Voyager spacecraft showed that large areas of its surface have recently (over a small fraction of the age of the solar system) melted. Interestingly, the E ring has its maximum density at the same orbital distance as Enceladus.

Iapetus, second largest of the icy moons (and third overall, at 1,436 kilometers [892 miles]), has one hemisphere that reflects as well as snow, whereas its other hemisphere is blacker than asphalt.

In a class by itself is the giant moon Titan. Its diameter of 5,150 kilometers (3,200 miles) exceeds that of the planet Mercury. It has a nitrogen (plus methane) atmosphere, like Earth's (nitrogen plus oxygen), but with a surface pressure about 1.5 times Earth's air pressure at sea level. Titan may be a deep-frozen copy of what Earth was like shortly after its formation.

Beginning in 2004, the Cassini spacecraft and Huygens probe will explore Saturn and Titan. Our understanding of the fascinating and mysterious Saturnian system will increase enormously. SEE ALSO Cassini, Giovanni Domenico (volume 2); Exploration Programs (volume 2);Galilei, Galileo (volume 2); Huygens, Christiaan (volume 2); Jupiter (volume 2); NASA (volume 3); Robotic Exploration of Space (volume 2); Planetary Exploration, Future of (volume 2).

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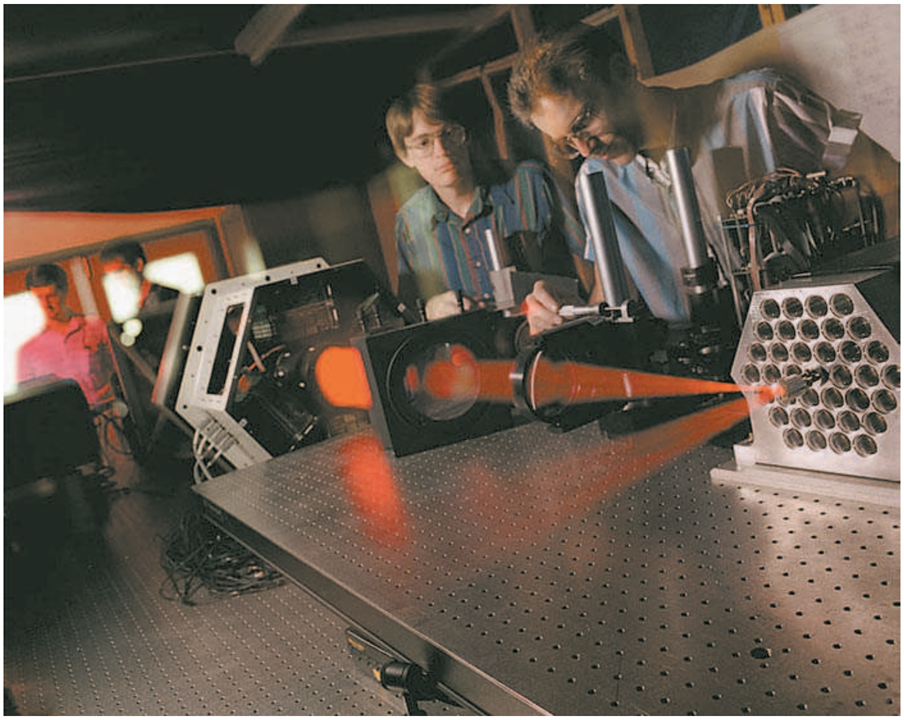
Sensors

Satellites and space probes are launched on their missions to a wide variety of destinations. Some satellites are sent into Earth orbit to look down at Earth's surface or atmosphere; others aim outward, to study the Moon, other planets, or the universe itself. Probes are sent beyond Earth orbit to pass near, land on, or orbit other planets or the Moon. No matter what their eventual destination, the primary objective of sending these craft into space is to gather information and relay it back to Earth in some direct or indirect way. To collect information, these space vehicles must carry with them some means of collecting and distinguishing this data. Sensors are one type of instrument that can collect information.

Sensors, as applied to spacecraft, are instruments and devices that can detect alterations or variations in the space environment and send electrical, radio, or other types of signals or transmissions back to a main collection or recording device. Such a device can be aboard the spacecraft itself, on another spacecraft nearby or close by, or at a receiving station or receptacle on Earth, such as a radio antenna.

While some sensors gather data remotely about the conditions found in space or on another planetary body, other types of sensors can be used by



Scientists demonstrate the Wave Front Sensor alignment. Sensors are an important tool in space exploration. They detect changes in space environment and send information back to Earth.

space vehicles to make determinations about the position or location of the vehicle itself or its condition while in flight. Such sensors, onboard the space vehicle and active during its flight, are essential elements in controlling the craft or flying it to a specific destination in space.

In their roles in remotely sensing the space environment, sensors can be of many different types and collect many different types of information. Radiometers aboard a probe can gather data on the temperature of a planet or Moon's surface, or the temperature of the gases contained in an atmosphere. A spectrometer can break down the composition of planetary gases or surface features across the visible or invisible spectrum of light. These instruments can also gather information on the environmental or weather conditions where they are located. Small **radar** units emitting radar signals can gather information about a planet's surface composition based on the radar's "return," or bounce, from the surface up to the sensor's instrument.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Satellite sensors may also include devices such as a thermocouple. This instrument, made from different types of metals, produces electrical voltage that can vary depending upon the temperature of the material through which the electrical current passes. In this way the device can chart changes in temperatures over a distance or across an altitude.

Sensors used to control satellites can include **gyroscopes** for attitude control or navigation equipment that can plot the craft's location based on sightings of stars and other space objects whose locations are fixed. Sensors are an essential part of a spacecraft, and they can contribute much to the mission and to the accuracy of the spacecraft's flight while in space. SEE ALSO GYROSCOPES (VOLUME 3); ROBOTIC EXPLORATION OF SPACE (VOLUME 2); SPACECRAFT BUSES (VOLUME 2).

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

Frank Sietzen, Jr.

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SETI

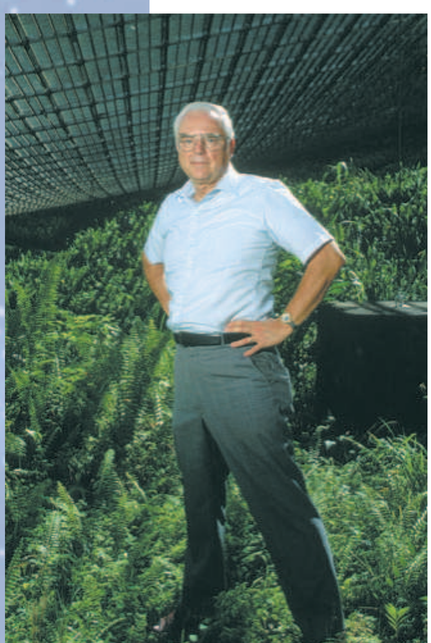
Of all the scientific efforts to find life in space, none has potential consequences as profound as SETI, the Search for Extraterrestrial Intelligence. SETI researchers are trying to uncover other civilizations whose technical sophistication is at a human level or higher.

While science fiction routinely describes face-to-face encounters with intelligent aliens, it may be that we will never actually meet extraterrestrials. Building fast rockets capable of carrying living cargo to the stars is a formidable, perhaps even impossible, challenge. The amount of energy required to hurl a craft the size of the space shuttle at even half the speed of light is enormous—equivalent to the energy required to keep New York City running for 10,000 years.✶ This is a problem of physics, not technology.

✶**At half the speed of light, travel time to Alpha Centauri, the nearest star system, would take nine years.**

On the other hand, there are ways to reach other civilizations without **interstellar** travel. In 1959 Philip Morrison and Giuseppe Cocconi, two physicists at Cornell University, made a simple calculation to determine how far away a good radio receiver and a large antenna could detect our most powerful military radar transmitters. To their surprise, the answer turned out to be light-years—typical of the distances to the stars. Morrison and Cocconi realized that while interstellar rocketry was hard, interstellar communication by radio was easy. They suggested that other galactic civilizations might be discovered by simply eavesdropping on their radio traffic.

interstellar between the stars



Frank Drake stands under the Arecibo radio telescope on October 12, 1992. Drake is one of the leaders in the Search for Extraterrestrial Intelligence (SETI).

The Search for Extraterrestrial Intelligence

Within months, Frank Drake, a young radio astronomer at the National Radio Astronomy Observatory in Green Bank, West Virginia, tried to do just that. He was unaware of the work of the two Cornell physicists but had independently thought of the same idea. For several weeks in the spring of 1960, Drake pointed an 85-foot antenna (a radio telescope) at two Sun-like stars, Tau Ceti and Epsilon Eridani, tuning his receiver up and down the dial near 1,420 megahertz (MHz). This particular frequency was chosen because it is truly a universal radio channel. Hydrogen gas, which drifts and swirls through the immense spaces between the stars, naturally emits some radio noise at 1,420 MHz. Drake believed that every sophisticated society in the cosmos would know of this hydrogen hiss, and consequently it would make sense to broadcast interstellar hailing signals near this sweet spot on the dial.

Drake's Project Ozma was the first modern SETI search. By the early twenty-first century, about seventy others were undertaken. One of the most ambitious was the NASA SETI program, which ultimately became known as the High Resolution Microwave Survey. NASA got into SETI slowly, beginning in the 1970s with a technical study of the equipment and strat-

The receiver for the Arecibo Radio Telescope in Puerto Rico requires three large poles to support its weight above the 305 meter (1,000 foot) dish. Scientists monitoring this telescope, which scrutinizes about 1,000 Sun-like stars less than 150 light-years distant, hope to find signs of intelligent extraterrestrial life.

egy required for a serious search. In the fall of 1992, sufficient equipment had been built to start the listening. However, very shortly thereafter, the U.S. Congress stopped all NASA SETI efforts. The rationale for canceling this research was to reduce federal spending during an era of large budget deficits.

SETI work continued, however, funded in the United States by private donations. Most of these projects have been radio experiments, of the type pioneered by Drake. The SETI Institute, in California, runs the most sensitive search, known as Project Phoenix. Various large radio telescopes, including the king-sized 305-meter (1,000-foot) antenna at Arecibo, Puerto Rico, have been used by Project Phoenix to carefully examine the neighborhoods of nearby, Sun-like stars. Other projects, such as the University of California, Berkeley's SERENDIP experiment, sweep the sky in an attempt to survey greater amounts of cosmic real estate. While more of the heavens are examined, the sensitivity in any given direction is lower. Some of the SERENDIP data have been distributed on the Web for processing at home with a screen saver program known as SETI@home.

Additional radio SETI experiments are being carried out in Australia (Southern SERENDIP), Argentina (META II), and Italy. Starting in the late twentieth century, another approach to SETI has gained a number of adherents: so-called optical SETI. Rather than tuning the dial in search of persistent, artificial signals, ordinary telescopes (with mirrors and lens) are outfitted with special detectors designed to find very short (less than a billionth of a second) laser pulses from distant worlds.

The Probability of Success

So far, no confirmed extraterrestrial signals—either radio or optical—have been found by SETI scientists. What are the chances that the aliens will *ever* be found? In 1961 Drake summarized the problem with a simple formula that predicts the number of galactic civilizations that are broadcasting now. Known as the Drake Equation, the computation is simply a product of factors bearing on the existence of intelligence. These factors include the number of galactic stars capable of supporting life, the fraction of such stars with planets, the number of planets in a solar system on which life evolves, the fraction of inhabited worlds where intelligence appears, and the lifetime of a broadcasting society. While we still do not know many of these factors, some scientists contend that the recent evidence for **extrasolar planets** and the growing suspicion that biology might be a common phenomenon have increased the chances for finding intelligence among the stars.

extrasolar planets planets orbiting stars other than the Sun

SETI scientists have made plans to greatly expand their search during the first two decades of the twenty-first century. The SETI Institute will build the Allen Telescope Array, a large grouping of small antennas that will be used for full-time searching. A world consortium of radio astronomers is considering the construction of a radio telescope a kilometer in size, a gargantuan instrument that could also be used for SETI. Optical SETI experiments are already increasing in number and sophistication.

In light of this rapid improvement in experimental technique, some scientists are optimistic that a signal will be found in the early decades of the twenty-first century. If so, the consequences would be dramatic. If we can ever successfully find and decode any message accompanying the signal, we might learn something of the knowledge and culture of other galactic beings, most likely from a society technologically far more advanced than our own. Even if we never understand or reply to an interstellar message, simply knowing that we are not the only "game" in town—let alone the most interesting game—would give us new and valuable perspective. SEE ALSO Extrasolar Planets (volume 2); Life in the Universe, Search for (volume 2); Why Human Exploration? (volume 3).

Seth Shostak

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Shapley, Harlow

Astronomer
1885–1972

Harlow Shapley discovered that the solar system does not rest in the center of the Milky Way, but is actually located in the outer regions of the galaxy.

Harlow Shapley was born on November 2, 1885, in Nashville, Missouri. He worked for a newspaper in Kansas and later attended the University of Missouri, intending to study journalism, but taking up astronomy instead. In 1911 Shapley went to Princeton University, where he worked with Henry Norris Russell on eclipsing binary stars. After completing his doctoral thesis, Shapley began work at Mt. Wilson Observatory in California in 1914, where he studied **Cepheid variables**. Brighter Cepheids have longer periods, and Shapley was able to determine the distances to faint Cepheids and show that the Milky Way galaxy was far larger than previously believed.

Cepheid variables a class of variable stars whose luminosity is related to their period; their periods can range from a few hours to about 100 days—the longer the period, the brighter the star

globular clusters roughly spherical collections of hundreds of thousands of old stars found in galactic haloes

Shapley's most important contribution to astronomy was to note that the **globular clusters** were concentrated toward the constellation Sagittarius, and he made the correct assumption that the center of this concentration marked the center of the Milky Way. He thus moved the universe from a Copernican Sun-centered system to a Sun located far from the galactic center in one of the spiral arms.

On April 20, 1920, a famous debate was held between Shapley and fellow astronomer Heber Curtis on the subject of "The Scale of the Universe." Curtis was correct in arguing that spiral nebulae were galaxies like our own but incorrect in placing the Sun at the center of the Milky Way. Shapley was correct in placing the Sun far from the center of the Milky Way but incorrect in saying the spiral nebulae were nearby gas clouds.

In 1920 Shapley was offered the directorship of the Harvard College Observatory, where he stayed for the rest of his career. He died in Boulder, Colorado, on October 20, 1972. Shapley's legacy as a popularizer of astronomy is maintained by the American Astronomical Society's Harlow Shapley Visiting Lectureships Program, which sends astronomers on two-day visits to universities and colleges in the United States, Canada, and Mexico. SEE ALSO Astronomy, History of (volume 2); Copernicus, Nicholas (volume 2); Galaxies (volume 2); Stars (volume 2).

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Shoemaker, Eugene

American Astrogeologist
1928–1997

Eugene Merle Shoemaker was instrumental in establishing the discipline of planetary geology. He founded the U.S. Geological Survey's Branch of

Eugene Shoemaker, here outside the Palomar Observatory near San Diego, is credited with originating the field of astrogeology within the U.S. Geological Survey.

Astrogeology, which mapped the Moon and prepared astronauts for lunar exploration.

Born in 1928, Shoemaker's early fascination with the Grand Canyon led him to recognize that the powerful tool of **stratigraphy** could be applied to unraveling the history of the Moon. His research at Meteor Crater in Arizona led to an appreciation of the role of asteroid and comet impacts as a primal and fundamental process in the evolution of planets.

stratigraphy the study of rock layers known as strata, especially the age and distribution of various kinds of sedimentary rocks

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

Shoemaker contributed greatly to space science exploration, particularly of the Moon. Although he hungered to become an Apollo astronaut himself, that aspiration was unfulfilled. Shoemaker was part of a leading comet-hunting team that discovered comet Shoemaker–Levy 9 and charted the object's breakup. Pieces of the comet slammed into Jupiter in July 1994—an unprecedented event in the history of astronomical observations. That same year, Shoemaker also led the U.S. Defense Department's Clementine mission, which first detected the possibility of pockets of water ice at the Moon's south pole.

While carrying out research on **impact craters** in the Australian outback in 1997, Shoemaker was killed in a car accident. A small vial of the astrogeologist's ashes were scattered on the lunar surface, deposited there by the National Aeronautics and Space Administration's Lunar Prospector spacecraft, which was purposely crashed on the Moon on July 31, 1999, after completing its mission. SEE ALSO Apollo (Volume 3); Asteroids (Volume 2); Jupiter (Volume 2).

Leonard David

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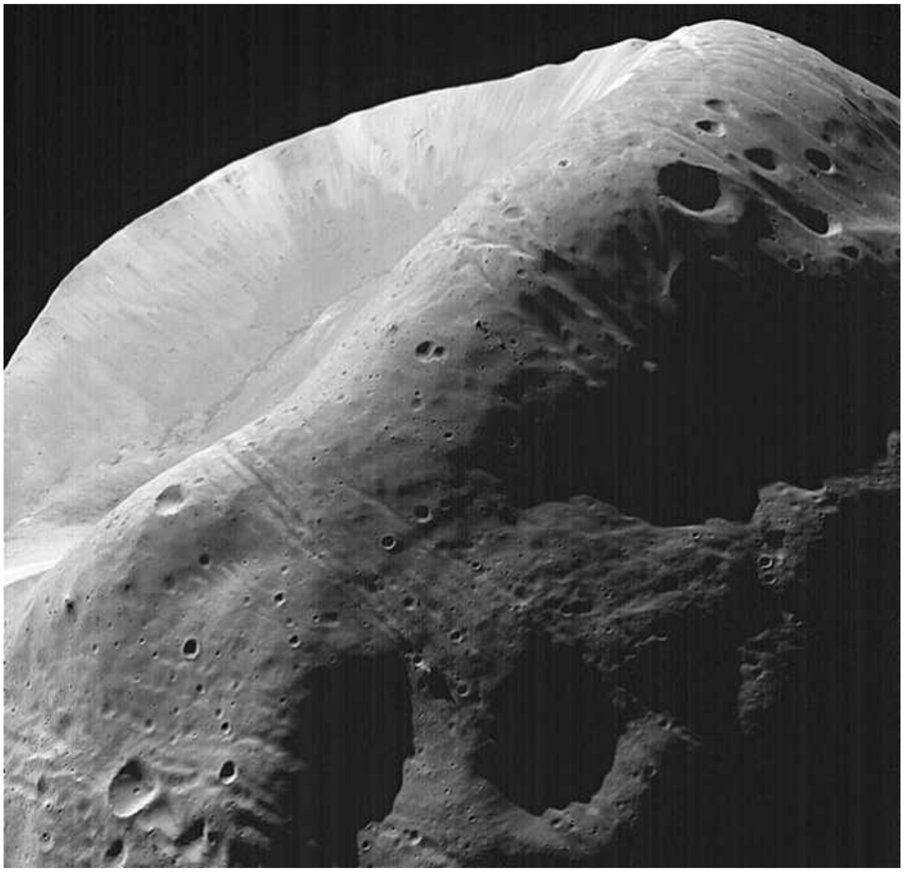
Small Bodies

For much of history, the solar system was thought to consist of large objects: Earth, the Moon, the Sun, and other planets. However, within the last two centuries astronomers have discovered a menagerie of small objects throughout the solar system, including asteroids, comets, Kuiper belt objects, and many small moons orbiting planets. Studies of these objects, from both telescopes and spacecraft, have provided new insights into the formation of the solar system and its true nature.

There is no good definition for what constitutes a "small body" in the solar system. Nevertheless, one definition used by some planetary scientists considers objects less than 400 kilometers (250 miles) in diameter to be small bodies. When objects are larger than 400 kilometers, they have enough mass so that their gravity is powerful enough to shape the object into a roughly spherical form. For smaller objects, their gravity is not powerful enough to accomplish this, and as a result many have irregular shapes. Even this, though, is not a precise definition. In reality, there is a continuum of objects from very large to very small, with no distinct, obvious differences between "large" and "small" bodies.



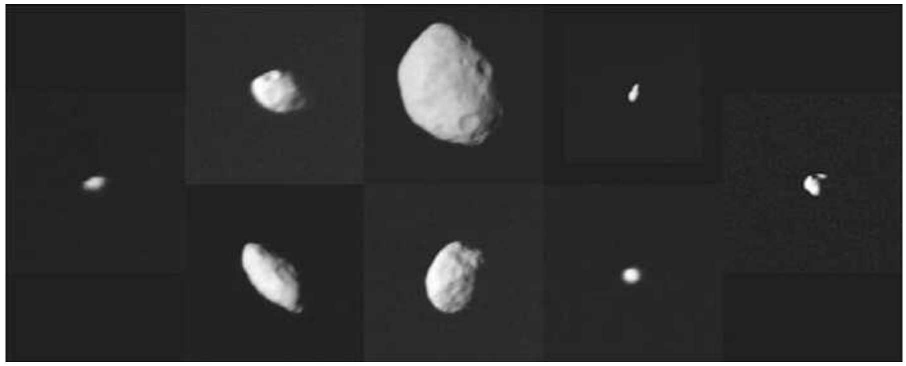
Phobos is the larger of the two moons of Mars, both of which are less than 30 kilometers in diameter and are irregularly shaped.

The Discovery of Small Bodies

The first objects that would qualify as small bodies were asteroids, discovered in the early nineteenth century. While the largest asteroids, such as Ceres (the first asteroid to be discovered), may be somewhat larger than the above definition for a small body✶, within a few decades a number of small bodies were discovered. In 1877 American astronomer Asaph Hall discovered Phobos and Deimos, the two moons of Mars. Both moons are very small objects, each less than 30 kilometers (18.5 miles) in diameter and irregularly shaped. In 1892 Amalthea, a moon less than 250 kilometers (155 miles) in diameter, was found orbiting Jupiter. In the late nineteenth and early twentieth centuries, a number of small moons were found orbiting Jupiter and Saturn. In addition, during this time the rate of asteroid discoveries increased.

✶Ceres was initially considered to be a planet until other asteroids with similar orbits were found.

The era of spacecraft exploration brought many more discoveries of small bodies. The Voyager 1 and Voyager 2 spacecraft discovered many small moons orbiting Jupiter, Saturn, Uranus, and Neptune. Telescopes on the ground, as well as the Hubble Space Telescope, have also discovered small moons around these planets. The rate of asteroid and comet discoveries increased dramatically starting in the 1990s. By October 2001, more than 30,000 asteroids had been discovered, compared to 20,000 just at the beginning of that year. Dozens of comets are discovered each year as well, many by automated telescopes and spacecraft.



This montage of the smaller satellites of Saturn was taken by Voyager 2 as it made its way through the Saturnian system. These satellites range in size from small on the asteroidal scales, to nearly as large as Saturn's moon Mimas.

Difficulties in Classification

These discoveries, and follow-up observations, have shown how difficult it can be to classify small bodies. Astronomers in the past attempted to fit these bodies into one of three classes: asteroids, comets, and moons. Now, however, there is evidence that many asteroids may be extinct comets, having exhausted their supply of ice that generates a tail when approaching the Sun. Some small moons orbiting Jupiter, as well as Phobos and Deimos, may have originally been asteroids captured into orbit by the gravity of Mars and Jupiter. In the outer solar system astronomers discovered in the early 1990s a family of icy bodies called Kuiper belt objects, some of which are larger than even the largest asteroids and are far larger than an ordinary comet. Spacecraft and ground-based telescopes have discovered several asteroids that have their own small moons.

Some planetary scientists have elected to classify objects in a different way, based on their composition and likely location in the solar system where they formed. Bodies that formed from the Sun out to a distance of about 2.5 **astronomical units** (AU) are primarily rocky and metallic. That close to the Sun, temperatures are too high for anything else to condense out of the protoplanetary nebula from which the solar system formed. This explains the composition of much of the asteroid belt as well as the inner planets. At around 2.5 to 2.7 AU is what some call the "soot line." At this distance temperatures are low enough for carbon-rich compounds, such as soot, to form. Asteroids in the outer portion of the belt, beyond the soot line, tend to be rich in these materials. At around 3 to 4 AU is the "frost line," beyond which water ice can form. Objects that formed beyond this distance tend to be rich in water ice and often in carbon dioxide, methane, and other ices.

astronomical units one AU is the average distance between Earth and the Sun (152 million kilometers [93 million miles])

This scheme allows scientists to understand where an object originated, regardless of where it is today. With this information, scientists can then try to understand how the object evolved over the history of the solar system from the location where it formed to where it is now located. The problem with this approach is that there is only limited information about the composition of many small bodies, including many of the moons of the giant planets. Even Phobos and Deimos, the two moons of nearby Mars, have not been examined enough to know their compositions well.

Sorting out the true nature of small bodies in the solar system will take many more years of research and observations by telescopes and spacecraft.

A number of missions by the National Aeronautics and Space Administration (NASA) and the European Space Agency will study asteroids and comets in detail in the early twenty-first century. In addition, NASA's Cassini spacecraft will arrive at Saturn in 2004 and spend several years studying the planet and its moons, which may uncover key clues about the origin of Saturn's small moons. Through these observations, it should be possible to learn not only about the origins of the small bodies in the solar system but also how the solar system itself formed. SEE ALSO Asteroids (volume 2); Comets (volume 2); Exploration Programs (volume 2); Jupiter (volume 2); Kuiper Belt (volume 2); Mars (volume 2); Meteorites (volume 2); Neptune (volume 2); Oort Cloud (volume 2); Planetesimals (volume 2); Saturn (volume 2); Uranus (volume 2).

Jeff Foust

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Solar Particle Radiation

The Sun radiates more than just life-sustaining light into the solar system. At irregular intervals, it also produces bursts of high-energy particles. These solar particles have energies that range from 30,000 **electron volts** to 30 billion electron volts per **nucleon** and consist primarily of protons (96% of the total number of nuclei) and helium nuclei (3%). The remaining particles are ions of elements that are common in the solar atmosphere, such as carbon, nitrogen, oxygen, neon, magnesium, silicon, and iron, as well as small numbers of even heavier elements. The processes that produce high-energy protons and ions also accelerate **electrons** to at least 20 million electron volts. Collisions between energetic particles and the solar atmosphere also produce **neutrons** and **gamma rays**. All these particles flow outward from the Sun into the **heliosphere**, where they can affect space systems and are a major concern for astronaut safety.

electron volt unit of energy equal to the energy gained by an electron when it passes through a potential difference of 1 volt in a vacuum

nucleon a proton or a neutron; one of the two particles found in a nucleus

electrons negatively charged subatomic particles

neutrons subatomic particles with no electrical charge

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

heliosphere the volume of space extending outward from the Sun that is dominated by solar wind; it ends where the solar wind transitions into the interstellar medium, somewhere between 40 and 100 astronomical units from the Sun

flares intense, sudden releases of energy

The Origins of Solar Particles

Until recently, it was thought that solar energetic particles came only from **flares**. Now solar physicists know that they are produced in both flares and coronal mass ejections. Flares occur when stressed magnetic fields in solar active regions release their energy. The energy appears as both heated plasma and energetic particles, some of which stream out along magnetic field lines into the heliosphere. Because they come from a small area on the Sun, the energetic particles follow a narrow set of field lines and affect only a small region of the heliosphere. Flare-generated energetic particle events tend to be impulsive, meaning that the flux of particles measured near Earth rises and decays rapidly, often within a day.

Prominences that drift like clouds above the solar surface may suddenly erupt and break away from the Sun in a cataclysmic action.

solar corona the thin outer atmosphere of the Sun that gradually transitions into the solar wind

solar prominence cool material with temperatures typical of the solar photosphere or chromosphere; suspended in the corona above the visible surface layers

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

Coronal mass ejections are the result of a large-scale restructuring of the magnetic field in the **solar corona**. In this process significant amounts of plasma are ejected into the heliosphere. Usually a coronal mass ejection includes the eruption of a **solar prominence** and often is accompanied by a flare. The fastest coronal mass ejections travel at speeds above 800 kilometers per second (500 miles per second) and drive shock waves, which accelerate coronal plasma and **solar wind** into energetic particle events. Since the coronal mass ejection is a large-scale event, the accelerated particles cover a much broader region of the heliosphere than is the case for particles accelerated in flares alone. Coronal mass ejection-associated energetic particle events tend to be gradual, sometimes lasting for many days.

The Impact of Solar Particle Radiation

Because solar energetic particles have been stripped of some or all their electrons, they are positively charged and must follow the magnetic field lines away from the Sun. Near Earth, they are prevented from directly penetrating the near-Earth environment by the **magnetosphere** that surrounds the planet. Some particles can penetrate in the polar regions where Earth's magnetic field lines connect more directly with the space environment. There they produce fade-outs of radio communication at high latitudes and can bombard high-flying aircraft, including commercial flights. During a solar particle event, a passenger on a high-flying supersonic aircraft can receive a radiation dose equivalent to about one chest X ray an hour.

Energetic particles are stopped when they strike other matter. When this happens, they give up their energy to that material. On an orbiting satellite, energetic particle exposure degrades the efficiency of the solar-cell panels used to provide operating power. A large energetic particle event can also damage sensitive electronic components, leading to the failure of critical subsystems and loss of the satellite.

When energetic particles strike living tissue, the transfer of energy to the atoms and molecules in the cellular structure causes the atoms or molecules to become ionized or excited. These processes can break chemical bonds, produce highly reactive **free radicals**, and produce new chemical bonds and cross-linkage between **macromolecules**. Cells can repair small amounts of damage from low doses of particle radiation. Higher doses overwhelm this ability, resulting in cell death. If the dose of radiation is high enough, entire organs can fail to function properly and the organism dies.

free radical a molecule with a high degree of chemical reactivity due to the presence of an unpaired electron

macromolecules large molecules such as proteins or DNA containing thousands or millions of individual atoms

Radiation doses are measured in rads or grays, where 1 gray equals 100 rads. One rad equals 100 ergs of absorbed energy per gram of target matter. The potential for radiation to cause biological damage is called the dose equivalent, which is measured in rems or sieverts, where 1 sievert equals 100 rems. The dose equivalent is simply the dose (in rads or grays) multiplied by the so-called radiation weighting factor, which depends on the type of radiation and other factors. The average American receives 360 millirems a year, and a typical X ray gives a patient 50 millirems (a millirem is a thousandth of a rem). The National Aeronautics and Space Administration (NASA) limits exposure to radiation absorbed by the skin to 600 rems for an astronaut's career, with additional limits of 300 rems per year and 150 rems for every thirty-day period.

A large solar particle event can produce enough radiation to kill an unprotected astronaut. For example, the large solar storm of August 1972 would have given an unshielded astronaut on the Moon a dose equivalent of 2,600 rems, probably resulting in death. **Shielding** can reduce the radiation levels, but the amount required for a large solar particle event is too large for an entire Mars-bound spacecraft or lunar surface base. Instead, a highly shielded storm shelter is necessary. This must be combined with a warning capability to give astronauts who are away from the shelter sufficient time to seek safety.

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

Solar activity is monitored continuously from specially designed ground-based observatories and from the National Oceanic and Atmospheric Administration's geostationary operational environmental satellites. These satellites continuously observe the solar flux in soft X rays and monitor energetic particles at the satellite location. A sudden increase in soft X rays signifies a solar flare. Coronal mass ejections are not currently monitored continuously, but ground-based observatories can often detect the disappearance of a solar filament, which is usually related to a coronal mass ejection. Significant solar particle events occur much less frequently than flares and coronal mass ejections, so many false alarms are possible. Thus, with current observing systems, astronauts must always be able to seek a sheltered environment within the roughly one-hour period that it takes for the particle radiation to rise to dangerous levels. This limits, for example, the distances away from a lunar base that an astronaut can safely explore. SEE ALSO LIVING ON OTHER WORLDS (VOLUME 4); SOLAR WIND (VOLUME 2); SPACE ENVIRONMENT, NATURE OF THE (VOLUME 2); SUN (VOLUME 2).

John T. Mariska

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Solar Wind

The area between the Sun and the planets, the interplanetary medium, is a turbulent area dominated by a constant stream of hot plasma that billows out from the Sun's corona. This hot plasma is called the solar wind.

The first indication that the Sun might be emitting a "wind" came in the seventeenth century from observations of comet tails. The tails were always seen to point away from the Sun, regardless of whether the comet was approaching the Sun or moving away from it.

Basic Characteristics

protons positively charged subatomic particles

electrons negatively charged subatomic particles

The solar wind is composed mostly of **protons** and **electrons** but also contains ions of almost every element in the periodic table. The temperature of the corona is so great that the Sun's gravity is unable to hold on to these accelerated and charged particles and they are ejected in a stream of coronal gases at speeds of about 400 kilometers per second (1 million miles per hour). Although the composition of the solar wind is known, the exact mechanism of formation is not known at this time.

sunspots dark, cooler areas on the solar surface consisting of transient, concentrated magnetic fields

flares intense, sudden releases of energy

The solar wind is not ejected uniformly from the Sun's corona but escapes primarily through holes in the honeycomb-like solar magnetic field. These gaps, located at the Sun's poles, are called coronal holes. In addition, massive disturbances associated with **sunspots**, called solar **flares**, can dramatically increase the strength and speed of the solar wind. These events occur during the peak of the Sun's eleven-year sunspot cycle.

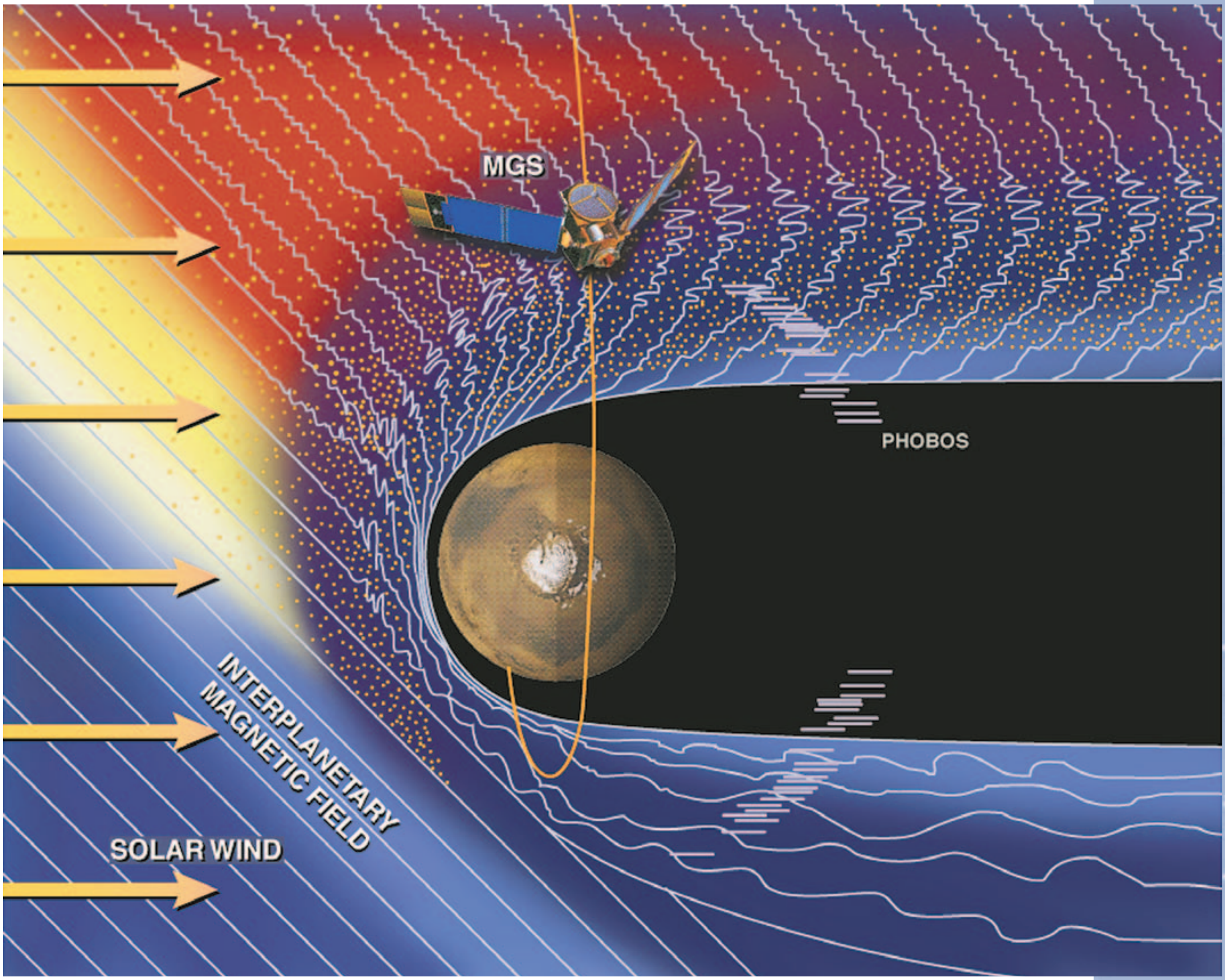
The solar wind affects the magnetic fields of all planets in the solar system. The interaction of the solar wind, Earth's magnetic field, and Earth's upper atmosphere causes geomagnetic storms that produce the awe-inspiring Aurora Borealis (northern lights) and Aurora Australis (southern lights).

Undesirable Consequences

auroras atmospheric phenomena consisting of glowing bands or sheets of light in the sky caused by high-speed charged particles striking atoms in Earth's upper atmosphere

Although the solar wind produces beautiful **auroras**, it can also cause a variety of undesirable consequences. Electrical current surges in power lines; interference in broadcast of satellite radio, television, and telephone signals; and problems with defense communications are all associated with geomagnetic storms. Odd behavior in air and marine navigation instruments have also been observed, and geomagnetic storms are known to alter the atmospheric ozone layer and even increase the speed of pipeline corrosion in Alaska. For this reason, the U.S. government uses satellite measurements of the solar wind and observations of the Sun to predict space weather.

Major solar wind activity is also a very serious concern during spaceflight. Communications can be seriously disrupted. Large solar disturbances



Depiction of the response of solar wind to an obstacle—Mars—in its path. (MGS identifies the Mars Surveyor spacecraft.)

heat Earth's upper atmosphere, causing it to expand. This creates increased atmospheric **drag** on spacecraft in low orbits, shortening their orbital lifetime. Intense solar flare events contain very high levels of radiation. On Earth humans are protected by Earth's **magnetosphere**, but beyond it astronauts could be subjected to lethal doses of radiation.

There have been a number of scientific missions that have enabled scientists to learn more about the Sun and the solar wind. Such missions have included Voyager, Ulysses, SOHO, Wind, and POLAR. The latest mission, Genesis, was launched in August 2001 and during its two years in orbit it will unfold its collectors and "sunbathe" before returning to Earth with its samples of solar wind particles. Scientists will study these solar wind samples for years to come. SEE ALSO Solar Particle Radiation (volume 2); Space Environment, Nature of the (volume 2); Sun (volume 2).

Alison Cridland Schutt

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

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Space Debris

The term "space debris" in its largest sense includes all naturally occurring remains of solar and planetary processes: interplanetary dust, meteoroids, asteroids, and comets. Human-made space debris in orbit around Earth is commonly called orbital debris. Examples include dead satellites, spent rocket bodies, explosive bolt fragments, telescope lens covers, and the bits and pieces left over from satellite explosions and collisions.

Orbital debris is found wherever there are working satellites. Of the more than 9,000 objects larger than 10 centimeters (3.94 inches) in Earth orbit, 94 percent are debris. The densest regions are low Earth orbit (LEO), an altitude range from 400 to 2,000 kilometers (248.5 to 1,242.7 miles) above Earth; and geosynchronous Earth orbit (GEO) at 35,786 kilometers (22,300 miles), sometimes called the **Clarke orbit**, where the orbital period of a satellite is one day. More than 100,000 particles between 1 and 10 centimeters (0.39 and 3.94 inches) are thought to exist and probably tens of millions of times smaller than that can be found in space. By mass, there are more than 4 million kilograms (4,409.2 tons) in orbit.

Clarke orbit geostationary orbit; named after science fiction writer Arthur C. Clarke, who first realized the usefulness of this type of orbit for communications and weather satellites

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

The U.S. Air Force and Navy operate a network of **radar** sensors all over the world that can observe objects in space. These observations are combined to produce mathematical orbits that are maintained at U.S. Space Command as the Space Surveillance Catalog (SSC). Objects in LEO as small as 10 centimeters (3.94 inches) can be reliably tracked. GEO objects are harder to track because of their high altitude. Telescopes are used to observe GEO objects, and those observations are converted into orbits that are included in the SSC.

From 10 centimeters down to about 3 millimeters (0.12 inches), powerful ground radars like the Massachusetts Institute of Technology Haystack radar in Westford, Massachusetts are used to statistically sample the debris population. Analysis of **impact craters** on returned spacecraft surfaces, such as those from the Long Duration Exposure Facility, produce data concerning very small particles, those under 0.5 millimeters (0.02 inches) in size.

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

Orbital debris can severely damage or destroy a spacecraft. Due to the high average speed at impact, about 10 kilometers (6.21 miles) per second, a 3-millimeter (0.12 inch) fragment could penetrate the walls of a pressurized spacecraft. An unmanned satellite could be disabled by debris smaller than 1 millimeter (0.04 inches) if such particles were to disable critical power or data cables. The International Space Station (ISS) carries a variety of shields to protect it against space debris up to 1 centimeter in size. Debris objects larger than 10 centimeters will be avoided using orbital information from U.S. Space Command. Too large to shield against and too small to track with radar, objects of 1 to 10 centimeters pose a risk to the ISS that, while small, cannot be eliminated.

Because satellites can stay in orbit for more than 10,000 years, care must be taken in the world's policies concerning orbital debris. The Inter-Agency Space Debris Coordination Committee, composed of representatives from the world's leading space agencies, has developed agreements that minimize the creation of new debris. Most countries deplete their spent rocket bodies and payloads of stored energy, thereby decreasing their possibility of exploding and minimizing the largest historical source of debris. Other topics,

During this Space Debris Impact Experiment, changes can be seen in the prelaunch versus postlaunch color condition of Tray D06. Prelaunch, the center panel section has a pink tint and the end section panel is pale green. Postlaunch, the center panel has a green tint, and the end section panel has a pink tint. At the time of this experiment, there was no definitive explanation for the color changes in the panels.

such as forced de-orbiting of satellites, continue to be discussed in an international effort to control space debris. SEE ALSO Long Duration Exposure Facility (LDEF) (volume 2).

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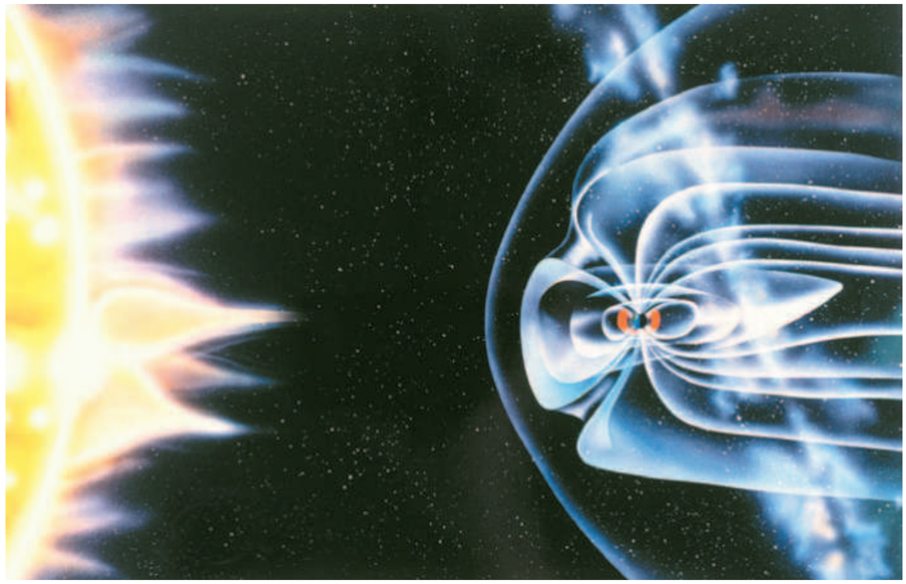
Space Environment, Nature of the

Near-Earth space is a complex, dynamic environment that affects not just objects in space, but our everyday lives as well. It exists as the interaction



This illustration of the space environment shows the Earth, surrounded by Van Allen Radiation Belts (orange) and its outlying magnetosphere, and solar ejections from the Sun.

of energy and mass from a variety of sources. Earth, with its magnetic field and its atmosphere, interacts with the Sun to form the solar-terrestrial system, which accounts for most of the effects of the near-Earth space environment. Deep space sources (e.g., other stars and galaxies) contribute particle and electromagnetic radiation that also interacts with Earth. Finally, there are solid bodies within and passing through the solar system that can and do interact with Earth. All of these systems affect orbiting artificial satellites and also have more direct effects on life on Earth, right down to the planet's surface.

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

wavelength the distance from crest to crest on a wave at an instant in time

ultraviolet radiation electromagnetic radiation with a shorter wavelength and higher energy than visible light

electrons negatively charged subatomic particles

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

The Sun's Interactions with Earth

The Sun is the greatest source of energy in the solar system. It drives most of the activity of the near-Earth space environment. Solar energy couples with Earth's atmosphere and surface, giving rise to terrestrial weather. In a similar way, **solar radiation** interacts with near-Earth space to give rise to space weather. The Sun continuously emits radiation in two primary forms: electromagnetic and particle.

The electromagnetic radiation emitted by the Sun spans the spectrum, from radio waves up through **infrared** and the visible light **wavelengths** to the ionizing energies of extreme ultraviolet, X-ray, and gamma radiation. **Ultraviolet radiation** is the familiar radiation that can burn human skin and fade curtains. Fortunately, the gases in Earth's atmosphere shield us from most ultraviolet radiation. It is the interaction of intense radiation, such as extreme ultraviolet radiation, that strips **electrons** from (or ionizes) the gases in the upper atmosphere, creating what is called the **ionosphere**. One example of how the ionosphere is affected by direct radiation by the Sun and by nighttime shielding by Earth is AM radio. At night, the thickness of the ionosphere shrinks. Radio waves then bounce off the bottom of the ionosphere at a higher altitude, giving these waves longer pathways to follow. This leads to the signals of certain AM stations reaching much larger areas at night than they do during the day.

The interaction of the Earth's magnetic field, Earth's upper atmosphere, and solar wind produces geomagnetic storms that produce the Aurora Australis (pictured here from space) and the Aurora Borealis.

Particle-type radiation from the Sun, referred to as the **solar wind**, consists primarily of electrons and protons that are thrust from the Sun's surface at speeds of hundreds of kilometers per second. These flowing charged particles constitute and interact with an interplanetary magnetic field. When these particles stream past Earth, they change the shape of Earth's magnetic field (called the geomagnetic field), creating a region called the magnetosphere, and affecting currents that flow about the planet. Charged particles are accelerated along the concentrated field lines at Earth's magnetic polls, generating eerie and beautiful auroral displays.

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun

Satellites are affected by the harsh radiation environment more directly. Penetrating charged particles can cause upsets in sensitive electronics components. Surface charge buildup and discharge can cause a wide variety of failures. Intense radiation can reduce the effectiveness of solar power arrays. And thermal expansion and contraction can cause mechanical failures.

Deep Space Contributions

Other sources that contribute to the near-Earth space environment include galactic cosmic ray particles, which originate from outside of the solar system. The higher the altitude, the less atmosphere there is to act as a shield, leading to greater exposure to these cosmic ray particles. A Geiger counter would detect a much higher number of such particles during an airplane flight than it would on the surface of Earth (away from radioactive sources, of course). For astronauts, the radiation hazards from all sources are serious. The National Aeronautics and Space Administration (NASA) monitors many different sources of information on the radiation environment to keep astronauts safe. Significant (though not complete) shielding can be afforded to spacewalking astronauts by simply having them go back inside their shuttle or space station.

Interactions with Comets and Asteroids

Comets and asteroids also contribute to the near-Earth space environment. Comets pass through the solar system, sometimes repeatedly because of their

THE IMPACT OF SOLAR FLARES

With fair frequency, the Sun's surface erupts with solar flares, which send intense bursts of electromagnetic radiation into space. If directed at Earth, this radiation heats the atmosphere, expanding gases into higher altitudes, which increases drag on low Earth orbiting satellites. This radiation also generates more charged particles in the ionosphere, affecting the reflection and transmission paths of radio frequencies used by satellites and ground-based communications. Since the space-based global positioning system uses radio frequency signals, navigation errors are also introduced.

orbits. Both forms of solar radiation act on these dirty snowballs in space. As comets come near the Sun, the absorbed heat and solar wind pressure cause particles to come loose from the comet.* Solid particles of ice and rock (**meteoroids**) blown off by the Sun stay suspended in the comet's orbital path. When that path is close to our own orbit around the Sun, Earth will collide with these particle streams, giving rise to our annual **meteor** showers. While most of these particles are very small and carry very little mass, they pose yet another hazard to our satellites. Though immediate failure from meteoroid impacts seldom occurs, the continuous bombardment of these grains of sand have a degrading effect on satellite surfaces. For example, they chip and crack the **cover glass** on solar panels, making them less efficient. Pitting allows atomic oxygen, present in low Earth orbits, to react with an exposed surface, causing corrosion and reducing the serviceable lifetimes of satellites.

***Solar wind is responsible for the direction of a comet's tail, which always points away from the Sun.**

meteoroid a piece of interplanetary material smaller than an asteroid or comet

meteor the physical manifestation of a meteoroid interacting with Earth's atmosphere; this includes visible light and radio frequency generation, and an ionized trail from which radar signals can be reflected

cover glass a thin sheet of glass used to cover the solid state device in a solar cell

perturbations term used in orbital mechanics to refer to changes in orbits due to "perturbing" forces, such as gravity

Meteoroids can also come from outside the solar system (sporadics) or from other Sun-orbiting bodies, such as asteroids. The main asteroid belt lies between Mars and Jupiter, and may be the remnants of what would have been another planet that never formed in the solar system. While most of these stay in safe orbits away from Earth, some have made their way into Earth-crossing orbits, perhaps through collisions and gravitational **perturbations**. Such objects have been known to collide with Earth over time and are expected to do so in the future. An asteroid as small as 0.5 to 1 kilometer (0.3 to 0.6 mile) in diameter impacting Earth can cause significant immediate and long-lasting damage. It is believed that a somewhat larger event may be responsible for the extinction of the dinosaurs and the destruction of perhaps one-fourth of all life on Earth about 65 million years ago. Another major impact event occurred in Siberia in 1908. What may have been a small asteroid exploded over the Tunguska forestlands, laying flat hundreds of square kilometers of trees. Evidence of these large impact events exists in the form of the craters they have left on Earth.

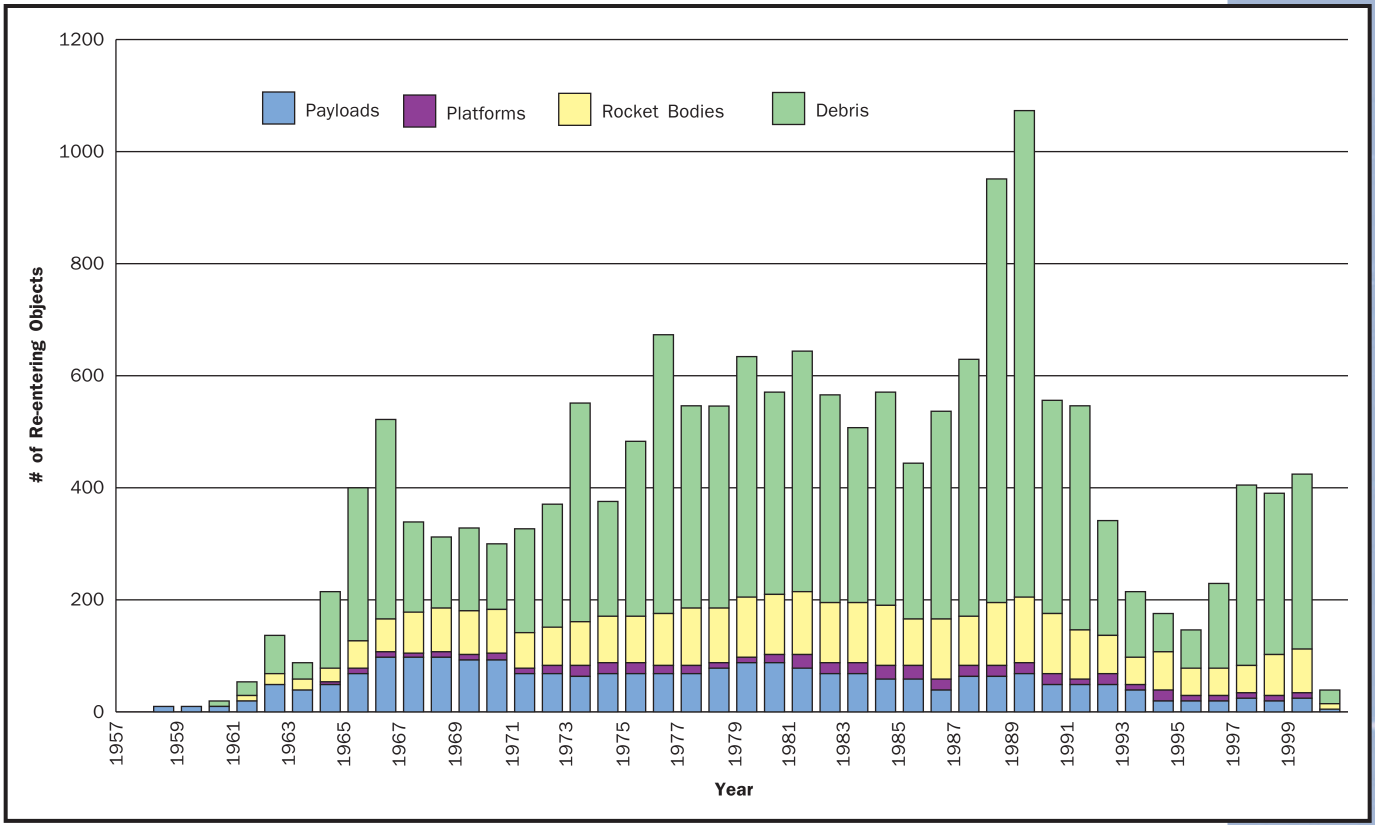
Recognizing that such events are very rare but may occur and cause great catastrophe, in the early 1990s the U.S. Congress formalized a scientific effort called Planetary Defense to look for near Earth objects (NEOs) that might collide with Earth. Since that time, many NEOs have been discovered. Major impacts are certain to occur in the future, but it is hard to say when.

CORONAL MASS EJECTIONS

In addition to solar flares, another frequently occurring solar event is the coronal mass ejection, in which the Sun sends concentrated bursts of solar wind into space. These events typically generate the equivalent energy of several atomic bombs. If Earth is in the path of the increased solar wind from one of these events, a geomagnetic storm may occur as a result of the solar wind distorting Earth's magnetic field (the magnetosphere). Such storms have been responsible for power system failures on Earth, including a major blackout in Quebec, Canada, on March 13, 1989, which left six million people without power for nine hours.

Space Debris: A Growing Concern

Finally, humankind itself contributes to our near-Earth space environment through launch and space activities over the years. Space debris from such activities is a growing concern. Windows on the space shuttle are replaced regularly because of chipping caused by collisions with small pieces of space junk or by natural meteoroid strikes. Collision risk during launch, orbit, and reentry operations continues to rise. Larger objects in low Earth orbits (rocket boosters, space stations, etc.) eventually fall back through Earth's atmosphere, posing a small, yet real risk to human life. Debris objects actually reenter the atmosphere quite frequently. Observers often mistake these reentering objects for meteors or UFOs. A woman named Lottie Williams may have the distinction of being the first person to be hit by reentering space debris. While her claim of being hit on the shoulder by a small piece



of a Delta II rocket may be difficult to verify, the piece of debris that she claims hit her has been verified to be from just such an object. SEE ALSO Asteroids (volume 2); Close Encounters (volume 2); Comets (volume 2); Cosmic Rays (volume 2); Solar Particle Radiation (volume 2); Space Debris (volume 2); Sun (volume 2); Weather, Space (volume 2).

David Desrocher

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Spacecraft Buses

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The structural body and primary system of a space vehicle is commonly referred to as a spacecraft bus. The spacecraft bus is used as a transport mechanism for a spacecraft **payload** much like an ordinary city bus is a transport vehicle for its passengers. Although each spacecraft payload may be quite different from another, all spacecraft buses are similar in their makeup. The spacecraft bus consists of several different subsystems, each with a unique purpose. The structural subsystem consists of the primary structure of the spacecraft, and supports all the spacecraft hardware, including the payload instruments. The structure, which can take various forms depending on the requirements of the particular mission, must be designed to minimize mass and still survive the severe forces exerted on it during launch and on its short trip to space.

The electrical power subsystem provides power for the payload, as well as the rest of the bus. This is usually achieved through the use of solar panels that convert solar radiation into electrical current. The solar panels sometimes must be quite large, so they are hinged and folded during launch then deployed once in orbit. The subsystem also may consist of batteries for storing energy to be used when the spacecraft is in Earth's shadow. Another major subsystem is command and data handling, which consists of the computer "brain" that runs the spacecraft, and all the electronics that control how data is transported from component to component. All other subsystems "talk" to this subsystem by sending data back and forth through hundreds of feet of wiring carefully routed throughout the spacecraft bus.

The communications subsystem contains components such as receivers and transmitters to communicate with controllers back on Earth. Many operations the spacecraft must perform are controlled through software commands sent from Earth by radio signals. Another important subsystem is the attitude control subsystem. This consists of specialized sensors able to look at the Earth, Sun, and stars to determine the exact position of the spacecraft and the direction in which it should point. Many operations spacecraft perform require very precise pointing, such as positioning imaging satellites that must point at specific spots on Earth.

In order to adjust the orbit to maintain the spacecraft in orbit for many years, a propulsion subsystem is sometimes required. There are many types of propulsion systems, but most consist of various types of rocket thrusters, which are small engines that burn special fuel to produce thrust. One additional crucial subsystem worth discussion is the thermal control subsystem, which maintains the proper temperatures for the entire spacecraft bus and all its components. This is achieved through the use of small heater strips,

Typical spacecraft bus (High Energy Solar Spectroscopic Imager [HESSI] built by Spectrum Astro, Inc., for NASA).

special paints and coatings that either reflect or absorb heat from Earth and the Sun, and multi-layered insulation blankets to protect from the extreme cold of space. SEE ALSO Exploration Programs (volume 2); Government Space Programs (volume 2); Robotic Exploration of Space (volume 2); Sensors (volume 2); Solid Rocket Boosters (volume 3).

Kevin Jardine

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Spaceflight, History of

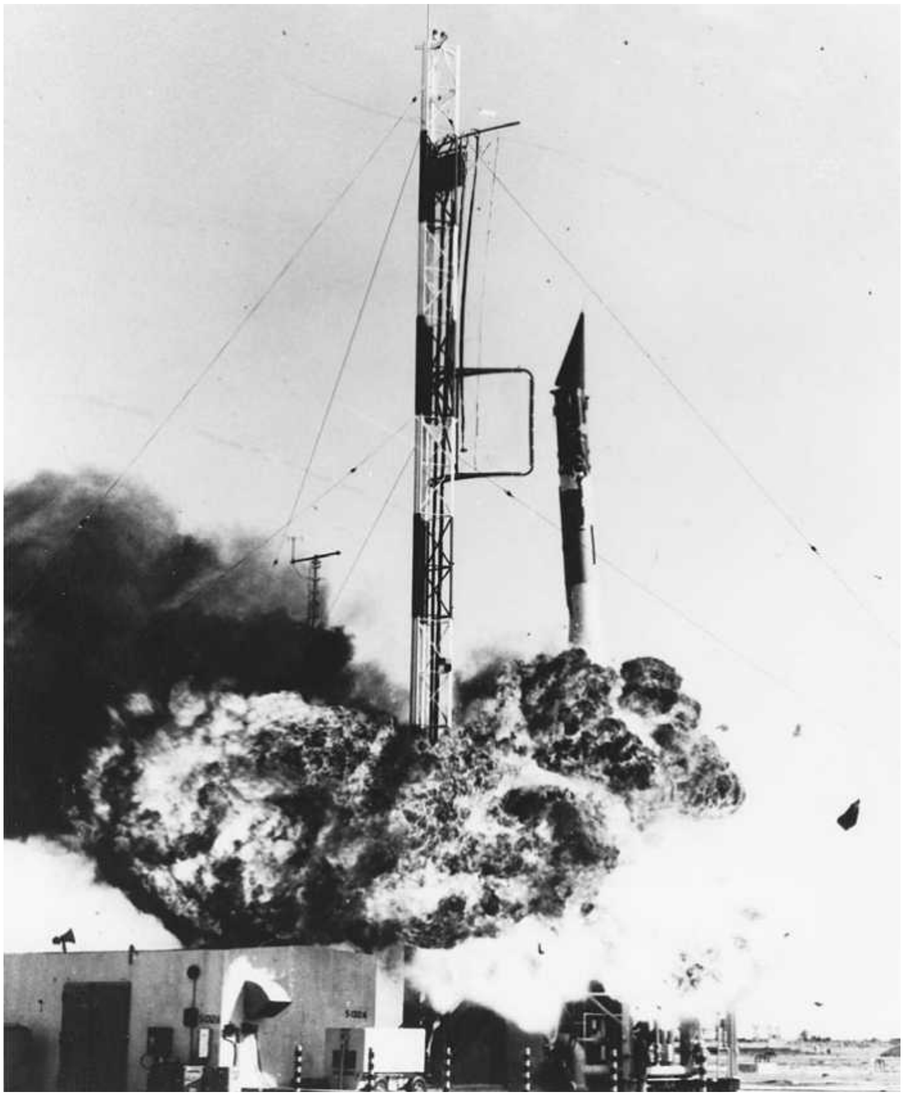
On October 4, 1957, the Union of Soviet Socialist Republics (USSR) launched a rocket that inserted a small satellite into orbit around Earth. Three months later, on January 31, 1958, the United States launched a satellite into a higher Earth orbit. Most historians consider these two events as denoting the beginning of the space age. This new age historically marked the first time that humans had been able to send objects—and, later, themselves—into outer space, that is, the region beyond the detectable atmosphere. The flight of machines into and through space, while a product of mid-twentieth-century technology, was a dream held by scientists, engineers, political leaders, and visionaries for many centuries before the means existed to convert these ideas into reality. And while the USSR and United States first created the enabling space technologies, the ideas that shaped these machines spanned other continents and the peoples of many other nations. The idea of spaceflight, like the capabilities that today's spaceships and rockets make possible, belongs to humanity without the limitations of any single nation or people.

The Origins of Spaceflight

The ideas that gave birth to spaceflight are ancient in origin and international in scope. Like many such revolutionary concepts, spaceflight was first expressed in myth and later in the writings of fiction authors and academicians. The Chinese developed rudimentary forms of rockets, adapted from solid gunpowder, as devices for celebrations of religious anniversaries. In 1232 China used rockets for the first time as weapons against invading Mongols. A decade later, Roger Bacon, an English monk, developed a formula for mixing gunpowder into controlled explosive devices. In the eighteenth century, British Captain Thomas Desaguliers conducted studies of rockets obtained from India in an attempt to determine their range and capabilities. In the nineteenth century William Congrieve, a British colonel, developed a series of rockets that extended the range of the rockets developed by India and that were adapted for use by armies. Congrieve's rockets were used in the Napoleonic wars of 1806. The nineteenth century would see the growth of the technology of solid-fueled rockets as weapons and the wider application of their use.

In 1857 a self-taught Russian mathematics teacher, Konstantin Eduardovich Tsiolkovsky, was born. Over the next eight decades, his writings and teachings would form the basis of modern spaceflight goals and systems, including multistage rockets, winged shuttlecraft, space stations, and interplanetary missions. Upon his death in Kaluga, Russia, on September 19, 1935, Tsiolkovsky would be considered one of the major influences upon space technology and later became known as the "Father" of the Soviet Union's space exploration program.

During the same period, the idea of space travel received attention in the form of fiction writings. The French science fiction author Jules Verne penned several novels with spaceflight themes. In his 1865 novel *From the Earth to the Moon*, Verne constructed a scenario for a piloted flight to the Moon that contained elements of the future space missions a century later, including a launching site on the Florida coast and a spaceship named Co-



During a test of the Vanguard rocket for the United States Geophysical Year, a first stage malfunction causes a loss of thrust, resulting in the destruction of the vehicle on December 6, 1957.

lumbia, the same name chosen for the Apollo 11 spaceship that made the first lunar landing mission in July 1969. In his 1869 novel *The Brick Moon* and an 1870 sequel *Life in the Brick Moon*, American writer Edward Everett Hale predicted the first uses for an orbiting space station, including military and navigation functions. These novels, first published in the *Atlantic Monthly* magazine, address issues related to permanent spaceflight and satellite observations of Earth.

Twentieth Century Development of the Liquid-Fueled Rocket

In the early years of the twentieth century, American academician Robert Goddard developed the first controlled liquid-fueled rocket. Launching from a rudimentary test laboratory in Auburn, Massachusetts, on March 16, 1926, his rocket flights and test stand firings advanced the technology of rocketry. In Europe, rocket enthusiasts formed the Society for Space Travel to better promote rocket development and space exploration themes. Members of the group included Hermann Oberth, whose writings and space advocacy would include engineering and mathematical models for interplanetary rocket flights, and Wernher von Braun, who designed the Saturn V booster that carried Apollo spacecraft to the Moon. Germany also paid for rocketry research conducted by Austrian engineer Eugen Sänger. Sänger and his research assistant (and later his wife) Irene Brendt contributed studies on advanced winged cargo rockets that were the forerunners of today's space shuttles. In the Soviet Union, academician Valentin P. Glushko developed the USSR's first liquid propellant rockets.

Although there were many others as well whose works detailed different types of space vehicles, space missions, and space utilization, the basis of many of the space launch vehicles of the twentieth century arose from the work of von Braun, who was subsidized by the German government during World War II (1939–1945). Working at a laboratory and launching complex called Peenemünde on the Baltic coast, von Braun and his associates developed the first **ballistic** missiles capable of exiting Earth's atmosphere during their brief flights. The most advanced of these designs was called the V-2. On October 3, 1942, the first of the V-2 rockets were successfully launched to an altitude of 93 kilometers (58 miles) and a range of 190 kilometers (118 miles). The successful test was referred to by German Captain Walter Dornberger, von Braun's superior at the Peenemünde complex, as the "birth of the Space Age," for it marked the first flight of a missile out of the atmosphere, in essence the world's first spaceship. While von Braun's task was to develop military weapons, he and his staff stole away as much time as possible to work on rocket-powered spaceship designs, a fact that was discovered by the German military. This discovery led von Braun to be briefly imprisoned until he was able to assure the Nazi military that the energy of his workers was directed toward weapons and not planetary rocket flights.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

After the war ended in 1945, von Braun, his engineers and technicians, his unfired inventory of V-2 rockets, and his research data formed a treasure trove of space and rocketry concepts for both the United States and the Soviet Union. Von Braun himself and much of his team came to the United States, bringing along a good portion of the German rocketry archive and many V-2 rockets and rocket parts. Others of the von Braun group and some of the V-2 missiles and data were captured by the Soviet government. These two elements of the former German rocketeers led to major advances for the space enthusiasts of the United States and USSR. Beginning in January 1947, at a site located at White Sands, New Mexico, von Braun modified his V-2 rockets for scientific flights to the upper atmosphere. In the Soviet Union, Sergei Korolev undertook similar testing, using the captured V-2s. Over the next decade, data gained from firings of the V-2s led each nation to develop its own rocket and space vehicle designs.

Space Program Development

In the Soviet Union, a ballistic missile called the R-7 was the first design to emerge from the early Soviet rocket programs that was powerful enough to strike targets in the United States or to insert satellites into Earth orbits. In the United States, a series of intermediate, medium, and intercontinental missiles emerged from the drawing boards. These had names such as Thor, Redstone, Atlas, and Titan. Along with the R-7, these missiles became the foundation of space-launching vehicles used by both nations to send the first satellites, probes, and human beings into space. Once begun on October 4, 1957, this so-called space race for dominance of the space environment was a defining element of the Cold War between the two superpowers. Rocketry gave each nation both a means to carry destructive nuclear weapons to the soil of the other country and a means of gaining scientific exploration of space. This race eventually formed up around four major elements: humans in space, advanced space exploration, reusable spaceflight, and permanent spaceflight.

The early humans in space efforts saw leadership by the Soviet Union. On April 12, 1961, using a version of the R-7 missile, the Soviet Union launched the first human, Air Force Major Yuri Gagarin, into orbital flight around Earth. Sealed inside a single seat in the space capsule Vostok 1, Gagarin completed a single orbit before descending under parachute for a landing in the Soviet Union (Gagarin himself actually ejected from the capsule's cabin before it landed in a field about ninety minutes after liftoff). The United States followed with more limited suborbital flights of astronauts Alan B. Shepard Jr. and Virgil I. "Gus" Grissom aboard single-seat Mercury spacecraft named Freedom 7 and Liberty Bell 7 on May 5 and July 19, 1961. Throughout 1961, 1962, and 1963 the United States and the USSR launched astronauts and cosmonauts into Earth orbit aboard these limited craft.

Beginning in 1965, the United States launched a two-seat space capsule called Gemini using larger Titan II missiles. The Soviet Union continued to launch Vostok capsules, modified to carry two and three persons. But the American Gemini craft were more capable, performing rendezvous and docking and long-duration space missions. This era of advanced human spaceflight now centered on a race between the superpowers to send a human expedition to the Moon's surface.

The Americans announced a program to land astronauts on the Moon called Project Apollo. The United States initiated a series of advanced space vehicles, including a new three-seat capsule capable of maneuvering between Earth and the Moon, a lunar landing craft that could carry two astronauts to the Moon's surface, and a family of advanced space rockets not based on earlier missile designs. The Soviets began a series of advanced rocket designs and a series of advanced Earth-orbiting space capsules called Soyuz. A lunar landing program was also underway in secret in the Soviet Union. But from 1965 to 1969 the Americans maintained a lead in human space missions that included the first space rendezvous and docking of two craft in orbit and long-duration spaceflights of one and two weeks in duration. Following the first walk in space performed during the Soviet Voshkod 2 mission in March 1965, American spacewalkers achieved extensive data on working outside space vehicles, considered key learning steps before astronauts could walk on the Moon's surface. But both nations suffered casualties during this peaceful scientific race. In January 1967, the first crew of an Apollo flight, Apollo 1, was killed in a launch pad fire. In April 1967 the first cosmonaut testing the Soyuz capsule was killed during a reentry mishap. Gradually, however, the United States was pulling ahead in the lunar race.

Using the lifting power of the Saturn rockets, the United States sent the first astronauts beyond Earth to lunar orbit in December 1968. The following summer, Apollo 11 and its crew of astronauts Neil A. Armstrong, Edwin E. "Buzz" Aldrin Jr., and Michael Collins were launched toward the

Moon and on July 20, 1969, accomplished the first of six piloted landings. The Soviets were forced to abandon their lunar landing program because of continued malfunctions of the large N-1 lunar booster. No Russian cosmonauts ever made the attempt.

Instead, the Soviet space program redefined itself by the development of semipermanent space stations. The first in this series, called Salyut, was launched in 1971. Eventually the experience gained in the Salyut space station series led the Soviets to develop a larger and more expandable station complex called Mir. The Mir space station, resupplied by both Soyuz rockets and U.S. space shuttles, provided valuable long-duration space experience from 1986 to the spring of 2001 when the Mir complex was successfully and safely deorbited.

Both the U.S. and Soviet programs explored space with robotic probes. The Soviets were successful in accomplishing landings on Venus with an unmanned probe called Venera. Soviet robots also landed on the Moon and returned lunar soils to Earth for analysis by Russian scientists. The United States successfully accomplished robotic landings on Mars in 1976 and 1997 in the Viking and Mars Pathfinder programs.

An era of reusable space vehicles began in April 1981 with the first launch of the partially reusable space shuttle. From 1981 through 2001 more than 100 flights of the shuttles were accomplished. Only one, the launch of space shuttle Challenger on January 28, 1986, was unsuccessful and resulted in the loss of the spacecraft and the entire crew of seven astronauts. Following the accident, the shuttles were redesigned and returned to safe spaceflight. A Soviet shuttle project called Buran was abandoned in 1993 because of the collapse of the Russian economy. Construction of a permanent space station began in 1998. The project brought together sixteen international partners, including Russia and the United States.

As the twenty-first century began, space activities assumed more of an international and commercial flavor, begetting a process of evolution and change as old as the idea of spaceflight itself. SEE ALSO Apollo (volume 3); Government Space Programs (volume 2); International Cooperation (volume 3); International Space Station (volume 3); Mir (volume 3); NASA (volume 3).

Frank Sietzen, Jr.

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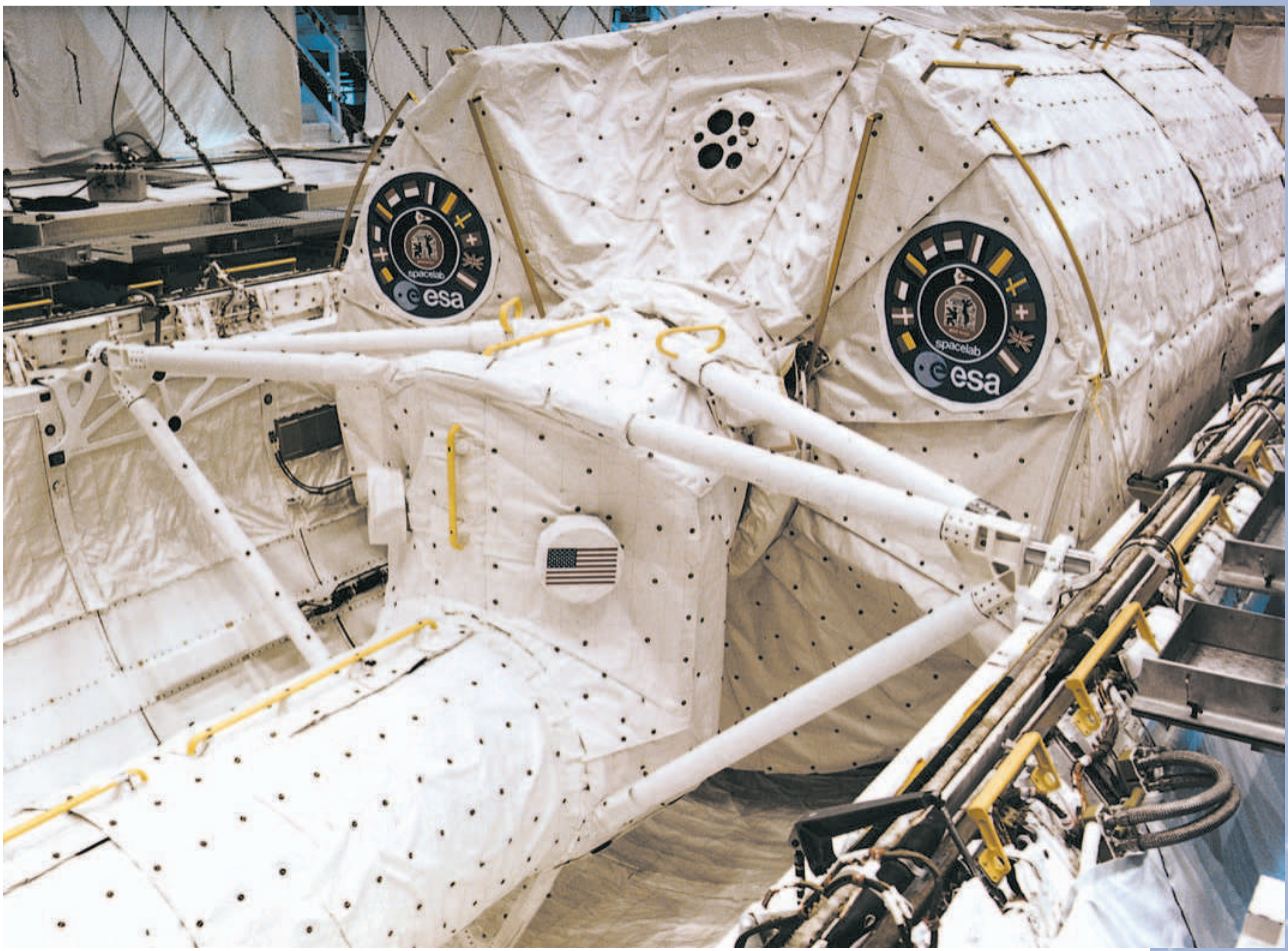
Spacelab

Spacelab was a cylindrically shaped reusable laboratory carried aboard the space shuttle that was designed to allow scientists to perform experiments in **microgravity** conditions while orbiting Earth. It was designed and de-

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

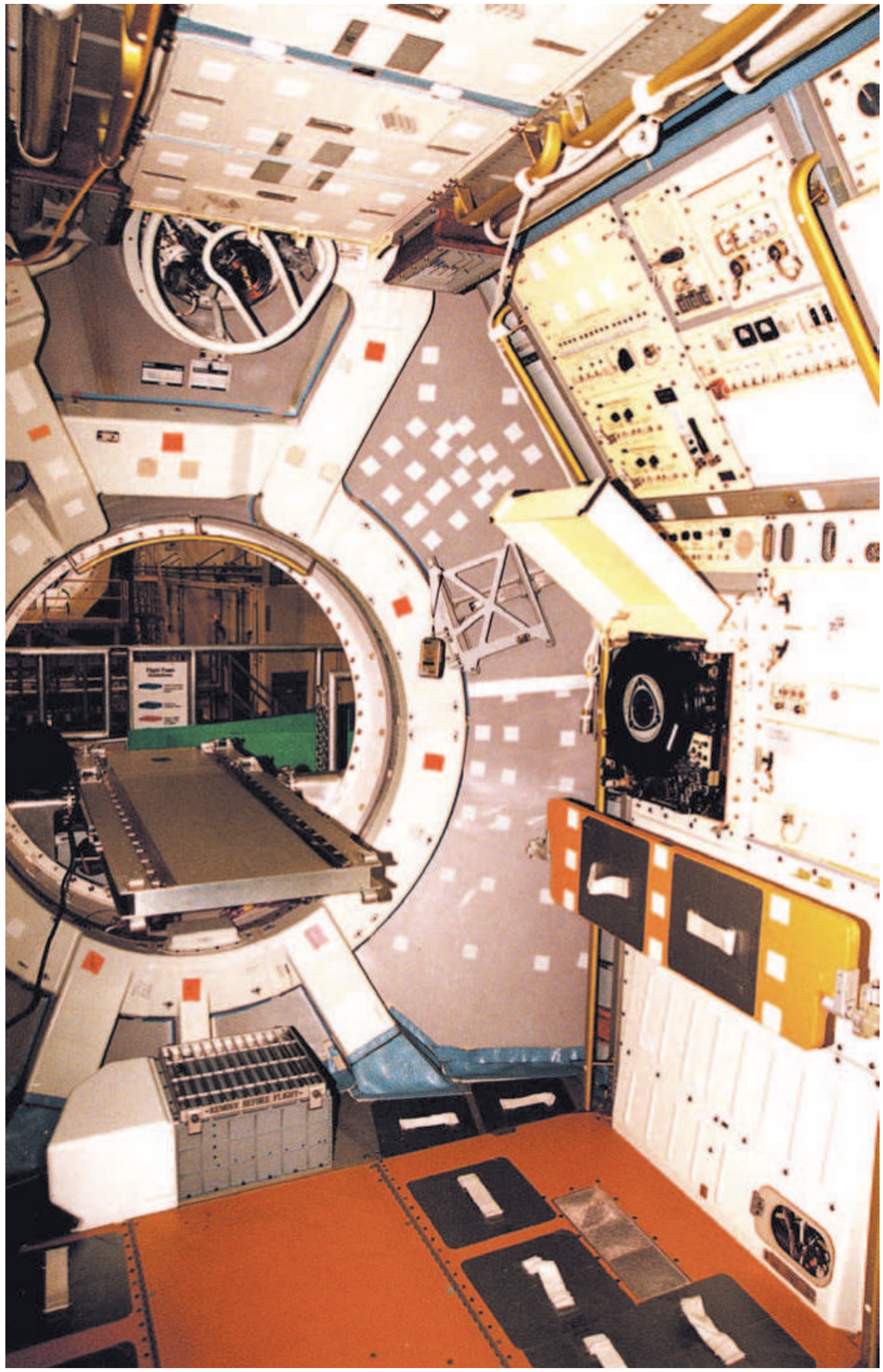


An access tunnel joins with the Spacelab 1 module in the cargo bay of the space shuttle Columbia at the Kennedy Space Center. Spacelab was a reusable laboratory carried aboard the space shuttle, which was designed to allow scientists to perform experiments in microgravity conditions.

veloped by the European Space Agency (ESA) in cooperation with the National Aeronautics and Space Administration's (NASA) George C. Marshall Space Flight Center. Cradled in the shuttle's spacious cargo bay, Spacelab was used on numerous shuttle missions between 1983 and 1997. In addition to the United States, countries like Germany and Japan also conducted dedicated Spacelab missions.

Spacelab Components

Spacelab was developed as a modular structure with several components that could be connected and installed to meet specific mission requirements. For each mission, Spacelab components were assembled and placed into the shuttle's cargo bay at Kennedy Space Center (KSC) in Florida. Its four principal components consisted of the pressurized module, which contained a laboratory with a shirt-sleeve working environment; one or more open pallets that exposed materials and equipment to space; a tunnel to gain access to the module from the shuttle; and an instrument pointing subsystem.



An interior view of an empty Spacelab module, prior to its move to the National Air and Space Museum in Washington, D.C., September 22, 1998.

The pressurized module, or laboratory, provided a habitable environment for the crew. It was available in several configurations that included either one segment (core) or two segments (core and experiment) that could be reused for up to fifty missions. The core segment contained supporting systems, such as data processing equipment and utilities for the pressurized module and pallets. Inside the module, laboratory equipment was mounted in racks and other areas. The laboratory also had fixtures, such as floor-mounted racks and a workbench. The so-called "experiment segment," provided more working laboratory space and contained only floor-mounted racks.

Together, the core and experiment segments were approximately 7 meters long. Added to this assembly were U-shaped pallets located outside the pressurized module. The pallets were often used on Spacelab missions for mounting instrumentation, large instruments, experiments needing exposure to space, and instruments requiring a large field of view, such as telescopes.

Conducting Experiments on Spacelab

Scientists onboard Spacelab included mission specialists and **payload specialists**, who were primarily scientists, not career astronauts. To make working in space easier, handrails were mounted on the racks and overhead. Foot restraints were also provided on the floor and on rack platforms. During some missions, the crew split into two twelve-hour shifts, allowing research to continue around the clock.

payload specialists scientists or engineers selected by a company or a government employer for their expertise in conducting a specific experiment or commercial venture on a space shuttle mission

Each Spacelab mission required years of planning. Before each mission, support personnel developed a timeline for conducting experiments, and worked closely with the principal investigators to make sure the resources for each experiment were available. In addition, scientists on the ground could follow the progress of experiments aboard Spacelab using television and computer displays from orbit. Earth-bound scientists also could command experiments, and talk with the crew.

Spacelab Research

Research into many fields of science was performed aboard Spacelab. Experiments on Earth's atmosphere included research into atmospheric chemistry, energy, and dynamics. In addition, Spacelab was used to correlate atmospheric data from satellites. The space-based laboratory also provided an ideal platform to conduct experiments on space plasma. From orbit, scientists could closely observe the electrified gases in the **ionosphere** layer of the atmosphere.

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

Studies of the Sun were a major focus of Spacelab activities. Crews onboard Spacelab were able to observe all of the Sun's radiant energy. Using the instruments on Spacelab missions, astronomers obtained some of the best images of the Sun in both still photographs and videos. Additionally, sensitive **spectrometers** collected information on the chemistry and the physics of our nearest star. The images and spectral analysis contributed to the modeling of the Sun's dynamics and structure.

spectrometer an instrument with a scale for measuring the wavelength of light

wavelength the distance from crest to crest on a wave at an instant in time

Spacelab also allowed scientists to look farther into space and conduct sophisticated astronomical research. While in orbit, scientists had the opportunity to select targets, fine-tune their instruments based on the current conditions, and look at interesting events, just like an astronomer at a ground-based observatory. In addition, astronomers were able to view the universe at various **wavelengths**, including cosmic rays, **X rays**, **ultraviolet**, and **infrared**. Increasingly complex astronomical instruments were deployed with succeeding Spacelab missions, allowing scientists to increase the quality and quantity of data collected.

X rays a form of high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

Progress in materials science on Earth has been limited in some areas due to the effects of gravity. However, the microgravity condition on Spacelab provided scientists an opportunity to study how materials behave outside of the influence of Earth's gravity. Experiments conducted on Spacelab significantly advanced the science of material processing by providing a sustained microgravity environment for melting, combining or separating raw materials into useful products, and creating defect-free crystals.

semiconductors one of the groups of elements with properties intermediate between the metals and nonmetals

In addition, the microgravity environment in the Spacelab module allowed scientists to test basic theories and to develop new processing techniques. This research advanced the study of new metals and alloys, as well as protein crystals for drug research, electronics and **semiconductors**, and fluid physics. Improvements in processing developed on Spacelab might lead to the development of valuable drugs; high-strength, temperature resistant ceramics and alloys; and other improved materials.

Many life sciences experiments were also conducted aboard Spacelab. Scientists were able to study life from the simplest, one-celled forms such as bacteria, to larger, more complex systems such as animals and humans. The Spacelab module provided habitats for plants and animals, and most importantly, the trained scientists to perform experiments. Basic biology questions were investigated, as well as practical questions related human adaptation to space and the phenomena of "space sickness." Commercial and pharmacologic products were also produced in purer forms than ever before onboard Spacelab. At the same time, biological materials could be studied with great precision because crystals could be grown both larger and purer.

Spacelab's Contribution to Space Exploration

Over a 15-year period, Spacelab served as an orbiting laboratory that allowed scientists to study the universe, the Sun and Earth, and conduct materials and biologic experiments. During that time, Spacelab served as both a laboratory and an observatory as scientists could both stimulate the environment with active experiments and observe the effects. Work on Spacelab also provided a "dress rehearsal" into the types of activities that are currently performed on the International Space Station. SEE ALSO Crystal Growth (volume 3); International Space Station (volumes 1 and 3); Made in Space (volume 1); Microgravity (volume 2); Space Shuttle (volume 3).

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Stars

light year the distance that light in a vacuum would travel in one year, or about 5.9 trillion miles (9.5 trillion kilometers)

Stars are huge balls of very hot, mostly ionized, gas (plasma) that are held together by gravity. They form when vast agglomerations of gas and dust known as molecular clouds (typically 10 to 100 **light years** across) fragment into denser cores (tenths of a light-year across) that can collapse inward under their own gravity. Matter falling inward forms one or more dense, hot, central objects known as protostars. Rotation forces some of the matter to

Optical image of the Pleiades open star cluster in the constellation of Taurus. Stars are huge balls of very hot gas (plasma) that are held together by gravity.

accumulate in a disk rotating around the protostar(s). As gravity pulls rotating material inward, it spins faster, akin to what happens to figure skaters when they pull their initially outstretched arms in toward their bodies.

In order for material to fall onto a protostar from a rapidly spinning disk, it must slow down. Recent theoretical work suggests that this is accomplished through the interaction of the material with magnetic fields that thread the disks of protostars. Near the disk, the magnetic field is bent into an hourglass shape. Gas particles are flung off the rotating disk by **centrifugal** force, slowing the rotation of the disk. The ejected material is channeled into narrow jets perpendicular to the disk, while material from the disk falls onto the protostar. Planets may eventually form within the disk. The jets plow into the surrounding medium, sweeping up a **bipolar outflow** on opposite sides of the protostar. It is not yet known whether the final mass of a star is determined by the initial mass of the core in which it was born or from the clearing of material by bipolar outflows. In any case, the final mass of the star determines how it will evolve from this point on.

centrifugal directed away from the center through spinning

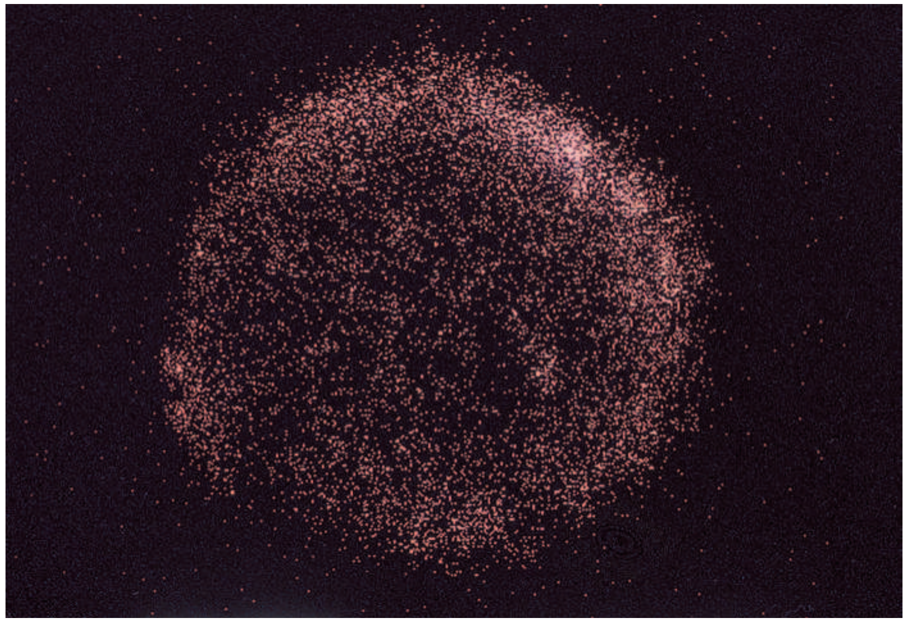
bipolar outflow jets of material (gas and dust) flowing away from a central object (e.g., a protostar) in opposite directions

Main Sequence Stars

When the star has accumulated enough material so that the temperature and pressure are high enough, nuclear **fusion** reactions, which convert hydrogen into helium, begin deep within the core of the star. The energy from the reactions makes its way to the surface of the star in about a million years, causing the star to shine. The pressure from these nuclear reactions at the star's core balances the pull of gravity, and the star is now called a main sequence star.

fusion releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

This name is derived from the relationship between a star's intrinsic brightness and its temperature, which was discovered independently by Danish astronomer Ejnar Hertzsprung (in 1911) and American astronomer Henry Norris Russell (in 1913). This relationship is displayed in a Hertzsprung-Russell diagram. A star's color depends on its surface temperature; red stars



Massive stars may explode in an event known as a supernova. This supernova in the constellation Cassiopeia was observed by astronomer Tycho Brahe in 1572.

are the coolest and blue stars are the hottest. The temperature, brightness, and longevity of a star on the main sequence are determined by its mass; the least massive main sequence stars are the coolest and dimmest, and the most massive stars are the hottest and brightest. Objects less than about one-thirteenth the mass of the Sun can never sustain fusion reactions. These objects are known as brown dwarfs.

Red Giants and Red Supergiants

Counterintuitively, the more massive a star is, the more rapidly it uses up the hydrogen at its core. The most massive stars deplete their central hydrogen supply in a million years, whereas stars that are only about one-tenth the mass of the Sun remain on the main sequence for hundreds of billions of years. When hydrogen becomes depleted in the core, the core starts to collapse, and the temperature and pressure rise, so that fusion reactions can begin in a shell around the helium core. This new heat supply causes the outer layers of the star to expand and cool, and the star becomes a red giant, or a red supergiant if it is very massive.

Planetary Nebulae, White Dwarfs, and Black Dwarfs

Once stars up to a few times the mass of the Sun reach the red giant phase, the core continues to contract and temperatures and pressures in the core become high enough for helium nuclei to fuse together to form carbon. This process occurs rapidly (only a few minutes in a star like the Sun), and the star begins to shed the outer layers of its atmosphere as a **diffuse** cloud called a planetary nebula. Eventually, only about 20 percent of the star's initial mass remains in a very dense core, about the size of Earth, called a white dwarf. White dwarfs are stable because the pressure of **electrons** repulsing each other balances the pull of gravity. There is no fuel left to burn, so the star slowly cools over billions of years, eventually becoming a cold, dark object known as a black dwarf.

diffuse spread out; not concentrated

electrons negatively charged subatomic particles

Supernovae, Neutron Stars, and Black Holes

After a star more than about five times the mass of the Sun has become a red supergiant, its core goes through several contractions, becoming hotter and denser each time, initiating a new series of nuclear reactions that release energy and temporarily halt the collapse. Once the core has become primarily iron, however, energy can no longer be released through fusion reactions, because energy is required to fuse iron into heavier elements. The core then collapses violently in less than a tenth of a second.

The energy released from this collapse sends a shock wave through the star's outer layers, compressing the material and fusing new elements and radioactive isotopes, which are propelled into space in a spectacular explosion known as a supernova. This material seeds space with heavy elements and may collide with other clouds of gas and dust, compressing them and initiating the formation of new stars. The core that remains behind after the explosion may become either a neutron star, as the intense pressure forces electrons to combine with **protons**, or a black hole, if the original star was massive enough so that not even the pressure of the neutrons can overcome gravity. Black holes are stars that have literally collapsed out of existence, leaving behind only an intense gravitational pull. SEE ALSO Astronomer (volume 2); Astronomy, Kinds of (volume 2); Black Holes (volume 2); Galaxies (volume 2); Gravity (volume 2); Pulsars (volume 2); Sun (volume 2); Supernova (volume 2).

protons positively charged subatomic particles

Grace Wolf-Chase

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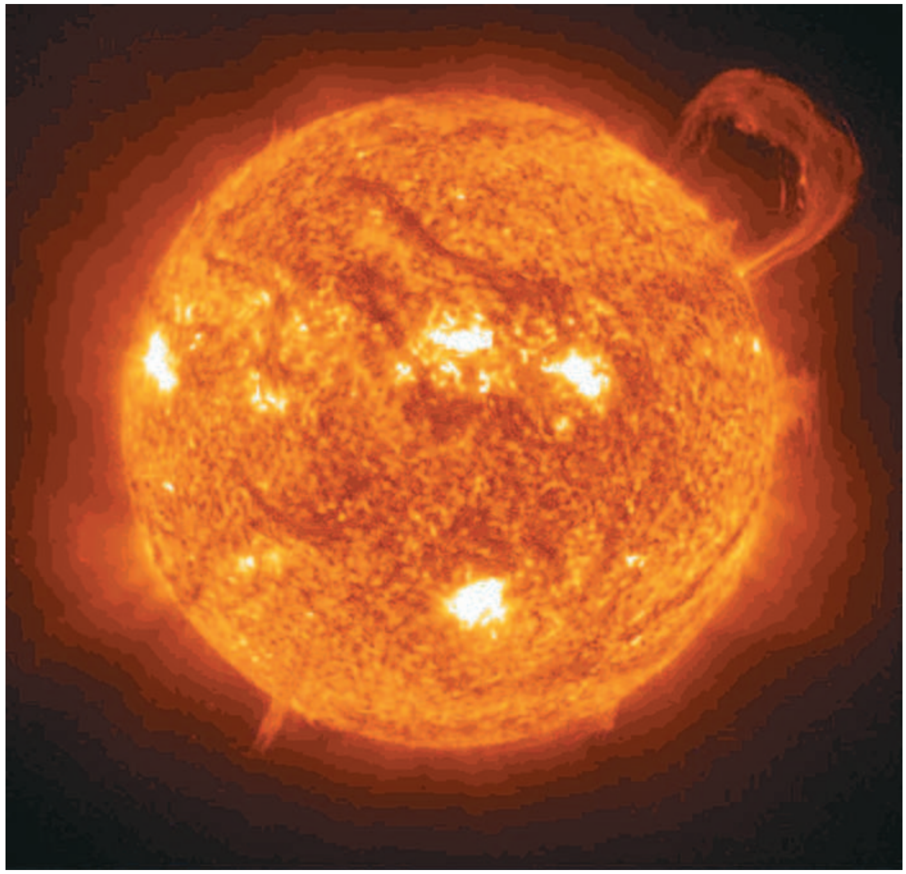
Sun

Of all of the astronomical objects, the Sun is the most important to human beings. Since the dawn of civilization, knowing the daily and annual behavior of the Sun has meant the difference between life and death for people learning when to plant crops and when to harvest. Ancient mythologies preserved this knowledge in story form. These were often picturesque descriptions of the Sun's behavior—for example, the Chinese interpretation of a solar eclipse as a dragon chasing and eating the Sun. Sometimes the stories included precise enough details for predicting solar behavior—for instance, in the version from India, the dragon is sliced into two invisible halves. When the position in the sky of one of these halves is lined up with the Sun and the Moon, an eclipse occurs.



A large, handle-shaped prominence is visible in this extreme ultraviolet imaging telescope (EIT) shot of the Sun. Prominences are giant clouds of relatively cool plasma suspended in the Sun's hot corona, which occasionally can erupt. The cooler temperatures are indicated by darker red areas, while the hottest areas appear almost white.

Solar Eclipses

Over centuries of observations and study, a scientific understanding of the Sun has grown out of these myths. The invisible dragon halves were a way of describing the serendipitous arrangement of the relative locations and sizes of Earth, the Moon, and the Sun. In order for a solar eclipse to happen, the Moon not only has to be in new phase (between the Sun and Earth) but also has to line up exactly with the disk of the Sun. Since the Moon's orbit around Earth is tilted with respect to Earth's orbit around the Sun, this happens about twice a year instead of once a month. Solar eclipses are not visible all over Earth, but only under the moving shadow of the Moon. In areas not completely covered by the Moon's shadow, observers see a "partial eclipse," which looks like a bite has been taken out of the Sun. Or, if the Moon is in the far reaches of its orbit it might not be quite big enough to cover the Sun's disk. Then observers would see the Sun shining in a thin, bright ring around the Moon in what is known as an "annular eclipse," even if they are perfectly lined up. Total eclipses of the Sun are rarely seen, because the timing and geometry have to be just right to position a large enough Moon-shadow right over a particular location. When this happens, observers in that location have an opportunity to observe parts of the Sun that are usually impossible to see.

Solar Corona

It is when the Sun is totally eclipsed that the solar corona is visible. "Corona" means "crown," and indeed the outer atmosphere of the Sun appears to encircle its blacked-out disk in an extended pearly crown. Ordinarily, the corona is so much dimmer than the bright disk of the Sun that it cannot be seen—even during a partial or annular eclipse. There is another way to see the corona, however, even without an eclipse. Although the part of the Sun seen with the naked eye normally outshines it, the corona is actually the brightest part of the Sun when observed with an X-ray telescope. The Sun emits light at a wide range of **frequencies**, or colors. Most of the light it emits is in the range visible to human eyes—the colors that make up a rainbow. Human eyes have actually adapted to be sensitive to the frequencies at which the majority of the sunlight shines. X rays are light emitted at much higher frequencies than humans can see, in the same way as a dog whistle blows at a frequency that is beyond the sensitivity of the human ear. An X-ray telescope filters out all the light from the Sun except X rays, and what is left is mostly the solar corona.

An eclipse of the Sun is photographed from the Apollo 12 spacecraft during its journey back to Earth from the Moon.

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

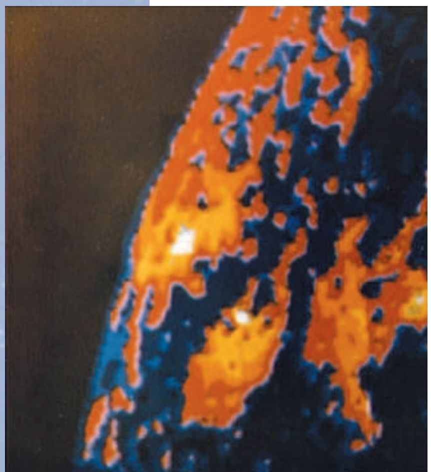
Because the corona shines in X rays we know it is very hot. This is strange. It means that although the temperature of the Sun decreases from its center out to its surface (from several million degrees Celsius down to several thousand), it increases again in the corona (up again to several million degrees). How and why the corona gets heated is one of the big mysteries of solar physics. It probably has to do with the energy that comes from magnetic fields generated inside the Sun, which is dumped into the corona, heating it up.

Sunspots and Magnetic Fields

Besides the more obvious daily and annual variations of the Sun, an approximately eleven-year cycle was discovered once people started observing with telescopes. This was first seen by counting the number of sunspots on the Sun. Sunspots are dark regions on the solar surface that are fairly infrequent during the minimum phase of the eleven-year solar cycle, but that become more and more common during the maximum phase. They are dark because they are cooler than their surroundings, and they are cool because they are regions of very strong magnetic field where less heat escapes the solar surface.

Sunspots are not the only solar features that are most abundant at solar cycle maximum. Explosive flashes known as "solar flares," and massive eruptions of material out from the Sun known as coronal mass ejections also become more and more frequent. The material that is hurled outward in a coronal mass ejection can affect us here on Earth, damaging satellites and even power stations, and potentially causing blackouts or disrupting satellite TV or cell phone transmissions. Like sunspots, flares and coronal mass ejections are related to solar magnetic fields. In general, magnetic activity increases at solar cycle maximum.

Magnetic fields are an important part of almost everything that is observed about the Sun. So where do they come from? The motions of sunspots provide a clue. Like Earth, the Sun is spinning so it has its own north pole, south pole, and equator. As they move around as the Sun spins, sunspots



The Sun is photographed here by the Apollo Telescope Mount through a spectroheliometer. The reds, yellows, and white areas are the Sun's corona, approximately 70,000 kilometers above its surface, while the black regions are the surface of the star.

near the solar equator return to their starting point in about twenty-five days. Sunspots near the north and south pole of the Sun, however, take about thirty-five days to spin all the way around. The reason for this difference is that the Sun is not solid like a baseball, but fluid—more like a water balloon. Just below the surface this fluid is vigorously boiling and churning around, and this motion causes different parts of the Sun to spin around at different speeds. Furthermore, all this churning and spinning creates a magnetic field that is pointing one way near the north pole of the Sun and the opposite way near the south pole, like a giant bar magnet. Every eleven years, this magnet flips upside down so that in twenty-two years it has flipped over twice and is back where it started. Solar minimum happens when the magnet is pointing either due north or due south, and solar maximum occurs while it is in the process of flipping over.

Inside the Sun

When we look at the Sun, we see only the outside; how do we know what is happening below the surface? It turns out we can use techniques that are similar to those used in studying earthquakes. The surface of the Sun is continuously vibrating like a never-ending earthquake or a bell that is constantly being rung. By looking at the pattern of these vibrations and their frequency (like the tone of the bell), we can figure out what the inside of the Sun must be like. Thanks in part to these vibrations, we can confidently say that the churning motions below the surface not only create magnetic fields and make the Sun spin at different speeds, but they also move heat from the center of the Sun to the surface, where it is radiated away as light.

Near the center of the Sun the churning motions stop and the fluid becomes very dense and hot. Hydrogen atoms fly around at incredible speeds and when they collide they can stick together, creating helium atoms. This process, which is called fusion, provides the energy that causes stars to shine. In some stars, fusion can convert hydrogen and helium into heavier elements, such as carbon, oxygen, and nitrogen, which can in turn be combined to make still heavier elements, such as iron, lead, and even gold! In fact, everything on Earth—air, water, dirt, rocks, buildings, cars, trees, dogs, and even people—is made of elements that were created in stars by fusion.

The Evolution of the Sun

As exciting as it is, the Sun is often referred to as an "ordinary" star. This means that the information gained from the vast array of solar observations can be applied to understanding many of the stars in the sky. Furthermore by studying similar stars at various stages of their lifetimes, astronomers can tell how the Sun formed and how it will eventually die.

The Sun and the solar system began as a huge clump of gas in space, mostly made of hydrogen with some helium and only a relatively small amount of everything else (carbon, oxygen, iron, etc.). This clump slowly condensed and heated up due to gravity, and eventually it became dense and hot enough that fusion began and it started to shine. Not all of the gas fell into the young Sun; some of it stayed behind and was flattened into a pancake-like disk because it was spinning (just as a skilled pizza cook can flatten a clump of dough by tossing and spinning it). This disk then broke up into smaller clumps, which eventually became Earth and the other planets.

Meanwhile, the Sun settled down to a quieter life, slowly converting hydrogen into helium by fusion and shining the energy away into space. That was about 5 billion years ago and the Sun is still going strong.

The Sun's Future

But that is not the end of the story. Eventually, there will not be any hydrogen left in the center of the Sun to make helium. Gravity will then cause the center part of the Sun to collapse in on itself, and the energy given off by this implosion will cause the outer part to inflate. So, while the inner part of the Sun shrinks, the outer part will expand, and it will become so big that it will envelop Mercury, Venus, and even Earth.

The Sun will then continue its life as a red giant star, but not for long. As its last hydrogen is used up, the center of the Sun will heat up and start to convert helium into other elements in a last-ditch effort to keep fusion going and to keep shining. The available helium will be used up relatively quickly, however, and before long all fusion in the center will stop. The outer part of the Sun will then slowly expand and dissipate into space while the inner part will become a white dwarf, a relatively small, inactive lump of matter, which will slowly cool down as it radiates all its remaining energy into space. Life on Earth would not survive these events—but as this terrible fate is not due to happen for another 5 billion years, we have plenty more time to study the Sun in all its splendor! SEE ALSO Cosmic Rays (volume 2); Solar Particle Radiation (volume 2); Solar Wind (volume 2); Space Environment, Nature of (volume 2); Stars (volume 2); Weather, Space (volume 2).

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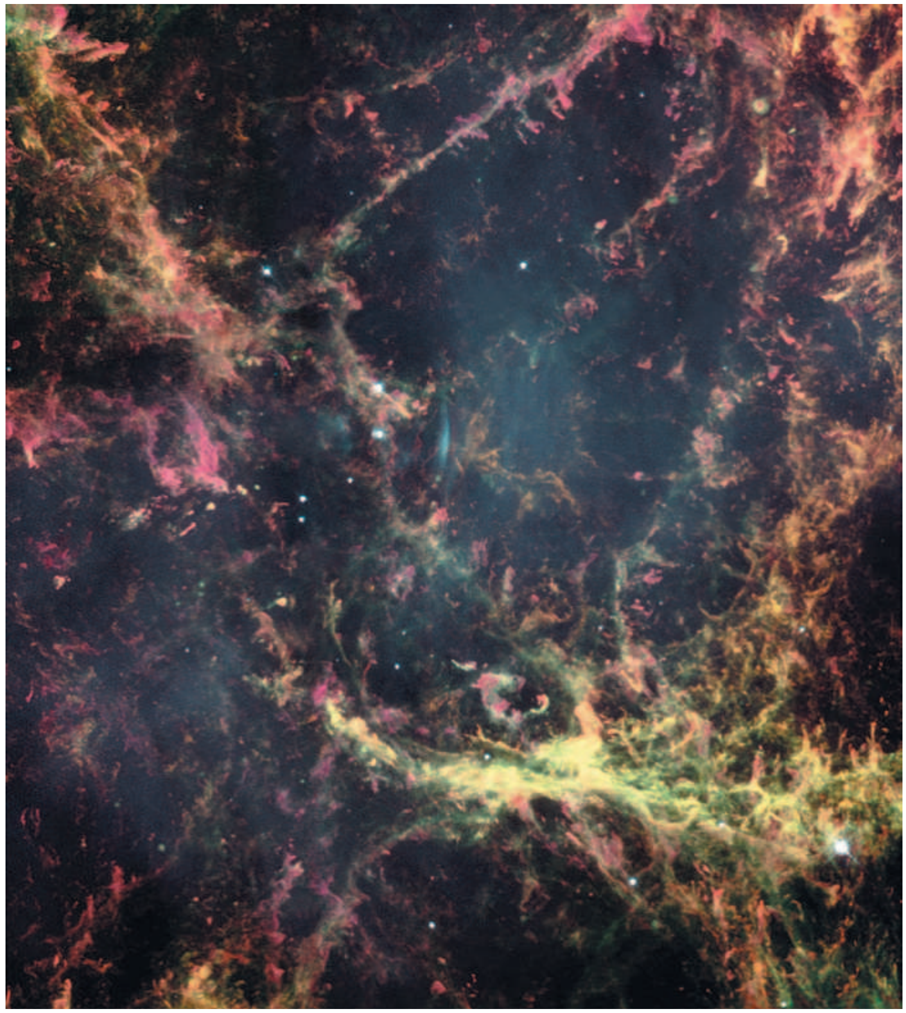
Supernova

As stars age, many use up their fuel and fade away to oblivion. Others, however, go out with a bang as supernovae, releasing energies of up to 10^{44} joules—an amount of energy equivalent to 30 times the power of a typical



The center of the Crab Nebula as viewed by the Hubble Space Telescope. The Crab was created by a supernova explosion on July 4, 1054, and is located approximately 6,500 light years from Earth.

accretion the growth of a star or planet by accumulation of material from a companion star or the surrounding interstellar matter

spectra representations of the brightness of objects as a function of the wavelength of the emitted radiation

nuclear fusion the combining of low-mass atoms to create heavier ones; the heavier atom's mass is slightly less than the sum of the mass of its constituents, with the remaining mass converted to energy

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

nuclear bomb. The explosions of low-mass stars can be triggered by the **accretion** of mass from a companion star in a binary system to create classical, or Type Ia, supernovae. These supernovae show no hydrogen in their **spectra**. Massive stars, on the other hand, proceed through normal **nuclear fusion** but then, when their energy supply runs out, there is no outward pressure to hold them up and they rapidly collapse. The core is crushed into a neutron star or black hole, and the outer layers bounce and are then hurled outward into the surroundings at many million kilometers per hour. These are Type Ib and II supernovae. The Type II supernovae still eject some hydrogen from the unprocessed atmosphere of the star. During a supernova explosion, temperatures are so high that all the known elements can be produced by nuclear fusion.

The most recent supernova that was close enough to be seen without a telescope occurred in early 1987 within a nearby **galaxy**, the Large Magellanic Cloud. Known as 1987A, it is the only supernova for which there is accurate data on the **progenitor star** before it exploded. It has been a tremendous help in understanding how stars explode and expand.

The rapidly growing surface of the star can brighten by up to 100 billion times. Then, as the material gets diluted, it becomes transparent and the brightness fades on time scales of a few years. The **ejecta** are still moving rapidly, however, and quickly sweep up surrounding matter to form a shell that slows down as mass gets accumulated, an action similar to that of a snowplow. This is the beginning of the supernova remnant that can be visible for tens of thousands of years. 1987A is starting to show such interaction with its surroundings.

Supernova remnants emit various forms of radiation. The material is moving highly supersonically and creates a shock wave ahead of it. The shock heats the material in the shell to temperatures over 1 million degrees, producing bright **X rays**. In the presence of **interstellar** magnetism, shocks also accelerate some **electrons** to almost the speed of light, to produce strong **synchrotron radiation** at radio **wavelengths**. Sometimes, even high-energy **gamma rays** can be produced. Dense areas can also cool quickly and we observe filaments of cool gas, at about 10,000 degrees, in various **spectral lines** at optical wavelengths.

In 1054 astronomers in China and New Mexico observed a famous example of the explosion of a massive star. What remains is a large volume of material that, with a lot of imagination, looks like a crab and, hence, is named the Crab Nebula. The object is being stimulated by jets from a rapidly spinning (about thirty times a second) neutron star called a pulsar. In most supernova remnants, this pulsar wind nebula is surrounded by the shell discussed above, but remarkably, no one has yet detected the shell around the Crab Nebula. Oppositely, the young supernova remnant Cassiopeia A has a shell and a neutron star but no pulsar wind nebula. Astronomers hope to explain these and many other mysteries about supernovae and their remnants using more multiwavelength observations with new telescopes. SEE ALSO BLACK HOLES (VOLUME 2); COSMIC RAYS (VOLUME 2); GALAXIES (VOLUME 2); PULSARS (VOLUME 2); STARS (VOLUME 2).

John R. Dickel

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progenitor star the star that existed before a dramatic change, such as a supernova, occurred

ejecta the pieces of material thrown off by a star when it explodes

X rays a form of high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

interstellar between the stars

electrons negatively charged subatomic particles

synchrotron radiation the radiation from electrons moving at almost the speed of light inside giant magnetic accelerators of particles, called synchrotrons, either on Earth or in space

wavelengths the distance from crest to crest on a wave at an instant in time

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

spectral lines the unique pattern of radiation at discrete wavelengths that every material produces

Tombaugh, Clyde

T

American Astronomer
1906–1997

Clyde W. Tombaugh, famous for his discovery of Pluto, the solar system's ninth major planet, was born in 1906 in Streator, Illinois. His family moved to Burdett, Kansas, when he was young. In 1928 he sent planetary drawings done using his homemade nine-inch telescope to Lowell Observatory. Its director, Vesto Slipher, was so impressed with the young astronomer's ability to sketch what he saw in a telescope that he offered him a job to conduct the search for a suspected ninth planet. On February 18, 1930, Tombaugh discovered Pluto on two photographs he had taken of the

Astronomer Clyde Tombaugh with his homemade, backyard telescope in Las Cruces, New Mexico. Tombaugh's most famous discovery, the planet Pluto, was photographed during a scan of the Delta Geminorum star region.

variable star a star whose light output varies over time

region centered on the star Delta Geminorum. During his fifteen-year sky search, he also discovered the cataclysmic **variable star** TV Corvi, six star clusters, and a supercluster of galaxies.

After World War II, at the fledgling New Mexico missile site called White Sands, Tombaugh developed the optical telescopes used to track the first rockets of the U.S. space program. In the 1950s he conducted the first and only search for small natural Earth satellites, a contribution to science that will, thanks to modern artificial satellites, be forevermore impossible to replicate.

Tombaugh died just short of his ninety-first birthday at his home in Las Cruces, New Mexico, where he had lived the second half of his productive and interesting life as a professor, writer, and observer. SEE ALSO Astronomer (volume 2); Pluto (volume 2).

David H. Levy

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Trajectories

Trajectories are the paths followed by spacecraft as they travel from one point to another. They are governed by two key factors: the spacecraft's own propulsion system and the gravity of the Sun, Earth, and other planets and moons. Because even the most powerful rockets have only a limited amount of thrust, engineers must carefully develop trajectories for spacecraft that will allow them to reach their intended destination. In some cases this can lead to complicated trajectories that get a boost from the gravity of other worlds.

The trajectory needed for a spacecraft to go into orbit around Earth is relatively straightforward. The spacecraft needs to gain enough altitude—typically at least 200 kilometers (124 miles)—to clear Earth's atmosphere and enough speed to keep from falling back to Earth. This minimum **orbital velocity** around Earth is about 28,000 kilometers per hour (17,360 miles per hour) for **low Earth orbits** and slower than that for higher orbits as Earth's gravitational pull weakens. Other parameters of the orbit, such as the inclination of the orbit to Earth's equator, can be altered by changing the direction of the spacecraft's launch.

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

low Earth orbits orbits between 300 and 800 kilometers above Earth's surface

Launching a spacecraft beyond Earth, such as on a mission to Mars or another planet, is more complicated. Because of the great distances between planets and the limited power of modern rockets, one cannot simply aim a spacecraft directly at its destination and launch it. Instead, trajectories must

Mission Control flight controllers at work confirming flight trajectories prior to the launch of the STS-101 shuttle mission on May 19, 2000.

be carefully calculated to allow a spacecraft to travel to its destination given the limited amount of rocket power available. A common way to do this is to use a Hohmann transfer orbit, a type of orbit that minimizes the amount of propellant needed to send a spacecraft to its destination. A Hohmann transfer orbit is an elliptical orbit with its **perihelion** at Earth and **aphelion** at the destination planet (or the reverse if traveling towards the Sun). If launched at the proper time a spacecraft will spend only half an orbit in a Hohmann orbit, catching up with the destination world at the opposite point of its orbit from Earth. To do this, the spacecraft much be launched during a relatively short launch window. For a mission to Mars, such launch windows are available every twenty-six months, for only a couple months at a time.

perihelion the point in an object's orbit that is closest to the Sun

aphelion the point in an object's orbit that is farthest from the Sun

Even a Hohmann orbit, however, may require more energy than a rocket can provide. Another technique, known as gravity assist, can allow spacecraft to reach more distant destinations by taking advantage of the gravity of other worlds. A spacecraft is launched on a Hohmann trajectory toward an intermediate destination, usually another planet. The spacecraft flies by this planet, gaining velocity by taking, though gravitational interaction, an infinitesimally small amount of the planet's **angular momentum**. This added velocity allows the spacecraft to continue on to its destination. Gravity assists allowed the Voyager 2 spacecraft, launched from Earth with only enough velocity to reach Jupiter, to travel on to Saturn, Uranus, and Neptune. Gravity assist **flybys** of Venus, Earth, and Jupiter will also allow the Cassini spacecraft to reach Saturn in 2004. SEE ALSO Orbits (Volume 2).

angular momentum the angular equivalent of linear momentum; the product of angular velocity and moment of inertia (moment of inertia = mass $\times$ radius^2)

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

Jeff Foust

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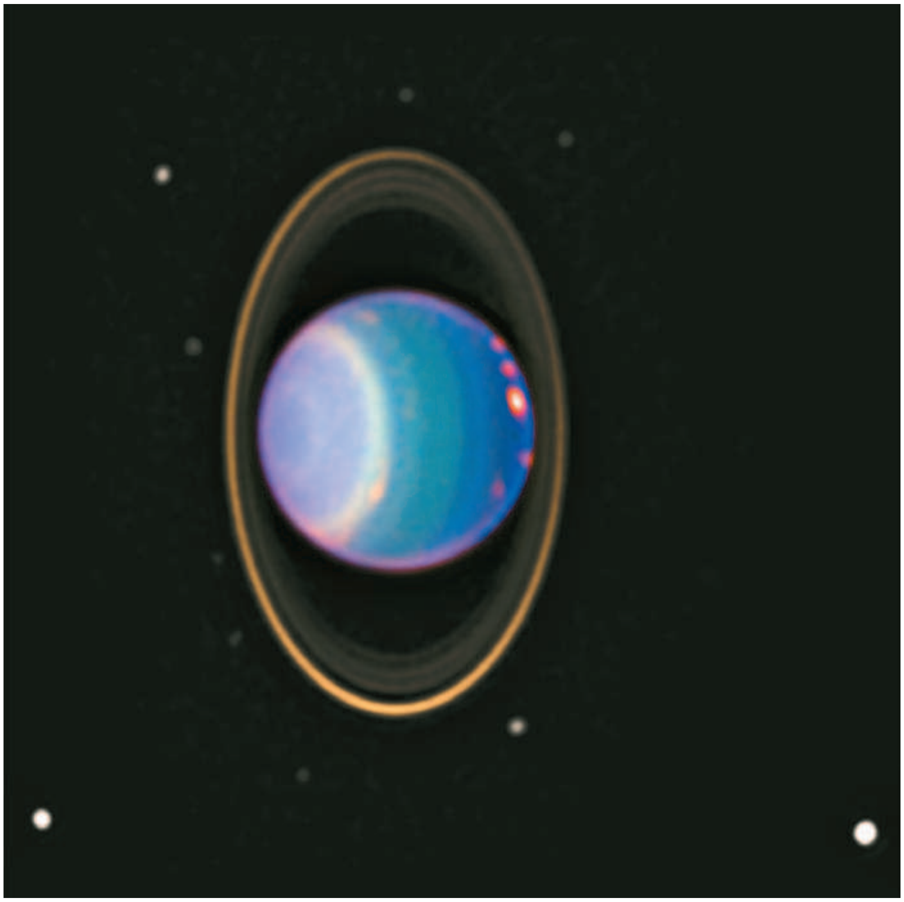
Uranus

Uranus was the first planet to be discovered that had not been known since antiquity. Although Uranus is just bright enough to be seen with the naked eye, and in fact had appeared in some early star charts as an unidentified star, English astronomer William Herschel was the first to recognize it as a planet in 1781.

The planet's benign appearance gives no hint of a history fraught with catastrophe: Sometime in Uranus's past, a huge collision wrenched the young planet. As a result, the rotation pole of Uranus is now tilted more than 90 degrees from the plane of the planet's orbit. Uranus travels in a nearly circular orbit at an average distance of almost 3 billion kilometers (1.9 billion miles) from the Sun (about nineteen times the distance from Earth to the Sun).



A Hubble Space Telescope generated image of Uranus, revealing 10 of its 21 known satellites and its four major rings, August 8, 1998.

A Somewhat Small Gas Planet

The composition of Uranus is similar to that of the other giant planets✶ and the Sun, consisting predominantly of hydrogen (about 80 percent) and helium (15 percent). The remainder of Uranus's atmosphere is methane (less than 3 percent), hydrocarbons (mixtures of carbon, nitrogen, hydrogen, and oxygen), and other trace elements. Uranus's color is caused by the methane, which preferentially absorbs red light, rendering the remaining reflected light a greenish-blue color.

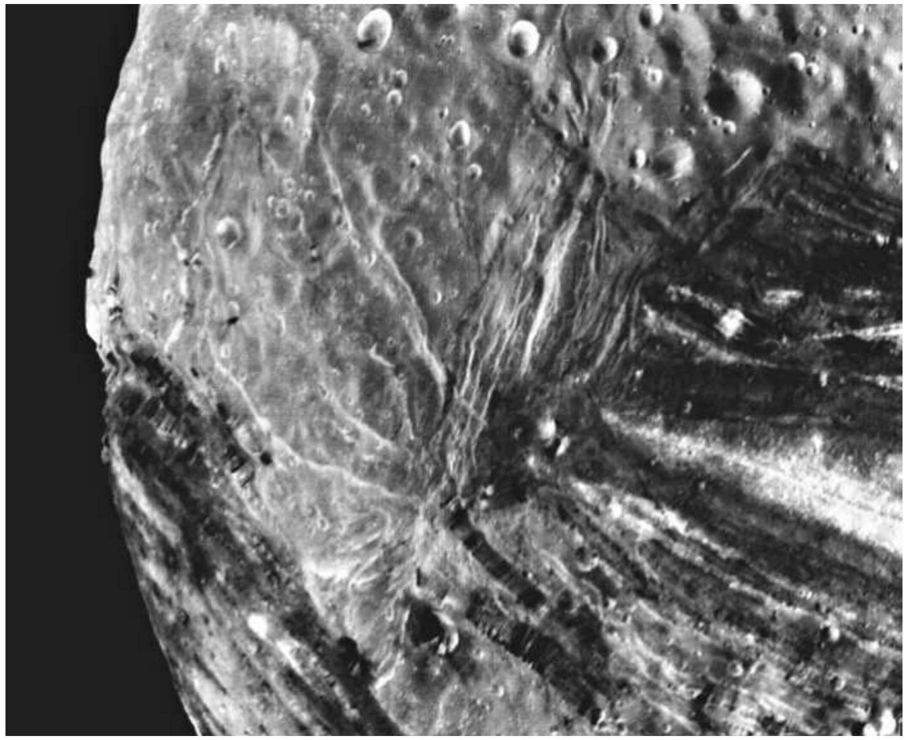
✶There are four giant planets in the solar system: Jupiter, Saturn, Uranus, and Neptune

Like Jupiter and Saturn, Uranus is a gas planet, although a somewhat small one (at its equator, its radius is about 25,559 kilometers [15,847 miles]). We see the outermost layers of clouds, which are probably composed of icy crystals of methane. Below this layer of clouds, the atmosphere gets thicker and warmer. Deep within the center of Uranus, at extremely high pressure, a core of rocky material is hypothesized to exist, with a mass almost five times that of Earth.

One of the more puzzling aspects of Uranus is the lack of excess heat radiating from its interior. In comparison, the other three giant planets radiate significant excess heat. Astronomers believe that this excess heat is left over from the time of the planets' formation and from continuing **gravitational contraction**. Why then does Uranus have none? Scientists theorize that perhaps the heat is there but is trapped by layers in the atmosphere, or perhaps the event that knocked Uranus over on its side somehow caused much of the heat to be released early in the planet's history.

gravitational contraction the collapse of a cloud of gas and dust due to the mutual gravitational attraction of the parts of the cloud; a possible source of excess heat radiated by some Jovian planets

This Voyager 2 image of Miranda reveals a significant variety of fractures and troughs, with varying densities of impact craters on them. These differences suggest that the moon had a long, complicated geologic evolution.



Magnetic Field

When the Voyager 2 spacecraft flew by Uranus in 1986, it detected a magnetic field about fifty times stronger than that of Earth. In a surprising twist, the magnetic field's source was not only offset from the center of the planet to the outer edge of the rocky core, but it was also tilted nearly 60 degrees from the planet's rotation axis. From variations in the magnetic field strength detected by Voyager 2, scientists determined that the planet's internal rotation period was 17.2 hours. The winds in the visible cloud layers have rotation periods ranging from about 16 to 18 hours depending on latitude, implying that wind speeds reach 300 meters per second (670 miles per hour) for some regions.

The Moons of Uranus

Within six years of the discovery of Uranus, two moons were discovered. They were subsequently named Titania and Oberon. It was more than sixty years before the next two Uranian moons, Ariel and Umbriel, were discovered. Nearly a century elapsed before Miranda was discovered in 1948, bringing the total of Uranus's large moons to five. Little was known about their surface structure or history until the Voyager 2 spacecraft returned detailed images of the surfaces of these moons.

On Miranda, huge geologic features dominate the small moon's landscape, indicating that some kind of intense heating must have occurred in the past. It is not yet clear whether a massive collision disturbed the small moon, which then reassembled into the current jumble, or whether, in the past, tidal interactions with other moons produced heat to melt and modify the surface, as is the case for Jupiter's moon Io. Oberon, the outermost major moon, shows many large craters, some with **bright rays**. Titania has fewer large craters, indicating that its surface has been "wiped clean" by resurfacing sometime in the moon's past. Ariel has the youngest surface of the major moons, based on cratering rates. Umbriel is much darker and smoother. Its heavily cratered surface is probably the oldest of the satellites.

bright rays lines of lighter material visible on the surface of a body, which are caused by relatively recent impacts

In 1986, Voyager 2 discovered ten additional moons, with Puck being the largest. Voyager 2 images of Puck showed it to be an irregularly shaped body with a mottled surface. Voyager 2 did not venture close enough to the other small moons to learn much about them. Since 1986, six more tiny moons have been discovered around Uranus, bringing its total to twenty-one. Little is known about these moons other than their sizes and orbits.

Rings and Seasons

In 1977, astronomers discovered that Uranus has a ring system. Voyager 2 studied the rings in detail when it flew by Uranus in 1986. There are nine well-defined rings, plus a fainter ring and a wider fuzzy ring. Unlike the broad system of Saturnian rings, the main Uranian rings are narrow. The rings are not perfectly circular and also vary in width. Like the rings of Saturn, the Uranian rings are thought to be composed mainly of rocky material (ranging in size from dust particles to house-sized boulders) mixed with small amounts of ice.

The atmosphere of Uranus has often been called bland, and even boring. These epithets are a consequence of fate and unfortunate timing. It was fate that caused the early collision of Uranus with a large body, creating the planet's extreme axial tilt, which in turn created extreme seasons. It was unfortunate timing that the Voyager 2 encounter (which gave us our highest resolution pictures) occurred at peak southern summer, when we had a view of only the southern half of the planet. Historically, this season is when Uranus has appeared blandest in the past.

As Uranus continues its eighty-four-year-long progression around the Sun, its equatorial region is now receiving sunlight again, and parts of its northern hemisphere are being bathed in **solar radiation** for the first time in decades. Today, images from the Hubble Space Telescope are revealing multiple bright cloud features and stunning banded structures on Uranus. It is fascinating to speculate how Uranus will appear to us by the time it reaches equinox in 2007. SEE ALSO Exploration Programs (volume 2); Herschel Family (volume 2); NASA (volume 3); Neptune (volume 2); Robotic Exploration of Space (volume 2).

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

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V

Venus

Venus was one of the last planets to be explored, despite its position as the closest planet to Earth. This is largely because it is perpetually shrouded in a uniformly bland covering of clouds. The cloud cover made looking at Venus through a telescope about as exciting as staring at a billiard ball. While Mars and the Moon were objects of much attention by early telescopic observation, the surface of Venus remained a mystery. It was even easier to say something about the outer planets, such as Jupiter and Saturn, than it was to make meaningful observations of Venus.

The absence of information about Venus was particularly ironic because Venus is the most like Earth in size and position within the solar system, thus suggesting that it could be more like Earth than any of the other planets. Venus's diameter is only 651 kilometers (404 miles) smaller than Earth's diameter of 12,755 kilometers (7,908 miles). Venus's density is 0.9 times that on Earth, and its surface gravity is 0.8 that of Earth. Venus orbits the Sun in just under one Earth year (224.7 days). When compared to Earth, all of the planets except Venus are much larger or smaller, higher or lower in density, located at much greater or lesser distances from the Sun, or enveloped in atmospheres much thinner or colder. Thus Venus was a cornerstone in scientists' survey of the solar system and offered the chance to see how an Earth-sized planet might have evolved similarly or differently. Planetary geologists now know that it is very different. This fact has revealed that the details of how a planet geologically evolves are probably as important in planetary evolution as differences in fundamental characteristics. Venus and Earth are truly twins separated at birth.

Atmospheric Characteristics

Because of the cloud cover, one of the first things that could be determined about Venus in the early days of planetary astronomy was the characteristics of the visible atmosphere. This was done first through telescopic measurements and early spacecraft **flybys**. In the nineteenth century, rare transits of Venus across the surface of the Sun were used to prove that Venus was enveloped in an atmosphere. This led to all sorts of early speculation that the clouds were, like clouds on Earth, water vapor clouds, and that the surface was a teeming **primordial swamp** filled with plants and animals similar to the **Paleozoic** coal swamps of Earth. This speculation withered under results of early spectroscopic observations, which were able to determine that the atmosphere was largely carbon dioxide, not oxygen and nitrogen as on Earth, and later on, that the clouds appeared to be sulfuric acid fog, not water vapor.

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

primordial swamp warm, wet conditions postulated to have occurred early in Earth's history as life was beginning to develop

Paleozoic relating to the first appearance of animal life on Earth

By the 1960s little was still known about Venus, but modern instruments were beginning to reveal more. Early surface temperature estimates were made by observing **infrared** wavelengths to better determine the temperature. Such observations, using radio telescopes and the first U.S. interplanetary flyby spacecraft, Mariner 2, in 1962, implied that the surface temperatures were high. Over the next decade, several U.S. atmospheric entry probes (Pioneer-Venus 1 and 2) and Soviet landers (Venera 9, 10, 13, and 14) directly measured the temperature and pressure within the atmosphere. These measurements revealed a surface temperature of 450°C

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

A global view of Venus, created with data obtained during the Magellan mission. At image center is a bright feature, the mountainous region of Ovda Regio, located in the western portion of the great Aphrodite equatorial highland.

(842°F), or about as hot as the surface of a catalytic converter on an automobile. The surface pressure on Venus was found to be ninety-two times that of Earth (92 bars or 9.2 million pascals). This is equivalent to pressures at about 1 kilometer (0.6 mile) of depth in the sea, or about fifty times greater than a pressure cooker.

The atmosphere is so dense that pressures and temperatures similar to the surface of Earth occur at about 60 to 70 kilometers (37 to 43 miles) of altitude. Most of the atmosphere on Earth lies below 10 kilometers (6.2 miles), and it pretty much peters out before 30 kilometers (18.6 miles). On Venus, a daring future adventurer in a balloon with an oxygen mask (and protection from sulfuric acid clouds) could float in the upper atmosphere at an altitude of 60 to 70 kilometers (37 to 43 miles) in relative comfort. The global trip would be rapid since the atmosphere super-rotates, meaning that it flows from west to east faster than the underlying surface rotates. A balloon traveler in the upper atmosphere of Venus could circumnavigate the planet in only four days, especially near the equator where the speeds are greatest. This is unlike Earth, where the surface spins beneath a relatively sluggishly moving atmosphere that takes several weeks for a complete circuit. The balloon traveler's view would be boring, however, because the surface of Venus would be obscured by the main cloud layer, which occurs at 45 to 70 kilometers (28 to 43 miles) of altitude.

These conditions are the result of early development of a thick atmosphere consisting mostly of carbon dioxide (about 97 percent) through a

THE GREENHOUSE EFFECT ON VENUS

The greenhouse effect refers to a condition on Venus in which solar heating of the upper atmosphere at the short wavelengths of visible light radiation results in warming of the atmosphere, but the longer wavelengths of thermal radiation in the lower atmosphere cannot penetrate the atmosphere and reradiate to space. As a result, the temperature of the atmosphere continually increased.

so-called runaway greenhouse effect. First discovered from the study of Venus, the greenhouse effect is now discussed for Earth, where it is recognized that industrial additions of carbon dioxide to the atmosphere pose potential environmental problems of similar global magnitude.

Surface Features and Geologic Findings

Although the surface of Venus has been seen locally around a few Russian landers with optical cameras, a true picture of the global surface was obtained only with the advent of **radar** that could penetrate the dense obscuring clouds and create radar images. Early results were obtained through Earth-based radio telescopes at Goldstone (in California) and Arecibo (in Puerto Rico), which emitted tight beams of radar and built up images showing differences in the radar reflecting properties of the surfaces. These images were low in resolution, but they enabled large areas of unusually radar-reflective terrain to be detected. These also allowed the first estimates of the rotation to be made, and they showed that Venus rotates backwards, or west to east, and slowly. It takes about 243 days to do so. Oddly, this is a little longer than its year (224.7 days). Stranger still, at closest approach to Earth (a distance of just under 40 million kilometers [24.8 million miles]), or opposition, Venus presents the same hemisphere to Earth. The origin of this unusual set of rotation conditions is not known.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

radar altimetry using radar signals bounced off the surface of a planet to map its variations in elevation

The first truly global maps of Venus was made by the Pioneer-Venus orbiter using **radar altimetry**. This showed the surface elevations over the globe resolved at scales of about 100 kilometers (62 miles) and revealed a relatively flat surface, with the absolute range of elevations much less than that found on Earth. More than 80 percent of the surface area lies within a kilometer of the mean planetary radius (6,051.8 kilometers [3,752.1 miles]). A few highland regions rise from one to several kilometers above the mean planetary radius, but these cover only about 15 percent of the surface of Venus. Whereas Earth has two common elevations, seafloors and continents, Venus has one most common elevation, broad plains.

Radar images of the surface, somewhat similar to photographs, were made later for large areas of the globe by the Russian Venera 15 and 16 orbiters, for the northern quarter of Venus, and, several years later, by the U.S. Magellan orbiter, for about 98 percent of the surface. These efforts obtained images of the surface at scales of 2 kilometers (1.2 miles) and 0.3 kilometers (0.2 miles), respectively, thus generating the first true images of what the surface of Venus really looks like and permitting the first geologic analysis.

fault a fracture in rock in the upper crust of a planet along which there has been movement

rift valley a linear depression in the surface, several hundred to thousand kilometers long, along which part of the surface has been stretched, faulted, and dropped down along many normal faults

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

orthogonal composed of right angles or relating to right angles

The radar images show that the surface of Venus is a complex of plains, mountains, **faults**, ridges, **rift valleys**, volcanoes, and a few **impact craters**, a surface more complex and geologically modified than any of the other planets seen previously. The highland regions seen first in low-resolution Earth-based radar images and Pioneer-Venus radar altimetry are among the most complex surfaces and consist of a terrain that is complexly faulted in **orthogonal** patterns. These regions are known as tessera after the Greek word for mosaics of tiles. The sequence of geologic surfaces suggests that tesserae (plural of "tessera") also represent the oldest preserved surfaces on Venus. One of the highlands is surrounded by ridgelike mountain belts that rise from 6 to 11 kilometers (3.7 to 6.8 miles) above the mean planetary radius and appear to have formed from compression and buckling of the surface, similar to mountain belts on Earth. Low ridges of possibly similar origin, in a range of sizes, occur singly or in belts throughout the plains areas.

Faults, **fractures**, and immense rift valleys are present in abundance. One rift valley, Diana Chasma, is similar in size to the great East African rift valley and Rio Grande rift valley of Earth. Like those on Earth, it probably formed from the stretching and pulling apart of the surface. On Earth, erosion and **sedimentation** quickly obscure all but the latest structures associated with such rifts. But on Venus the absence of erosion means that all of the structural details are perfectly preserved as a complex mass of faults.

Large volcanoes up to several hundreds of kilometers across but only a few kilometers high are common, as are long lava flow fields, extensive low-lying regions of lava plains, and lava channels. One lava channel is longer than the largest rivers on Earth. Low-relief domical volcanoes, many less than several kilometers in diameter, are globally abundant, numbering in the hundreds of thousands. Some volcanoes appear similar to those formed from eruption of thick, viscous lavas on Earth. Additional volcanic features include **calderas** similar to those on Earth, although generally much larger; complex topographic **annular** spider-and-web-shaped features known as arachnoids; and circular structural patterns up to several hundred kilometers across with associated volcanism known as coronae. Many of these are generally thought to represent local formation of large and deep magma reservoirs. Radial patterns of fractures associated with volcanoes are common and may represent the surface deformation associated with radial-dike-like magma intrusions.

Impact craters are about as numerous on Venus as they are on continental areas of Earth, and are thus not as common as they are on most other planets. Only about 900 have been identified on Venus. Meteors smaller than a certain size disintegrate on entering the atmosphere. As a result, impact craters smaller than 2 kilometers (1.2 miles) are infrequent. Morphologically, craters on Venus resemble those on other planets with several exceptions related to the interaction of the crater **ejecta** with the dense atmosphere. These include extensive parabola-shaped halos much like fallout from plumes associated with volcanic eruptions on Earth. These open to the west and possibly record the interaction of the upward expanding cloud of crater ejecta with the strong global easterly winds. Many craters are characterized by large lava-flow-like features that may represent molten ejecta flowing outward from the crater after the impact.

Impact craters also appear nearly uniformly distributed, unlike most planets where large areas of different crater abundance indicate variations in age of large areas of their surfaces. Based on estimates of their rates of formation on surfaces in the inner solar system, impact crater statistics indicate an average surface age on Venus of about 500 million years. Either most of the surface was formed over 500 million years ago in a catastrophic resurfacing event and volcanism has been much reduced since that time, or continual, widespread, and evenly spaced volcanism and **tectonism** remove craters with a rate that yields an average lifetime of the surface of 500 million years. The rate of volcanism on Venus is estimated to be less than 1 cubic kilometer per year, somewhat less than the 20 cubic kilometers associated largely with seafloor spreading on Earth. The surface of Venus

Venus has a complex surface, with plains, mountains, volcanoes, ridges, rift valleys, and a few impact craters.

fracture any break in rock, ranging from small "joints" that divide rocks into planar blocks (such as that seen in road cuts) to vast breaks in the crusts of unspecified movement

sedimentation process of depositing sediments, which result in a thick accumulation of rock debris eroded from high areas and deposited in low areas

calderas the bowl-shaped crater at the top of a volcano caused by the collapse of the central part of the volcano

annular ring-like

ejecta the material thrown out of an impact crater during its formation

tectonism process of deformation in a planetary surface as a result of geological forces acting on the crust; includes faulting, folding, uplift, and down-warping of the surface and crust

subduction the process by which one edge of a crustal plate is forced to move under another plate

lithosphere the rocky outer crust of a planet

convective processes processes that are driven by the movement of heated fluids resulting from a variation in density

asthenosphere the weaker portion of a planet's interior just below the rocky crust, over which tectonic plates slide

basalts dark, volcanic rock with abundant iron and magnesium and relatively low silica common on all of the terrestrial planets

appears to be dominated by volcanic hot spots rather than spreading and **subduction** associated with plate tectonics.

Another spacecraft observation method allowed something to be determined about the interior of Venus. By carefully tracking spacecraft orbits, variations in gravitational acceleration associated with differences in mass on and beneath the surface can be detected. On Venus, this technique reveals that the strength of gravity is mostly proportional to the surface topography, in contrast to Earth, where mass associated with topography is generally compensated underneath by lower density roots. This means that many large topographic features on Venus are supported either by strong **lithosphere** without a low-density root, or by topography originating from the dynamical uplift of the surface through **convective processes** in the deep interior. If the first type is assumed, it may indicate that the lithosphere is strong and that a low-strength layer at the base of the lithosphere (called the **asthenosphere** on Earth) is not present. The second type may be attributed to upwelling associated with volcanic hot spots.

Several Venera landers of the Russian space program returned both optical images of the surface and chemical information about the rocks at several sites. Early landers had searchlights in case the cloud cover made it too dark to see anything. Despite the dense cloud cover, enough light gets through that the surface is illuminated to the equivalent of a cloudy day on Earth. But the sky as seen from the surface is probably a bland fluorescent yellow-white, rather than mottled gray. The relatively rocky surroundings appeared to be volcanic lava flow surfaces or associated rubble. The measured chemical compositions are indistinguishable for the most part from tholeiitic and alkali **basalts** typical of ocean basins and hot spots on Earth.

The low number of impact craters scattered over the surface implies that only the last 20 percent of the history of Venus appears to be preserved, and little is known about the earlier surface geologic history. The geological complexity and young surface ages of both Venus and Earth relative to smaller terrestrial planets can be attributed to their larger sizes and correspondingly warmer and more mobile interiors, extensive surface deformation (tectonism), and mantle melts (volcanism) over a greater period of geological time. SEE ALSO Exploration Programs (volume 2); Government Space Programs (volume 2); NASA (volume 3); Robotic Exploration of Space (volume 2); Planetary Exploration, Future of (volume 2).

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W

Weather, Space

Space weather describes the conditions in space that affect Earth and its technological systems. Space weather is a consequence of the behavior of

GEOMAGNETIC STORMS

Category: Scale	Category: Descriptor	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects	Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	*Power systems*: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. *Spacecraft operations*: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. *Other systems*: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	*Power systems*: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. *Spacecraft operations*: may experience surface charging and tracking problems, corrections may be needed for orientation problems. *Other systems*: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**	Kp=8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	*Power systems:* voltage corrections may be required, false alarms triggered on some protection devices. *Spacecraft operations*: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. *Other systems*: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	*Power systems:* high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. *Spacecraft operations:* corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. *Other systems*: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	*Power systems*: weak power grid fluctuations can occur. *Spacecraft operations*: minor impact on satellite operations possible. *Other systems:* migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**	Kp=5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.
** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.sec.noaa.gov/Aurora)

SOLAR RADIATION STORMS

Category: Scale	Category: Descriptor	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects	Flux level of ≥10 MeV (ions)*	Number of events when flux level was met**
S 5	Extreme	*Biological*: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); high radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 chest X-rays) is possible. *Satellite operations*: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. *Other systems*: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	*Biological*: unavoidable radiation hazard to astronauts on EVA; elevated radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 10 chest X-rays) is possible. *Satellite operations*: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. *Other systems*: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	*Biological*: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in commercial jets at high latitudes may receive low-level radiation exposure (approximately 1 chest X-ray). *Satellite operations*: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. *Other systems*: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	*Biological*: none. *Satellite operations*: infrequent single-event upsets possible. *Other systems*: small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	*Biological*: none. *Satellite operations*: none. *Other systems*: minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2} based on this measure, but other physical measures are also considered.
** These events can last more than one day.

RADIO BLACKOUTS

Category: Scale	Category: Descriptor	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
		Duration of event will influence severity of effects	GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	*HF Radio*: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. *Navigation*: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1 per cycle
R 4	Severe	*HF Radio*: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. *Navigation*: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	*HF Radio*: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. *Navigation*: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	*HF Radio*: Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. *Navigation*: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	*HF Radio*: Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. *Navigation*: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.
** Other frequencies may also be affected by these conditions.

sunspots dark, cooler areas on the solar surface consisting of transient, concentrated magnetic fields

coronal holes large, dark holes seen when the Sun is viewed in X-ray or ultraviolet wavelengths; solar wind emanates from the coronal holes

prominences inactive "clouds" of solar material held above the solar surface by magnetic fields

flares intense, sudden releases of energy

coronal mass ejections large quantities of solar plasma and magnetic field launched from the Sun into space

vacuum a space where air and all other molecules and atoms of matter have been removed

the Sun, the nature of Earth's magnetic field and atmosphere, and our location in the solar system.

While most people know that the Sun is overwhelmingly important to life on Earth, few of us know about the effects caused by this star and its variations. Scientists can observe variations such as **sunspots**, **coronal holes**, **prominences**, **flares**, and **coronal mass ejections**. These dramatic changes to the Sun send material and energy hurtling towards Earth.

Space is sometimes considered a perfect **vacuum**, but between the Sun and the planets is a turbulent area dominated by the fast-moving **solar wind**. The solar wind flows around Earth and distorts the **geomagnetic field** lines. During solar storms, the solar wind can gust wildly, causing geomagnetic storms.

Systems affected by space weather include satellites, navigation, radio transmissions, and power grids. Space weather also produces harmful radiation to humans in space. The NOAA Space Weather Scales list the likely effects of various storms. The list of consequences has grown in proportion to humankind's dependence on technological systems, and will continue to do so. SEE ALSO Solar Wind (Volume 2); Space Environment, Nature of (Volume 2); Sun (Volume 2).

Barbara Poppe

Internet Resources

NOAA Space Weather Scales. <http://www.sec.noaa.gov/NOAAscales/>.

What is Space?

Space, most generally, might be described as the boundless container of the universe. Its contents are all physical things that we know of, and more. To describe the contents of space, we use terms of distance, mass, force, motion, energy, and time. The units we use depend on the scale we are considering. Units useful to us on the scale of human life become difficult to use for much smaller domains (such as atoms), and as we describe space beyond our planet Earth.

Consider a distribution of mass at very large distances throughout space and the motion and energy transformation processes going on all the time. While these masses are very distant from each other, they do interact in various ways. These include gravitational force attraction; emitting, absorbing, or reflecting energy; and sometimes, though statistically very seldom, colliding.

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun

geomagnetic field Earth's magnetic field; under the influence of solar wind, the magnetic field is compressed in the Sun-ward direction and stretched out in the downwind direction, creating the magnetosphere, a complex, teardrop-shaped cavity around Earth.

Interplanetary Space

Interplanetary space refers to that region of our container that holds the Sun, the nine major planets that revolve about the Sun, and all other mass, distances, force interactions, motions, and transformations of energy within that realm. Distances are often given in terms of the average distance separating the Sun and Earth, in units called **astronomical units** (AU). Pluto, our most distant planet, is 39 AU from the Sun. Each body in the solar system exerts a gravitational pull on every other body, proportional to their masses but reduced by the separation between them. These forces keep the planets in orbit about the Sun, and moons in orbit about planets. Earth's moon, though relatively small in mass, is close enough to cause tidal changes in Earth's oceans with its pull. The massive planet Jupiter, however, affects orbits throughout the solar system.

astronomical units one AU is the average distance between Earth and the Sun (152 million kilometers [93 million miles])

Between Mars and Jupiter lies a ring of debris called the main asteroid belt, consisting of fragments of material that never became a planet. Gravitational forces (primarily those of the Sun and Jupiter) pull the asteroids into more defined orbits within this doughnut-shaped region. Some of these asteroids, because of collisions or by gravitational **perturbations**, leave the main belt and fall into Earth-crossing orbits. These are the ones that are the subject of disaster films and to which craters on Earth and the extinction of the dinosaurs are attributed. In addition to these asteroids, comets (which are essentially large, dirty snowballs) pass through the solar system, leaving dust trails. As Earth travels about the Sun, it collides with some of these dust trails, giving rise to meteor showers.

perturbations term used in orbital mechanics to refer to changes in orbits due to "perturbing" forces, such as gravity

As we peer into space from our home planet, whether with our naked eye or with the most powerful telescope, we are looking back through time. Light arriving at our eyes carries information about how the source looked at a time equal to the travel time of the photons of light. For example, our

APPROXIMATE DISTANCE CONVERSIONS

Distance	Miles	Kilometers	Astronomical Units (AU)	Light Years*
1 mile	1	1.609	0.0000000108	0.0000000000001701
1 kilometer	0.62150404	1	0.0000000067	0.0000000000001057
1 AU	92,977,004	149,600,000	1	0.0000158129
1 light year*	5,879,833,998,757	9,460,652,904,000	63,239.66	1

*A light year is the distance that light travels through a vacuum in the period of one year.

light year the distance that light in a vacuum would travel in one year, or about 5.9 trillion miles (9.5 trillion kilometers)

nearest star neighbor is a three-star system called Alpha Centauri, which is 4.3 **light years** away. This means that, as we look at this star system, we can know only how it looked 4.3 years ago, and never as it looks right now. We see the light from more distant stars that may have died and vanished many, many years ago. SEE ALSO Space Environment, Nature of (volume 2).

David Desrocher

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Glossary

ablation removal of the outer layers of an object by erosion, melting, or vaporization

abort-to-orbit emergency procedure planned for the space shuttle and other spacecraft if the spacecraft reaches a lower than planned orbit

accretion the growth of a star or planet through the accumulation of material from a companion star or the surrounding interstellar matter

adaptive optics the use of computers to adjust the shape of a telescope's optical system to compensate for gravity or temperature variations

aeroballistic describes the combined aerodynamics and ballistics of an object, such as a spacecraft, in flight

aerobraking the technique of using a planet's atmosphere to slow down an incoming spacecraft; its use requires the spacecraft to have a heat shield, because the friction that slows the craft is turned into intense heat

aerodynamic heating heating of the exterior skin of a spacecraft, aircraft, or other object moving at high speed through the atmosphere

Agena a multipurpose rocket designed to perform ascent, precision orbit injection, and missions from low Earth orbit to interplanetary space; also served as a docking target for the Gemini spacecraft

algae simple photosynthetic organisms, often aquatic

alpha proton X-ray analytical instrument that bombards a sample with alpha particles (consisting of two protons and two neutrons); the X rays are generated through the interaction of the alpha particles and the sample

altimeter an instrument designed to measure altitude above sea level

amplitude the height of a wave or other oscillation; the range or extent of a process or phenomenon

angular momentum the angular equivalent of linear momentum; the product of angular velocity and moment of inertia (moment of inertia = mass $\times$ radius^2)

angular velocity the rotational speed of an object, usually measured in radians per second

anisotropy a quantity that is different when measured in different directions or along different axes

annular ring-like

anomalies phenomena that are different from what is expected

anorthosite a light-colored rock composed mainly of the mineral feldspar (an aluminum silicate); commonly occurs in the crusts of Earth and the Moon

anthropocentrism valuing humans above all else

antimatter matter composed of antiparticles, such as positrons and antiprotons

antipodal at the opposite pole; two points on a planet that are diametrically opposite

aperture an opening, door, or hatch

aphelion the point in an object's orbit that is farthest from the Sun

Apollo American program to land men on the Moon; Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

asthenosphere the weaker portion of a planet's interior just below the rocky crust

astrometry the measurement of the positions of stars on the sky

astronomical unit the average distance between Earth and the Sun (152 million kilometers [93 million miles])

atmospheric probe a separate piece of a spacecraft that is launched from it and separately enters the atmosphere of a planet on a one-way trip, making measurements until it hits a surface, burns up, or otherwise ends its mission

atmospheric refraction the bending of sunlight or other light caused by the varying optical density of the atmosphere

atomic nucleus the protons and neutrons that make up the core of an atom

atrophy condition that involves withering, shrinking, or wasting away

auroras atmospheric phenomena consisting of glowing bands or sheets of light in the sky caused by high-speed charged particles striking atoms in Earth's upper atmosphere

avionics electronic equipment designed for use on aircraft, spacecraft, and missiles

azimuth horizontal angular distance from true north measured clockwise from true north (e.g., if North = 0 degrees; East = 90 degrees; South = 180 degrees; West = 270 degrees)

ballast heavy substance used to increase the stability of a vehicle

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

basalt a dark, volcanic rock with abundant iron and magnesium and relatively low silica common on all of the terrestrial planets

base load the minimum amount of energy needed for a power grid

beacon signal generator a radio transmitter emitting signals for guidance or for showing location

berth space the human accommodations needed by a space station, cargo ship, or other vessel

Big Bang name given by astronomers to the event marking the beginning of the universe when all matter and energy came into being

biocentric notion that all living organisms have intrinsic value

biogenic resulting from the actions of living organisms; or, necessary for life

bioregenerative referring to a life support system in which biological processes are used; physiochemical and/or nonregenerative processes may also be used

biosignatures the unique traces left in the geological record by living organisms

biosphere the interaction of living organisms on a global scale

bipolar outflow jets of material (gas and dust) flowing away from a central object (e.g., a protostar) in opposite directions

bitumen a thick, almost solid form of hydrocarbons, often mixed with other minerals

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

bone mineral density the mass of minerals, mostly calcium, in a given volume of bone

breccia mixed rock composed of fragments of different rock types; formed by the shock and heat of meteorite impacts

bright rays lines of lighter material visible on the surface of a body and caused by relatively recent impacts

brown dwarf star-like object less massive than 0.08 times the mass of the Sun, which cannot undergo thermonuclear process to generate its own luminosity

calderas the bowl-shaped crater at the top of a volcano caused by the collapse of the central part of the volcano

Callisto one of the four large moons of Jupiter; named for one of the Greek nymphs

Caloris basin the largest (1,300 kilometers [806 miles] in diameter) well-preserved impact basin on Mercury viewed by Mariner 10

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

carbon-fiber composites combinations of carbon fibers with other materials such as resins or ceramics; carbon fiber composites are strong and lightweight

carbonaceous meteorites the rarest kind of meteorites, they contain a high percentage of carbon and carbon-rich compounds

carbonate a class of minerals, such as chalk and limestone, formed by carbon dioxide reacting in water

cartographic relating to the making of maps

Cassini mission a robotic spacecraft mission to the planet Saturn scheduled to arrive in July 2004 when the Huygens probe will be dropped into Titan's atmosphere while the Cassini spacecraft studies the planet

catalyst a chemical compound that accelerates a chemical reaction without itself being used up; any process that acts to accelerate change in a system

catalyze to change by the use of a catalyst

cell culture a means of growing mammalian (including human) cells in the research laboratory under defined experimental conditions

cellular array the three-dimensional placement of cells within a tissue

centrifugal directed away from the center through spinning

centrifuge a device that uses centrifugal force caused by spinning to simulate gravity

Cepheid variables a class of variable stars whose luminosity is related to their period. Their periods can range from a few hours to about 100 days and the longer the period, the brighter the star

Čerenkov light light emitted by a charged particle moving through a medium, such as air or water, at a velocity greater than the phase velocity of light in that medium; usually a faint, eerie, bluish, optical glow

chassis frame on which a vehicle is constructed

chondrite meteorites a type of meteorite that contains spherical clumps of loosely consolidated minerals

cinder field an area dominated by volcanic rock, especially the cinders ejected from explosive volcanoes

circadian rhythm activities and bodily functions that recur every twenty-four hours, such as sleeping and eating

Clarke orbit geostationary orbit; named after science fiction writer Arthur C. Clarke, who first realized the usefulness of this type of orbit for communication and weather satellites

coagulate to cause to come together into a coherent mass

comet matrix material the substances that form the nucleus of a comet; dust grains embedded in frozen methane, ammonia, carbon dioxide, and water

cometary outgassing vaporization of the frozen gases that form a comet nucleus as the comet approaches the Sun and warms

communications infrastructure the physical structures that support a network of telephone, Internet, mobile phones, and other communication systems

convection the movement of heated fluid caused by a variation in density; hot fluid rises while cool fluid sinks

convection currents mechanism by which thermal energy moves because its density differs from that of surrounding material. Convection current is the movement pattern of thermal energy transferring within a medium

convective processes processes that are driven by the movement of heated fluids resulting from a variation in density

coronal holes large, dark holes seen when the Sun is viewed in X-ray or ultraviolet wavelengths; solar wind emanates from the coronal holes

coronal mass ejections large quantities of solar plasma and magnetic field launched from the Sun into space

cosmic microwave background ubiquitous, diffuse, uniform, thermal radiation created during the earliest hot phases of the universe

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

cosmocentric ethic an ethical position that establishes the universe as the priority in a value system or appeals to something characteristic of the universe that provides justification of value

cover glass a sheet of glass used to cover the solid state device in a solar cell

crash-landers or hard-lander; a spacecraft that collides with the planet, making no—or little—attempt to slow down; after collision, the spacecraft ceases to function because of the (intentional) catastrophic failure

crawler transporter large, tracked vehicles used to move the assembled Apollo/Saturn from the VAB to the launch pad

cryogenic related to extremely low temperatures; the temperature of liquid nitrogen or lower

cryptocometary another name for carbonaceous asteroids—asteroids that contain a high percentage of carbon compounds mixed with frozen gases

cryptoendolithic microbial microbial ecosystems that live inside sandstone in extreme environments such as Antarctica

crystal lattice the arrangement of atoms inside a crystal

crystallography the study of the internal structure of crystals

dark matter matter that interacts with ordinary matter by gravity but does not emit electromagnetic radiation; its composition is unknown

density-separation jigs a form of gravity separation of materials with different densities that uses a pulsating fluid

desiccation the process of drying up

detruents microorganisms that act as decomposers in a controlled environmental life support system

diffuse spread out; not concentrated

DNA deoxyribonucleic acid; the molecule used by all living things on Earth to transmit genetic information

docking system mechanical and electronic devices that work jointly to bring together and physically link two spacecraft in space

doped semiconductor such as silicon with an addition of small amounts of an impurity such as phosphorous to generate more charge carriers (such as electrons)

dormant comet a comet whose volatile gases have all been vaporized, leaving behind only the heavy materials

downlink the radio dish and receiver through which a satellite or spacecraft transmits information back to Earth

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

dunites rock type composed almost entirely of the mineral olivine, crystallized from magma beneath the Moon's surface

dynamic isotope power the decay of isotopes such as plutonium-238, and polonium-210 produces heat, which can be transformed into electricity by radioisotopic thermoelectric generators

Earth-Moon LaGrange five points in space relative to Earth and the Moon where the gravitational forces on an object balance; two points, 60 degrees from the Moon in orbit, are candidate points for a permanent space settlement due to their gravitational stability

eccentric the term that describes how oval the orbit of a planet is

ecliptic the plane of Earth's orbit

EH condrites a rare form of meteorite containing a high concentration of the mineral enstatite (a type of pyroxene) and over 30 percent iron

ejecta the pieces of material thrown off by a star when it explodes; or, material thrown out of an impact crater during its formation

ejector ramjet engine design that uses a small rocket mounted in front of the ramjet to provide a flow of heated air, allowing the ramjet to provide thrust when stationary

electrodynamic pertaining to the interaction of moving electric charges with magnetic and electric fields

electrolytes a substance that when dissolved in water creates an electrically conducting solution

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

electron a negatively charged subatomic particle

electron volts units of energy equal to the energy gained by an electron when it passes through a potential difference of 1 volt in a vacuum

electrostatic separation separation of substances by the use of electrically charged plates

elliptical having an oval shape

encapsulation enclosing within a capsule

endocrine system in the body that creates and secretes substances called hormones into the blood

equatorial orbit an orbit parallel to a body's geographic equator

equilibruim point the point where forces are in balance

Europa one of the large satellites of Jupiter

eV an electron volt is the energy gained by an electron when moved across a potential of one volt. Ordinary molecules, such as air, have an energy of about $3x10^{-2}$ eV

event horizon the imaginary spherical shell surrounding a black hole that marks the boundary where no light or any other information can escape

excavation a hole formed by mining or digging

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

extrasolar planets planets orbiting stars other than the Sun

extravehicular activity a space walk conducted outside a spacecraft cabin, with the crew member protected from the environment by a pressurized space suit

extremophiles microorganisms that can survive in extreme environments such as high salinity or near boiling water

extruded forced through an opening

failsafe a system designed to be failure resistant through robust construction and redundant functions

fairing a structure designed to provide low aerodynamic drag for an aircraft or spacecraft in flight

fault a fracture in rock in the upper crust of a planet along which there has been movement

feedstock the raw materials introduced into an industrial process from which a finished product is made

feldspathic rock containing a high proportion of the mineral feldspar

fiber-optic cable a thin strand of ultrapure glass that carries information in the form of light, with the light turned on and off rapidly to represent the information sent

fission act of splitting a heavy atomic nucleus into two lighter ones, releasing tremendous energy

flares intense, sudden releases of energy

flybys flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

fracture any break in rock, from small "joints" that divide rocks into planar blocks (such as that seen in road cuts) to vast breaks in the crusts of unspecified movement

freefall the motion of a body acted on by no forces other than gravity, usually in orbit around Earth or another celestial body

free radical a molecule with a high degree of chemical reactivity due to the presence of an unpaired electron

frequencies the number of oscillations or vibrations per second of an electromagnetic wave or any wave

fuel cells cells that react a fuel (such as hydrogen) and an oxidizer (such as oxygen) together; the chemical energy of the initial reactants is released by the fuel cell in the form of electricity

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

fusion fuel fuel suitable for use in a nuclear fusion reactor

G force the force an astronaut or pilot experiences when undergoing large accelerations

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

Galilean satellite one of the four large moons of Jupiter first discovered by Galileo

Galileo mission succesful robot exploration of the outer solar system; this mission used gravity assists from Venus and Earth to reach Jupiter, where it dropped a probe into the atmosphere and studied the planet for nearly seven years

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

Ganymede one of the four large moons of Jupiter; the largest moon in the solar system

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

general relativity a branch of science first described by Albert Einstein showing the relationship between gravity and acceleration

geocentric a model that places Earth at the center of the universe

geodetic survey determination of the exact position of points on Earth's surface and measurement of the size and shape of Earth and of Earth's gravitational and magnetic fields

geomagnetic field Earth's magnetic field; under the influence of solar wind, the magnetic field is compressed in the Sunward direction and stretched out in the downwind direction, creating the magnetosphere, a complex, teardrop-shaped cavity around Earth

geospatial relating to measurement of Earth's surface as well as positions on its surface

geostationary remaining above a fixed point above Earth's equator

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

gimbal motors motors that direct the nozzle of a rocket engine to provide steering

global change a change, such as average ocean temperature, affecting the entire planet

global positioning systems a system of satellites and receivers that provide direct determination of the geographical location of the receiver

globular clusters roughly spherical collections of hundreds of thousands of old stars found in galactic haloes

grand unified theory (GUT) states that, at a high enough energy level (about 10^{25} eV), the electromagnetic force, strong force, and weak force all merge into a single force

gravitational assist the technique of flying by a planet to use its energy to "catapult" a spacecraft on its way—this saves fuel and thus mass and cost of a mission; gravitational assists typically make the total mission duration longer, but they also make things possible that otherwise would not be possible

gravitational contraction the collapse of a cloud of gas and dust due to the mutual gravitational attraction of the parts of the cloud; a possible source of excess heat radiated by some Jovian planets

gravitational lenses two or more images of a distant object formed by the bending of light around an intervening massive object

gravity assist using the gravity of a planet during a close encounter to add energy to the motion of a spacecraft

gravity gradient the difference in the acceleration of gravity at different points on Earth and at different distances from Earth

gravity waves waves that propagate through space and are caused by the movement of large massive bodies, such as black holes and exploding stars

greenhouse effect process by which short wavelength energy (e.g., visible light) penetrates an object's atmosphere and is absorbed by the surface, which reradiates this energy as longer wavelength infrared (thermal) energy; this energy is blocked from escaping to space by molecules (e.g., H_2O and CO_2) in the atmosphere; and as a result, the surface warms

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

hard-lander spacecraft that collides with the planet or satellite, making no attempt to slow its descent; also called crash-landers

heliosphere the volume of space extending outward from the Sun that is dominated by solar wind; it ends where the solar wind transitions into the interstellar medium, somewhere between 40 and 100 astronomical units from the Sun

helium-3 a stable isotope of helium whose nucleus contains two protons and one neutron

hertz unit of frequency equal to one cycle per second

high-power klystron tubes a type of electron tube used to generate high frequency electromagnetic waves

hilly and lineated terrain the broken-up surface of Mercury at the antipode of the Caloris impact basin

hydrazine a dangerous and corrosive compound of nitrogen and hydrogen commonly used in high powered rockets and jet engines

hydroponics growing plants using water and nutrients in solution instead of soil as the root medium

hydrothermal relating to high temperature water

hyperbaric chamber compartment where air pressure can be carefully controlled; used to gradually acclimate divers, astronauts, and others to changes in pressure and air composition

hypergolic fuels and oxidizers that ignite on contact with each other and need no ignition source

hypersonic capable of speeds over five times the speed of sound

hyperspectral imaging technique in remote sensing that uses at least sixteen contiguous bands of high spectral resolution over a region of the electromagnetic spectrum; used in NASA spacecraft Lewis' payload

ilmenite an important ore of titanium

Imbrium Basin impact largest and latest of the giant impact events that formed the mare-filled basins on the lunar near side

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

impact winter the period following a large asteroidal or cometary impact when the Sun is dimmed by stratospheric dust and the climate becomes cold worldwide

impact-melt molten material produced by the shock and heat transfer from an impacting asteroid or meteorite

in situ in the natural or original location

incandescence glowing due to high temperature

indurated rocks rocks that have been hardened by natural processes

information age the era of our time when many businesses and persons are involved in creating, transmitting, sharing, using, and selling information, particularly through the use of computers

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

infrared radiation radiation whose wavelength is slightly longer than the wavelength of light

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

intercrater plains the oldest plains on Mercury that occur in the highlands and that formed during the period of heavy meteoroid bombardment

interferometers devices that use two or more telescopes to observe the same object at the same time in the same wavelength to increase angular resolution

interplanetary trajectories the solar orbits followed by spacecraft moving from one planet in the solar system to another

interstellar between the stars

interstellar medium the gas and dust found in the space between the stars

ion propulsion a propulsion system that uses charged particles accelerated by electric fields to provide thrust

ionization removing one or more electrons from an atom or molecule

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

isotopic ratios the naturally occurring ratios between different isotopes of an element

jettison to eject, throw overboard, or get rid of

Jovian relating to the planet Jupiter

Kevlar® a tough aramid fiber resistant to penetration

kinetic energy the energy an object has due to its motion

KREEP acronym for material rich in potassium (K), rare earth elements (REE), and phosphorus (P)

L-4 the gravitationally stable Lagrange point 60 degrees ahead of the orbiting planet

L-5 the gravitationally stable Lagrange point 60 degrees behind the orbiting planet

Lagrangian point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

laser-pulsing firing periodic pulses from a powerful laser at a surface and measuring the length of time for return in order to determine topography

libration point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

lichen fungus that grows symbiotically with algae

light year the distance that light in a vacuum would travel in one year, or about 9.5 trillion kilometers (5.9 trillion miles)

lithosphere the rocky outer crust of a body

littoral the region along a coast or beach between high and low tides

lobate scarps a long sinuous cliff

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

lunar maria the large, dark, lava-filled impact basins on the Moon thought by early astronomers to resemble seas

Lunar Orbiter a series of five unmanned missions in 1966 and 1967 that photographed much of the Moon at medium to high resolution from orbit

macromolecules large molecules such as proteins or DNA containing thousands or millions of individual atoms

magnetohydrodynamic waves a low frequency oscillation in a plasma in the presence of a magnetic field

magnetometer an instrument used to measure the strength and direction of a magnetic field

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

majority carriers the more abundant charge carriers in semiconductors; the less abundant are called minority carriers; for n-type semiconductors, electrons are the majority carriers

malady a disorder or disease of the body

many-bodied problem in celestial mechanics, the problem of finding solutions to the equations for more than two orbiting bodies

mare dark-colored plains of solidified lava that mainly fill the large impact basins and other low-lying regions on the Moon

Mercury the first American piloted spacecraft, which carried a single astronaut into space; six Mercury missions took place between 1961 and 1963

mesons any of a family of subatomic particle that have masses between electrons and protons and that respond to the strong nuclear force; produced in the upper atmosphere by cosmic rays

meteor the physical manifestation of a meteoroid interacting with Earth's atmosphere; this includes visible light and radio frequency generation, and an ionized trail from which radar signals can be reflected. Also called a "shooting star"

meteorites any part of a meteoroid that survives passage through Earth's atmosphere

meteoroid a piece of interplanetary material smaller than an asteroid or comet

meteorology the study of atmospheric phenomena or weather

meteorology satellites satellites designed to take measurements of the atmosphere for determining weather and climate change

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

micrometeoroid flux the total mass of micrometeoroids falling into an atmosphere or on a surface per unit of time

micrometeoroid any meteoroid ranging in size from a speck of dust to a pebble

microwave link a connection between two radio towers that each transmit and receive microwave (radio) signals as a method of carrying information (similar to radio communications)

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

missing matter the mass of the universe that cannot be accounted for but is necessary to produce a universe whose overall curvature is "flat"

monolithic massive, solid, and uniform; an asteroid that is formed of one kind of material fused or melted into a single mass

multi-bandgap photovoltaic photovoltaic cells designed to respond to several different wavelengths of electromagnetic radiation

multispectral referring to several different parts of the electromagnetic spectrum, such as visible, infrared, and radar

muons the decay product of the mesons produced by cosmic rays; muons are about 100 times more massive than electrons but are still considered leptons that do not respond to the strong nuclear force

near-Earth asteroids asteroids whose orbits cross the orbit of Earth; collisions between Earth and near Earth asteroids happen a few times every million years

nebulae clouds of interstellar gas and/or dust

neutron a subatomic particle with no electrical charge

neutron star the dense core of matter composed almost entirely of neutrons that remain after a supernova explosion has ended the life of a massive star

New Millennium a NASA program to identify, develop and validate key instrument and spacecraft technologies that can lower cost and increase performance of science missions in the twenty-first century

Next Generation Space Telescope the telescope scheduled to be launched in 2009 that will replace the Hubble Space Telescope

nuclear black holes black holes that are in the centers of galaxies; they range in mass from a thousand to a billion times the mass of the Sun

nuclear fusion the combining of low-mass atoms to create heavier ones; the heavier atom's mass is slightly less than the sum of the mass of its constituents, with the remaining mass converted to energy

nucleon a proton or a neutron; one of the two particles found in a nucleus

occultations a phenomena that occurs when one astronomical object passes in front of another

optical interferometry a branch of optical physics that uses the wavelength of visible light to measure very small changes within the environment

optical-interferometry based the use of two or more telescopes observing the same object at the same time at the same visible wavelength to increase angular resolution

optical radar a method of determining the speed of moving bodies by sending a pulse of light and measuring how long it takes for the reflected light to return to the sender

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

orbital dynamics the mathematical study of the nature of the forces governing the movement of one object in the gravitational field of another object

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

orthogonal composed of right angles or relating to right angles

oscillation energy that varies between alternate extremes with a definable period

osteoporosis the loss of bone density; can occur after extended stays in space

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

paleolake depression that shows geologic evidence of having contained a lake at some previous time

Paleozoic relating to the first appearance of animal life on Earth

parabolic trajectory trajectory followed by an object with velocity equal to escape velocity

parking orbit placing a spacecraft temporarily into Earth orbit, with the engines shut down, until it has been checked out or is in the correct location for the main burn that sends it away from Earth

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

payload bay the area in the shuttle or other spacecraft designed to carry cargo

payload fairing structure surrounding a payload; it is designed to reduce drag

payload operations experiments or procedures involving cargo or "payload" carried into orbit

payload specialists scientists or engineers selected by a company or a government employer for their expertise in conducting a specific experiment or commercial venture on a space shuttle mission

perihelion the point in an object's orbit that is closest to the Sun

period of heavy meteoroid the earliest period in solar system history (more than 3.8 billion years ago) when the rate of meteoroid impact was very high compared to the present

perturbations term used in orbital mechanics to refer to changes in orbits due to "perturbing" forces, such as gravity

phased array a radar antenna design that allows rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

phased-array antennas radar antenna designs that allow rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

photolithography printing that uses a photographic process to create the printing plates

photometer instrument to measure intensity of light

photosynthesis a process performed by plants and algae whereby light is transformed into energy and sugars

photovoltaic pertaining to the direct generation of electricity from electromagnetic radiation (light)

photovoltaic arrays sets of solar panels grouped together in big sheets; these arrays collect light from the Sun and use it to make electricity to power the equipment and machines

photovoltaic cells cells consisting of a thin wafer of a semiconductor material that incorporates a p-n junction, which converts incident light into electrical power; a number of photovoltaic cells connected in series makes a solar array

plagioclase most common mineral of the light-colored lunar highlands

planetesimals objects in the early solar system that were the size of large asteroids or small moons, large enough to begin to gravitationally influence each other

pn single junction in a transistor or other solid state device, the boundary between the two different kinds of semiconductor material

point of presence an access point to the Internet with a unique Internet Protocol (IP) address; Internet service providers (ISP) like AOL generally have multiple POPs on the Internet

polar orbits orbits that carry a satellite over the poles of a planet

polarization state degree to which a beam of electromagnetic radiation has all of the vibrations in the same plane or direction

porous allowing the passage of a fluid or gas through holes or passages in the substance

power law energy spectrum spectrum in which the distribution of energies appears to follow a power law

primary the body (planet) about which a satellite orbits

primordial swamp warm, wet conditions postulated to have occurred early in Earth's history as life was beginning to develop

procurement the process of obtaining

progenitor star the star that existed before a dramatic change, such as a supernova, occurred

prograde having the same general sense of motion or rotation as the rest of the solar system, that is, counterclockwise as seen from above Earth's north pole

prominences inactive "clouds" of solar material held above the solar surface by magnetic fields

propagate to cause to move, to multiply, or to extend to a broader area

proton a positively charged subatomic particle

pseudoscience a system of theories that assumes the form of science but fails to give reproducible results under conditions of controlled experiments

pyroclastic pertaining to clastic (broken) rock material expelled from a volcanic vent

pyrotechnics fireworks display; the art of building fireworks

quantum foam the notion that there is a smallest distance scale at which space itself is not a continuous medium, but breaks up into a seething foam of wormholes and tiny black holes far smaller than a proton

quantum gravity an attempt to replace the inherently incompatible theories of quantum physics and Einstein gravity with some deeper theory that would have features of both, but be identical to neither

quantum physics branch of physics that uses quantum mechanics to explain physical systems

quantum vacuum consistent with the Heisenberg uncertainty principle, vacuum is not empty but is filled with zero-point energy and particle-antiparticle pairs constantly being created and then mutually annihilating each other

quasars luminous objects that appear star-like but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

quiescent inactive

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

radar altimetry using radar signals bounced off the surface of a planet to map its variations in elevation

radar images images made with radar illumination instead of visible light that show differences in radar brightness of the surface material or differences in brightness associated with surface slopes

radiation belts two wide bands of charged particles trapped in a planet's magnetic field

radio lobes active galaxies show two regions of radio emission above and below the plane of the galaxy, and are thought to originate from powerful jets being emitted from the accretion disk surrounding the massive black hole at the center of active galaxies

radiogenic isotope techniques use of the ratio between various isotopes produced by radioactive decay to determine age or place of origin of an object in geology, archaeology, and other areas

radioisotope a naturally or artificially produced radioactive isotope of an element

radioisotope thermoelectric device using solid state electronics and the heat produced by radioactive decay to generate electricity

range safety destruct systems system of procedures and equipment designed to safely abort a mission when a spacecraft malfunctions, and destroy the rocket in such a way as to create no risk of injury or property damage

Ranger series of spacecraft sent to the Moon to investigate lunar landing sites; designed to hard-land on the lunar surface after sending back television pictures of the lunar surface; Rangers 7, 8, and 9 (1964–1965) returned data

rarefaction decreased pressure and density in a material caused by the passage of a sound wave

reconnaissance a survey or preliminary exploration of a region of interest

reflex motion the orbital motion of one body, such as a star, in reaction to the gravitational tug of a second orbiting body, such as a planet

regolith upper few meters of a body's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

relative zero velocity two objects having the same speed and direction of movement, usually so that spacecraft can rendezvous

relativistic time dilation effect predicted by the theory of relativity that causes clocks on objects in strong gravitational fields or moving near the speed of light to run slower when viewed by a stationary observer

remote manipulator system a system, such as the external Canada2 arm on the International Space Station, designed to be operated from a remote location inside the space station

remote sensing the act of observing from orbit what may be seen or sensed below on Earth

retrograde having the opposite general sense of motion or rotation as the rest of the solar system, clockwise as seen from above Earth's north pole

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

reusables launches that can be used many times before discarding

rift valley a linear depression in the surface, several hundred to thousand kilometers long, along which part of the surface has been stretched, faulted, and dropped down along many normal faults

rille lava channels in regions of maria, typically beginning at a volcanic vent and extending downslope into a smooth mare surface

rocket vehicle or device that is especially designed to travel through space, and is propelled by one or more engines

"rocky" planets nickname given to inner or solid-surface planets of the solar system, including Mercury, Venus, Mars, and Earth

rover vehicle used to move about on a surface

rutile a red, brown, or black mineral, primarily titanium dioxide, used as a gemstone and also a commercially important ore of titanium

satellite any object launched by a rocket for the purpose of orbiting the Earth or another celestial body

scoria fragments of lava resembling cinders

secondary crater crater formed by the impact of blocks of rock blasted out of the initial crater formed by an asteroid or large meteorite

sedentary lifestyle a lifestyle characterized by little movement or exercise

sedimentation process of depositing sediments, which result in a thick accumulation of rock debris eroded from high areas and deposited in low areas

semiconductor one of the groups of elements with properties intermediate between the metals and nonmetals

semimajor axis one half of the major axis of an ellipse, equal to the average distance of a planet from the Sun

shepherding small satellites exerting their gravitational influence to cause or maintain structure in the rings of the outer planets

shield volcanoes volcanoes that form broad, low-relief cones, characterized by lava that flows freely

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

sine wave a wave whose amplitude smoothly varies with time; a wave form that can be mathematically described by a sine function

smooth plains the youngest plains on Mercury with a relatively low impact crater abundance

soft-landers spacecraft that uses braking by engines or other techniques (e.g., parachutes, airbags) such that its landing is gentle enough that the spacecraft and its instruments are not damaged, and observations at the surface can be made

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

solar corona the thin outer atmosphere of the Sun that gradually transitions into the solar wind

solar flares explosions on the Sun that release bursts of electromagnetic radiation, such as light, ultraviolet waves, and X rays, along with high speed protons and other particles

solar nebula the cloud of gas and dust out of which the solar system formed

solar prominence cool material with temperatures typical of the solar photosphere or chromosphere suspended in the corona above the visible surface layers

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

sounding rocket a vehicle designed to fly straight up and then parachute back to Earth, usually designed to take measurements of the upper atmosphere

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period; to date, only Earth-orbiting space stations have been launched

space-time in relativity, the four-dimensional space through which objects move and in which events happen

spacecraft bus the primary structure and subsystems of a spacecraft

spacewalking moving around outside a spaceship or space station, also known as extravehicular activity

special theory of relativity the fundamental idea of Einstein's theories, which demonstrated that measurements of certain physical quantities such as mass, length, and time depended on the relative motion of the object and observer

specific power amount of electric power generated by a solar cell per unit mass; for example watts per kilogram

spectra representations of the brightness of objects as a function of the wavelength of the emitted radiation

spectral lines the unique pattern of radiation at discrete wavelengths that many materials produce

spectrograph an instrument that can permanently record a spectra

spectrographic studies studies of the nature of matter and composition of substances by examining the light they emit

spectrometers an instrument with a scale for measuring the wavelength of light

spherules tiny glass spheres found in and among lunar rocks

spot beam technology narrow, pencil-like satellite beam that focuses highly radiated energy on a limited area of Earth's surface (about 100 to 500 miles in diameter) using steerable or directed antennas

stratigraphy the study of rock layers known as strata, especially the age and distribution of various kinds of sedimentary rocks

stratosphere a middle portion of a planet's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

subduction the process by which one edge of a crustal plate is forced to move under another plate

sublimate to pass directly from a solid phase to a gas phase

suborbital trajectory the trajectory of a rocket or ballistic missile that has insufficient energy to reach orbit

subsolar point the point on a planet that receives direct rays from the Sun

substrate the surface, such as glass, metallic foil, or plastic sheet, on which a thin film of photovoltaic material is deposited

sunspots dark, cooler areas on the solar surface consisting of transient, concentrated magnetic fields

supercarbonaceous term given to P- and D-type meteorites that are richer in carbon than any other meteorites and are thought to come from the primitive asteroids in the outer part of the asteroid belt

supernova an explosion ending the life of a massive star

supernovae ejecta the mix of gas enriched by heavy metals that is launched into space by a supernova explosion

superstring theory the best candidate for a "theory of everything" unifying quantum mechanics and gravity, proposes that all particles are oscillations in tiny loops of matter only 10^{-35} meters long and moving in a space of ten dimensions

superstrings supersymmetric strings are tiny, one dimensional objects that are about 10^{-33} cm long, in a 10-dimensional spacetime. Their different vibration modes and shapes account for the elementary particles we see in our 4-dimensional spacetime

Surveyor a series of spacecraft designed to soft-land robotic laboratories to analyze and photograph the lunar surface; Surveyors 1, 3, and 5–7 landed between May 1966 and January 1968

synchrotron radiation the radiation from electrons moving at almost the speed of light inside giant magnetic accelerators of particles, called synchrotrons, either on Earth or in space

synthesis the act of combining different things so as to form new and different products or ideas

technology transfer the acquisition by one country or firm of the capability to develop a particular technology through its interactions with the existing technological capability of another country or firm, rather than through its own research efforts

tectonism process of deformation in a planetary surface as a result of geological forces acting on the crust; includes faulting, folding, uplift, and downwarping of the surface and crust

telescience the act of operation and monitoring of research equipment located in space by a scientist or engineer from their offices or laboratories on Earth

terrestrial planet a small rocky planet with high density orbiting close to the Sun; Mercury, Venus, Earth, and Mars

thermodynamically referring to the behavior of energy

thermostabilized designed to maintain a constant temperature

thrust fault a fault where the block on one side of the fault plane has been thrust up and over the opposite block by horizontal compressive forces

toxicological related to the study of the nature and effects on humans of poisons and the treatment of victims of poisoning

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

transonic barrier the aerodynamic behavior of an aircraft moving near the speed of sound changes dramatically and, for early pioneers of transonic flight, dangerously, leading some to hypothesize there was a "sound barrier" where drag became infinite

transpiration process whereby water evaporates from the surface of leaves, allowing the plant to lose heat and to draw water up through the roots

transponder bandwidth-specific transmitter-receiver units

troctolite rock type composed of the minerals plagioclase and olivine, crystallized from magma

tunnelborer a mining machine designed to dig a tunnel using rotating cutting disks

Tycho event the impact of a large meteoroid into the lunar surface as recently as 100 million years ago, leaving a distinct set of bright rays across the lunar surface including a ray through the Apollo 17 landing site

ultramafic lavas dark, heavy lavas with a high percentage of magnesium and iron; usually found as boulders mixed in other lava rocks

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

ultraviolet radiation electromagnetic radiation with a shorter wavelength and higher energy than light

uncompressed density the lower density a planet would have if it did not have the force of gravity compressing it

Universal time current time in Greenwich, England, which is recognized as the standard time that Earth's time zones are based

vacuum an environment where air and all other molecules and atoms of matter have been removed

vacuum conditions the almost complete lack of atmosphere found on the surface of the Moon and in space

Van Allen radiation belts two belts of high energy charged particles captured from the solar wind by Earth's magnetic field

variable star a star whose light output varies over time

vector sum sum of two vector quantities taking both size and direction into consideration

velocity speed and direction of a moving object; a vector quantity

virtual-reality simulations a simulation used in training by pilots and astronauts to safely reproduce various conditions that can occur on board a real aircraft or spacecraft

visible spectrum the part of the electromagnetic spectrum with wavelengths between 400 nanometers and 700 nanometers; the part of the electromagnetic spectrum to which human eyes are sensitive

volatile ices (e.g., H_2O and CO_2) that are solids inside a comet nucleus but turn into gases when heated by sunlight

volatile materials materials that easily pass into the vapor phase when heated

wavelength the distance from crest to crest on a wave at an instant in time

X ray form of high-energy radiation just beyond the ultraviolet portion of the spectrum

X-ray diffraction analysis a method to determine the three-dimensional structure of molecules

Volume 2 Index

*Page numbers in **boldface type** indicate article titles; those in italic type indicate illustrations. A cumulative index, which combines the terms in all volumes of* Space Sciences, *can be found in volume 4 of this series.*

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VOLUME 3

Humans in Space

Pat Dasch, Editor in Chief

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Preface

Astronomers have studied the heavens for more than two millennia, but in the twentieth century, humankind ventured off planet Earth into the dark vacuum void of space, forever changing our perspective of our home planet and on our relationship to the universe in which we reside.

Our explorations of space—the final frontier in our niche in this solar system—first with satellites, then robotic probes, and finally with humans, have given rise to an extensive space industry that has a major influence on the economy and on our lives. In 1998, U.S. space exports (launch services, satellites, space-based communications services, and the like) totaled $64 billion. As we entered the new millennium, space exports were the second largest dollar earner after agriculture. The aerospace industry directly employs some 860,000 Americans, with many more involved in subcontracting companies and academic research.

Beginnings

The Chinese are credited with developing the rudiments of rocketry—they launched rockets as missiles against invading Mongols in 1232. In the nineteenth century William Congrieve developed a rocket in Britain based on designs conceived in India in the eighteenth century. Congrieve extended the range of the Indian rockets, adapting them specifically for use by armies. Congrieve's rockets were used in 1806 in the Napoleonic Wars.

The Birth of Modern Space Exploration

The basis of modern spaceflight and exploration came with the writings of Konstantin Tsiolkovsky (1857–1935), a Russian mathematics teacher. He described multi-stage rockets, winged craft like the space shuttle developed in the 1970s, space stations like Mir and the International Space Station, and interplanetary missions of discovery.

During the same period, space travel captured the imagination of fiction writers. Jules Verne wrote several novels with spaceflight themes. His book, *From the Earth to the Moon* (1865), describes manned flight to the Moon, including a launch site in Florida and a spaceship named Columbia—the name chosen for the Apollo 11 spaceship that made the first lunar landing in July 1969 and the first space shuttle, which flew in April 1981. In the twentieth century, Arthur C. Clarke predicted the role of communications satellites and extended our vision of human space exploration while

television series such as *Star Trek* and *Dr. Who* challenged the imagination and embedded the idea of space travel in our culture.

The first successful test of the V-2 rocket developed by Wernher von Braun and his team at Peenemünde, Germany, in October 1942 has been described as the "birth of the Space Age." After World War II some of the Peenemünde team under von Braun came to the United States, where they worked at the White Sands Missile Range in New Mexico, while others went to Russia. This sowed the seeds of the space race of the 1960s. Each team worked to develop advanced rockets, with Russia developing the R-7, while a series of rockets with names like Thor, Redstone, and Titan were produced in the United States.

When the Russians lofted Sputnik, the first artificial satellite, on October 4, 1957, the race was on. The flights of Yuri Gagarin, Alan Shepard, and John Glenn followed, culminating in the race for the Moon and the Apollo Program of the 1960s and early 1970s.

The Emergence of a Space Industry

The enormous national commitment to the Apollo Program marked a new phase in our space endeavors. The need for innovation and technological advance stimulated the academic and engineering communities and led to the growth of a vast network of contract supporters of the aerospace initiative and the birth of a vibrant space industry. At the same time, planetary science emerged as a new geological specialization.

Following the Apollo Program, the U.S. space agency's mission remained poorly defined through the end of the twentieth century, grasping at major programs such as development of the space shuttle and the International Space Station, in part, some argue, to provide jobs for the very large workforce spawned by the Apollo Program. The 1980s saw the beginnings of what would become a robust commercial space industry, largely independent of government programs, providing communications and information technology via space-based satellites. During the 1990s many thought that commercialization was the way of the future for space ventures. Commercially coordinated robotic planetary exploration missions were conceived with suggestions that NASA purchase the data, and Dennis Tito, the first paying space tourist in 2001, raised hopes of access to space for all.

The terrorist attacks on the United States on September 11, 2001 and the U.S. recession led to a re-evaluation of the entrepreneurial optimism of the 1990s. Many private commercial space ventures were placed on hold or went out of business. Commentators suggested that the true dawning of the commercial space age would be delayed by up to a decade. But, at the same time, the U.S. space agency emerged with a more clearly defined mandate than it had had since the Apollo Program, with a role of driving technological innovation—with an early emphasis on reducing the cost of getting to orbit—and leading world class space-related scientific projects. And military orders, to fill the needs of the new world order, compensated to a point for the downturn in the commercial space communications sector.

It is against this background of an industry in a state of flux, a discipline on the cusp of a new age of innovation, that this encyclopedia has been prepared.

Organization of the Material

The 341 entries in *Space Sciences* have been organized in four volumes, focusing on the business of space exploration, planetary science and astronomy, human space exploration, and the outlook for the future exploration of space. Each entry has been newly commissioned for this work. Our contributors are drawn from academia, industry, government, professional space institutes and associations, and nonprofit organizations. Many of the contributors are world authorities on their subject, providing up-to-the-minute information in a straightforward style accessible to high school students and university undergraduates.

One of the outstanding advantages of books on space is the wonderful imagery of exploration and achievement. These volumes are richly illustrated, and sidebars provide capsules of additional information on topics of particular interest. Entries are followed by a list of related entries, as well as a reading list for students seeking more information.

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Pat Dasch
Editor in Chief

For Your Reference

The following section provides information that is applicable to a number of articles in this reference work. Included in the following pages is a chart providing comparative solar system planet data, as well as measurement, abbreviation, and conversion tables.

SOLAR SYSTEM PLANET DATA

	Mercury	Venus[2]	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Mean distance from the Sun (AU): [1]	0.387	0.723	1	1.524	5.202	9.555	19.218	30.109	39.439
Siderial period of orbit (years):	0.24	0.62	1	1.88	11.86	29.46	84.01	164.79	247.68
Mean orbital velocity (km/sec):	47.89	35.04	29.79	24.14	13.06	9.64	6.81	5.43	4.74
Orbital essentricity:	0.206	0.007	0.017	0.093	0.048	0.056	0.047	0.009	0.246
Inclination to ecliptic (degrees):	7.00	3.40	0	1.85	1.30	2.49	0.77	1.77	17.17
Equatorial radius (km):	2439	6052	6378	3397	71492	60268	25559	24764	1140
Polar radius (km):	same	same	6357	3380	66854	54360	24973	24340	same
Mass of planet (Earth = 1):[3]	0.06	0.82	1	0.11	317.89	95.18	14.54	17.15	0.002
Mean density (gm/cm ^{3}):	5.44	5.25	5.52	3.94	1.33	0.69	1.27	1.64	2.0
Body rotation period (hours):	1408	5832.R	23.93	24.62	9.92	10.66	17.24	16.11	153.3
Tilt of equator to orbit (degrees):	0	2.12	23.45	23.98	3.08	26.73	97.92	28.8	96

[1]AU indicates one astronomical unit, defined as the mean distance between Earth and the Sun (~1.495 x 10^8 km).
[2]R indicates planet rotation is retrograde (i.e., opposite to the planet's orbit).
[3]Earth's mass is approximately 5.976 x 10^{26} grams.

SI BASE AND SUPPLEMENTARY UNIT NAMES AND SYMBOLS

Physical Quality	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
Plane angle	radian	rad
Solid angle	steradian	sr

Temperature

Scientists commonly use the Celsius system. Although not recommended for scientific and technical use, earth scientists also use the familiar Fahrenheit temperature scale (°F). 1°F = 1.8°C or K. The triple point of H_2O, where gas, liquid, and solid water coexist, is 32°F.

- To change from Fahrenheit (F) to Celsius (C):
  °C = (°F-32)/(1.8)
- To change from Celsius (C) to Fahrenheit (F):
  °F = (°C x 1.8) + 32
- To change from Celsius (C) to Kelvin (K):
  K = °C + 273.15
- To change from Fahrenheit (F) to Kelvin (K):
  K = (°F-32)/(1.8) + 273.15

UNITS DERIVED FROM SI, WITH SPECIAL NAMES AND SYMBOLS

Derived Quantity	Name of SI Unit	Symbol for SI Unit	Expression in Terms of SI Base Units
Frequency	hertz	Hz	s-1
Force	newton	N	m kg s-2
Pressure, stress	Pascal	Pa	N m-2 =m-1 kg s-2
Energy, work, heat	Joule	J	N m =m2 kg s-2
Power, radiant flux	watt	W	J s-1 =m2 kg s-3
Electric charge	coulomb	C	A s
Electric potential, electromotive force	volt	V	J C-1 =m-2 kg s-3 A-1
Electric resistance	ohm	_	V A-1 =m2 kg s-3 A-2
Celsius temperature	degree Celsius	C	K
Luminous flux	lumen	lm	cd sr
Illuminance	lux	lx	cd sr m-2

UNITS USED WITH SI, WITH NAME, SYMBOL, AND VALUES IN SI UNITS

The following units, not part of the SI, will continue to be used in appropriate contexts (e.g., angtsrom):

Physical Quantity	Name of Unit	Symbol for Unit	Value in SI Units
Time	minute	min	60 s
	hour	h	3,600 s
	day	d	86,400 s
Plane angle	degree	°	(π/180) rad
	minute	'	(π/10,800) rad
	second	"	(π/648,000) rad
Length	angstrom	Å	10^{-10} m
Volume	liter	l, L	1 dm^3 = 10^{-3} m^3
Mass	ton	t	1 mg = 10^3 kg
	unified atomic mass unit	u (=$m_a(^{12}C)/12$)	≈1.66054 x 10^{-27} kg
Pressure	bar	bar	10^5 Pa = 10^5 N m^{-2}
Energy	electronvolt	eV (= e X V)	≈1.60218 x 10^{-19} J

CONVERSIONS FOR STANDARD, DERIVED, AND CUSTOMARY MEASUREMENTS

Length

1 angstrom (Å)	0.1 nanometer (exactly) 0.000000004 inch
1 centimeter (cm)	0.3937 inches
1 foot (ft)	0.3048 meter (exactly)
1 inch (in)	2.54 centimeters (exactly)
1 kilometer (km)	0.621 mile
1 meter (m)	39.37 inches 1.094 yards
1 mile (mi)	5,280 feet (exactly) 1.609 kilometers
1 astronomical unit (AU)	1.495979×10^{13} cm
1 parsec (pc)	206,264.806 AU 3.085678×10^{18} cm 3.261633 light-years
1 light-year	9.460530×10^{17} cm

Area

1 acre	43,560 square feet (exactly) 0.405 hectare
1 hectare	2.471 acres
1 square centimeter (cm^2)	0.155 square inch
1 square foot (ft^2)	929.030 square centimeters
1 square inch (in^2)	6.4516 square centimeters (exactly)
1 square kilometer (km^2)	247.104 acres 0.386 square mile
1 square meter (m^2)	1.196 square yards 10.764 square feet
1 square mile (mi^2)	258.999 hectares

MEASUREMENTS AND ABBREVIATIONS

Volume

1 barrel (bbl)*, liquid	31 to 42 gallons
1 cubic centimeter (cm^3)	0.061 cubic inch
1 cubic foot (ft^3)	7.481 gallons 28.316 cubic decimeters
1 cubic inch (in^3)	0.554 fluid ounce
1 dram, fluid (or liquid)	$\frac{1}{8}$ fluid ounce (exactly) 0.226 cubic inch 3.697 milliliters
1 gallon (gal) (U.S.)	231 cubic inches (exactly) 3.785 liters 128 U.S. fluid ounces (exactly)
1 gallon (gal) (British Imperial)	277.42 cubic inches 1.201 U.S. gallons 4.546 liters
1 liter	1 cubic decimeter (exactly) 1.057 liquid quarts 0.908 dry quart 61.025 cubic inches
1 ounce, fluid (or liquid)	1.805 cubic inches 29.573 mililiters
1 ounce, fluid (fl oz) (British)	0.961 U.S. fluid ounce 1.734 cubic inches 28.412 milliliters
1 quart (qt), dry (U.S.)	67.201 cubic inches 1.101 liters
1 quart (qt), liquid (U.S.)	57.75 cubic inches (exactly) 0.946 liter

* There are a variety of "barrels" established by law or usage. For example, U.S. federal taxes on fermented liquors are based on a barrel of 31 gallons (141 liters); many state laws fix the "barrel for liquids" as 31½ gallons (119.2 liters); one state fixes a 36-gallon (160.5 liters) barrel for cistern measurment; federal law recognizes a 40-gallon (178 liters) barrel for "proof spirts"; by custom, 42 gallons (159 liters) comprise a barrel of crude oil or petroleum products for statistical purposes, and this equivalent is recognized "for liquids" by four states.

Units of mass

1 carat (ct)	200 milligrams (exactly) 3.086 grains
1 grain	64.79891 milligrams (exactly)
1 gram (g)	15.432 grains 0.035 ounce
1 kilogram (kg)	2.205 pounds
1 microgram (μg)	0.000001 gram (exactly)
1 milligram (mg)	0.015 grain
1 ounce (oz)	437.5 grains (exactly) 28.350 grams
1 pound (lb)	7,000 grains (exactly) 453.59237 grams (exactly)
1 ton, gross or long	2,240 pounds (exactly) 1.12 net tons (exactly) 1.016 metric tons
1 ton, metric (t)	2,204.623 pounds 0.984 gross ton 1.102 net tons
1 ton, net or short	2,000 pounds (exactly) 0.893 gross ton 0.907 metric ton

Pressure

1 kilogram/square centimeter (kg/cm^2)	0.96784 atmosphere (atm) 14.2233 pounds/square inch (lb/in^2) 0.98067 bar
1 bar	0.98692 atmosphere (atm) 1.02 kilograms/square centimeter (kg/cm^2)

Milestones in Space History

c. 850 The Chinese invent a form of gunpowder for rocket propulsion.

1242 Englishman Roger Bacon develops gunpowder.

1379 Rockets are used as weapons in the Siege of Chioggia, Italy.

1804 William Congrieve develops ship-fired rockets.

1903 Konstantin Tsiolkovsky publishes *Research into Interplanetary Science by Means of Rocket Power*, a treatise on space travel.

1909 Robert H. Goddard develops designs for liquid-fueled rockets.

1917 Smithsonian Institute issues grant to Goddard for rocket research.

1918 Goddard publishes the monograph *Method of Attaining Extreme Altitudes.*

1921 Soviet Union establishes a state laboratory for solid rocket research.

1922 Hermann Oberth publishes *Die Rakete zu den Planetenräumen*, a work on rocket travel through space.

1923 Tsiolkovsky publishes work postulating multi-staged rockets.

1924 Walter Hohmann publishes work on rocket flight and orbital motion.

1927 The German Society for Space Travel holds its first meeting.

Max Valier proposes rocket-powered aircraft adapted from Junkers G23.

1928 Oberth designs liquid rocket for the film *Woman in the Moon.*

1929 Goddard launches rocket carrying barometer.

1930 Soviet rocket designer Valentin Glusko designs U.S.S.R. liquid rocket engine.

1931 Eugene Sänger test fires liquid rocket engines in Vienna.

1932 German Rocket Society fires first rocket in test flight.

1933 Goddard receives grant from Guggenheim Foundation for rocket studies.

1934 Wernher von Braun, member of the German Rocket Society, test fires water-cooled rocket.

1935 Goddard fires advanced liquid rocket that reaches 700 miles per hour.

1936 Glushko publishes work on liquid rocket engines.

1937 The Rocket Research Project of the California Institute of Technology begins research program on rocket designs.

1938 von Braun's rocket researchers open center at Pennemünde.

1939 Sänger and Irene Brendt refine rocket designs and propose advanced winged suborbital bomber.

1940 Goddard develops centrifugal pumps for rocket engines.

1941 Germans test rocket-powered interceptor aircraft Me 163.

1942 V-2 rocket fired from Pennemünde enters space during ballistic flight.

1943 First operational V-2 launch.

1944 V-2 rocket launched to strike London.

1945 Arthur C. Clarke proposes geostationary satellites.

1946 Soviet Union tests version of German V-2 rocket.

1947 United States test fires Corporal missile from White Sands, New Mexico.

X-1 research rocket aircraft flies past the speed of sound.

1948 United States reveals development plan for Earth satellite adapted from RAND.

1949 Chinese rocket scientist Hsueh-Sen proposes hypersonic aircraft.

1950 United States fires Viking 4 rocket to record 106 miles from USS Norton Sound.

1951 Bell Aircraft Corporation proposes winged suborbital rocket-plane.

1952 Wernher von Braun proposes wheeled Earth-orbiting space station.

1953 U.S. Navy D-558II sets world altitude record of 15 miles above Earth.

1954 Soviet Union begins design of RD-107, RD-108 ballistic missile engines.

1955 Soviet Union launches dogs aboard research rocket on suborbital flight.

1956	United States announces plan to launch Earth satellite as part of Geophysical Year program.
1957	U.S. Army Ballistic Missile Agency is formed.
	Soviet Union test fires R-7 ballistic missile.
	Soviet Union launches the world's first Earth satellite, Sputnik-1, aboard R-7.
	United States launches 3-stage Jupiter C on test flight.
	United States attempts Vanguard 1 satellite launch; rocket explodes.
1958	United States orbits Explorer-1 Earth satellite aboard Jupiter-C rocket.
	United States establishes the National Aeronautics and Space Administration (NASA) as civilian space research organization.
	NASA establishes Project Mercury manned space project.
	United States orbits Atlas rocket with Project Score.
1959	Soviet Union sends Luna 1 towards Moon; misses by 3100 miles.
	NASA announces the selection of seven astronauts for Earth space missions.
	Soviet Union launches Luna 2, which strikes the Moon.
1960	United States launches Echo satellite balloon.
	United States launches Discoverer 14 into orbit, capsule caught in midair.
	Soviet Union launches two dogs into Earth orbit.
	Mercury-Redstone rocket test fired in suborbital flight test.
1961	Soviet Union tests Vostok capsule in Earth orbit with dummy passenger.
	Soviet Union launches Yuri Gagarin aboard Vostok-1; he becomes the first human in space.
	United States launches Alan B. Shepard on suborbital flight.
	United States proposes goal of landing humans on the Moon before 1970.
	Soviet Union launches Gherman Titov into Earth orbital flight for one day.
	United States launches Virgil I. "Gus" Grissom on suborbital flight.
	United States launches first Saturn 1 rocket in suborbital test.

1962	United States launches John H. Glenn into 3-orbit flight.
	United States launches Ranger to impact Moon; craft fails.
	First United States/United Kingdom international satellite launch; Ariel 1 enters orbit.
	X-15 research aircraft sets new altitude record of 246,700 feet.
	United States launches Scott Carpenter into 3-orbit flight.
	United States orbits Telstar 1 communications satellite.
	Soviet Union launches Vostok 3 and 4 into Earth orbital flight.
	United States launches Mariner II toward Venus flyby.
	United States launches Walter Schirra into 6-orbit flight.
	Soviet Union launches Mars 1 flight; craft fails.
1963	United States launches Gordon Cooper into 22-orbit flight.
	Soviet Union launches Vostok 5 into 119-hour orbital flight.
	United States test fires advanced solid rockets for Titan 3C.
	First Apollo Project test in Little Joe II launch.
	Soviet Union orbits Vostok 6, which carries Valentina Tereshkova, the first woman into space.
	Soviet Union tests advanced version of R-7 called Soyuz launcher.
1964	United States conducts first Saturn 1 launch with live second stage; enters orbit.
	U.S. Ranger 6 mission launched towards Moon; craft fails.
	Soviet Union launches Zond 1 to Venus; craft fails.
	United States launches Ranger 7 on successful Moon impact.
	United States launches Syncom 3 communications satellite.
	Soviet Union launches Voshkod 1 carrying three cosmonauts.
	United States launches Mariner 4 on Martian flyby mission.
1965	Soviet Union launches Voshkod 2; first space walk.
	United States launches Gemini 3 on 3-orbit piloted test flight.
	United States launches Early Bird 1 communications satellite.
	United States launches Gemini 4 on 4-day flight; first U.S. space walk.

	United States launches Gemini 5 on 8-day flight.
	United States launches Titan 3C on maiden flight.
	Europe launches Asterix 1 satellite into orbit.
	United States Gemini 6/7 conduct first space rendezvous.
1966	Soviet Union launches Luna 9, which soft lands on Moon.
	United States Gemini 8 conducts first space docking; flight aborted.
	United States launches Surveyor 1 to Moon soft landing.
	United States tests Atlas Centaur advanced launch vehicle.
	Gemini 9 flight encounters space walk troubles.
	Gemini 10 flight conducts double rendezvous.
	United States launches Lunar Orbiter 1 to orbit Moon.
	Gemini 11 tests advanced space walks.
	United States launches Saturn IB on unpiloted test flight.
	Soviet Union tests advanced Proton launch vehicle.
	United States launches Gemini 12 to conclude two-man missions.
1967	Apollo 1 astronauts killed in launch pad fire.
	Soviet Soyuz 1 flight fails; cosmonaut killed.
	Britain launches Ariel 3 communications satellite.
	United States conducts test flight of M2F2 lifting body research craft.
	United States sends Surveyor 3 to dig lunar soils.
	Soviet Union orbits anti-satellite system.
	United States conducts first flight of Saturn V rocket (Apollo 4).
1968	Yuri Gagarin killed in plane crash.
	Soviet Union docks Cosmos 212 and 213 automatically in orbit.
	United States conducts Apollo 6 Saturn V test flight; partial success.
	Nuclear rocket engine tested in Nevada.
	United States launches Apollo 7 in three-person orbital test flight.
	Soviet Union launches Soyuz 3 on three-day piloted flight.
	United States sends Apollo 8 into lunar orbit; first human flight to Moon.
1969	Soviet Union launches Soyuz 4 and 5 into orbit; craft dock.
	Largest tactical communications satellite launched.

	United States flies Apollo 9 on test of lunar landing craft in Earth orbit.
	United States flies Apollo 10 to Moon in dress rehearsal of landing attempt.
	United States cancels military space station program.
	United States flies Apollo 11 to first landing on the Moon.
	United States cancels production of Saturn V in budget cut.
	Soviet lunar rocket N-1 fails in launch explosion.
	United States sends Mariner 6 on Mars flyby.
	United States flies Apollo 12 on second lunar landing mission.
	Soviet Union flies Soyuz 6 and 7 missions.
	United States launches Skynet military satellites for Britain.
1970	China orbits first satellite.
	Japan orbits domestic satellite.
	United States Apollo 13 mission suffers explosion; crew returns safely.
	Soviet Union launches Venera 7 for landing on Venus.
	United States launches military early warning satellite.
	Soviet Union launches Luna 17 to Moon.
	United States announces modifications to Apollo spacecraft.
1971	United States flies Apollo 14 to Moon landing.
	Soviet Union launches Salyut 1 space station into orbit.
	First crew to Salyut station, Soyuz 11, perishes.
	Soviet Union launches Mars 3 to make landing on the red planet.
	United States flies Apollo 15 to Moon with roving vehicle aboard.
1972	United States and the Soviet Union sign space cooperation agreement.
	United States launches Pioneer 10 to Jupiter flyby.
	Soviet Union launches Venera 8 to soft land on Venus.
	United States launches Apollo 16 to moon.
	India and Soviet Union sign agreement for launch of Indian satellite.
	United States initiates space shuttle project.
	United States flies Apollo 17, last lunar landing mission.

1973	United States launches Skylab space station.
	United States launches first crew to Skylab station.
	Soviet Union launches Soyuz 12 mission.
	United States launches second crew to Skylab space station.
1974	United States launches ATS research satellite.
	Soviet Union launches Salyut 3 on unpiloted test flight.
	Soviet Union launches Soyuz 12, 13, and 14 flights.
	Soviet Union launches Salyut 4 space station.
1975	Soviet Union launches Soyuz 17 to dock with Salyut 4 station.
	Soviet Union launches Venera 9 to soft land on Venus.
	United States and Soviet Union conduct Apollo-Soyuz Test Project joint flight.
	China orbits large military satellite.
	United States sends Viking 1 and 2 towards landing on Martian surface.
	Soviet Union launches unpiloted Soyuz 20.
1976	Soviet Union launches Salyut 5 space station.
	First space shuttle rolls out; Enterprise prototype.
	Soviet Union docks Soyuz 21 to station.
	China begins tests of advanced ballistic missile.
1977	Soyuz 24 docks with station.
	United States conducts atmospheric test flights of shuttle Enterprise.
	United States launches Voyager 1 and 2 on deep space missions.
	Soviet Union launches Salyut 6 space station.
	Soviet Soyuz 25 fails to dock with station.
	Soyuz 26 is launched and docks with station.
1978	Soyuz 27 is launched and docks with Salyut 6 station.
	Soyuz 28 docks with Soyuz 27/Salyut complex.
	United States launches Pioneer/Venus 1 mission.
	Soyuz 29 docks with station.
	Soviet Union launches Progress unpiloted tankers to station.
	Soyuz 30 docks with station.
	United States launches Pioneer/Venus 2.
	Soyuz 31 docks with station.

1979	Soyuz 32 docks with Salyut station.
	Voyager 1 flies past Jupiter.
	Soyuz 33 fails to dock with station.
	Voyager 2 flies past Jupiter.
1980	First Ariane rocket launches from French Guiana; fails.
	Soviet Union begins new Soyuz T piloted missions.
	STS-1 first shuttle mission moves to launching pad.
1981	Soviet Union orbits advanced Salyut stations.
	STS-1 launched on first space shuttle mission.
	United States launches STS-2 on second shuttle flight; mission curtailed.
1982	United States launches STS-5 first operational shuttle flight.
1983	United States launches Challenger, second orbital shuttle, on STS-6.
	United States launches Sally Ride, the first American woman in space, on STS-7.
	United States launches Guion Bluford, the first African-American astronaut, on STS-8.
	United States launches first Spacelab mission aboard STS-9.
1984	Soviet Union tests advanced orbital station designs.
	Shuttle Discovery makes first flights.
	United States proposes permanent space station as goal.
1985	Space shuttle Atlantis enters service.
	United States announces policy for commercial rocket sales.
	United States flies U.S. Senator aboard space shuttle Challenger.
1986	Soviet Union launches and occupies advanced Mir space station.
	Challenger—on its tenth mission, STS-51-L—is destroyed in a launching accident.
	United States restricts payloads on future shuttle missions.
	United States orders replacement shuttle for Challenger.
1987	Soviet Union flies advanced Soyuz T-2 designs.
	United States' Delta, Atlas, and Titan rockets grounded in launch failures.
	Soviet Union launches Energyia advanced heavy lift rocket.

1988	Soviet Union orbits unpiloted shuttle Buran.
	United States launches space shuttle Discovery on STS-26 flight.
	United States launches STS-27 military shuttle flight.
1989	United States launches STS-29 flight.
	United States launches Magellan probe from shuttle.
1990	Shuttle fleet grounded for hydrogen leaks.
	United States launches Hubble Space Telescope.
1992	Replacement shuttle Endeavour enters service.
	United States probe Mars Observer fails.
1993	United States and Russia announce space station partnership.
1994	United States shuttles begin visits to Russian space station Mir.
1995	Europe launches first Ariane 5 advanced booster; flight fails.
1996	United States announces X-33 project to replace shuttles.
1997	Mars Pathfinder lands on Mars.
1998	First elements of International Space Station launched.
1999	First Ocean space launch of Zenit rocket in Sea Launch program.
2000	Twin United States Mars missions fail.
2001	United States cancels shuttle replacements X-33 and X-34 because of space cutbacks.
	United States orbits Mars Odyssey probe around Mars.
2002	First launches of United States advanced Delta IV and Atlas V commercial rockets.

Frank Sietzen, Jr.

Human Achievements in Space

The road to space has been neither steady nor easy, but the journey has cast humans into a new role in history. Here are some of the milestones and achievements.

Oct. 4, 1957 The Soviet Union launches the first artificial satellite, a 184-pound spacecraft named Sputnik.

Nov. 3, 1957 The Soviets continue pushing the space frontier with the launch of a dog named Laika into orbit aboard Sputnik 2. The dog lives for seven days, an indication that perhaps people may also be able to survive in space.

Jan. 31, 1958 The United States launches Explorer 1, the first U.S. satellite, and discovers that Earth is surrounded by radiation belts. James Van Allen, who instrumented the satellite, is credited with the discovery.

Apr. 12, 1961 Yuri Gagarin becomes the first person in space. He is launched by the Soviet Union aboard a Vostok rocket for a two-hour orbital flight around the planet.

May 5, 1961 Astronaut Alan Shepard becomes the first American in space. Shepard demonstrates that individuals can control a vehicle during weightlessness and high gravitational forces. During his 15-minute suborbital flight, Shepard reaches speeds of 5,100 mph.

May 24, 1961 Stung by the series of Soviet firsts in space, President John F. Kennedy announces a bold plan to land men on the Moon and bring them safely back to Earth before the end of the decade.

Feb. 20, 1962 John Glenn becomes the first American in orbit. He flies around the planet for nearly five hours in his Mercury capsule, Friendship 7.

June 16, 1963 The Soviets launch the first woman, Valentina Tereshkova, into space. She circles Earth in her Vostok spacecraft for three days.

Nov. 28, 1964 NASA launches Mariner 4 spacecraft for a flyby of Mars.

Mar. 18, 1965 Cosmonaut Alexei Leonov performs the world's first space walk outside his Voskhod 2 spacecraft. The outing lasts 10 minutes.

Mar. 23, 1965 Astronauts Virgil I. "Gus" Grissom and John Young blast off on the first Gemini mission and demonstrate for the first time how to maneuver from one orbit to another.

June 3, 1965 Astronaut Edward White becomes the first American to walk in space during a 21-minute outing outside his Gemini spacecraft.

Mar. 16, 1966 Gemini astronauts Neil Armstrong and David Scott dock their spacecraft with an unmanned target vehicle to complete the first joining of two spacecraft in orbit. A stuck thruster forces an early end to the experiment, and the crew makes America's first emergency landing from space.

Jan. 27, 1967 The Apollo 1 crew is killed when a fire breaks out in their command module during a prelaunch test. The fatalities devastate the American space community, but a subsequent spacecraft redesign helps the United States achieve its goal of sending men to the Moon.

Apr. 24, 1967 Tragedy also strikes the Soviet space program, with the death of cosmonaut Vladimir Komarov. His new Soyuz spacecraft gets tangled with parachute lines during reentry and crashes to Earth.

Dec. 21, 1968 Apollo 8, the first manned mission to the Moon, blasts off from Cape Canaveral, Florida. Frank Borman, Jim Lovell and Bill Anders orbit the Moon ten times, coming to within 70 miles of the lunar surface.

July 20, 1969 Humans walk on another world for the first time when astronauts Neil Armstrong and Edwin "Buzz" Aldrin climb out of their spaceship and set foot on the Moon.

Apr. 13, 1970 The Apollo 13 mission to the Moon is aborted when an oxygen tank explosion cripples the spacecraft. NASA's most serious inflight emergency ends four days later when the astronauts, ill and freezing, splash down in the Pacific Ocean.

June 6, 1971 Cosmonauts blast off for the first mission in the world's first space station, the Soviet Union's Salyut 1. The crew spends twenty-two days aboard the outpost. During reentry, however, a faulty valve leaks air from the Soyuz capsule, and the crew is killed.

Jan. 5, 1972 President Nixon announces plans to build "an entirely new type of space transportation system," pumping life into NASA's dream to build a reusable, multi-purpose space shuttle.

Dec. 7, 1972 The seventh and final mission to the Moon is launched, as public interest and political support for the Apollo program dims.

May 14, 1973 NASA launches the first U.S. space station, Skylab 1, into orbit. Three crews live on the station between May 1973 and February 1974. NASA hopes to have the shuttle fly-

ing in time to reboost and resupply Skylab, but the outpost falls from orbit on July 11, 1979.

July 17, 1975 In a momentary break from Cold War tensions, the United States and Soviet Union conduct the first linking of American and Russian spaceships in orbit. The Apollo-Soyuz mission is a harbinger of the cooperative space programs that develop between the world's two space powers twenty years later.

Apr. 12, 1981 Space shuttle Columbia blasts off with a two-man crew for the first test-flight of NASA's new reusable spaceship. After two days in orbit, the shuttle lands at Edwards Air Force Base in California.

June 18, 1983 For the first time, a space shuttle crew includes a woman. Astronaut Sally Ride becomes America's first woman in orbit.

Oct. 30, 1983 NASA's increasingly diverse astronaut corps includes an African-American for the first time. Guion Bluford, an aerospace engineer, is one of the five crewmen assigned to the STS-8 mission.

Nov. 28, 1983 NASA flies its first Spacelab mission and its first European astronaut, Ulf Merbold.

Feb. 7, 1984 Shuttle astronauts Bruce McCandless and Robert Stewart take the first untethered space walks, using a jet backpack to fly up to 320 feet from the orbiter.

Apr. 9–11, 1984 First retrieval and repair of an orbital satellite.

Jan. 28, 1986 Space shuttle Challenger explodes 73 seconds after launch, killing its seven-member crew. Aboard the shuttle was Teacher-in-Space finalist Christa McAuliffe, who was to conduct lessons from orbit. NASA grounds the shuttle fleet for two and a half years.

Feb. 20. 1986 The Soviets launch the core module of their new space station, Mir, into orbit. Mir is the first outpost designed as a module system to be expanded in orbit. Expected lifetime of the station is five years.

May 15, 1987 Soviets launch a new heavy-lift booster from the Baikonur Cosmodrome in Kazakhstan.

Oct. 1, 1987 Mir cosmonaut Yuri Romanenko breaks the record for the longest space mission, surpassing the 236-day flight by Salyut cosmonauts set in 1984.

Sept. 29, 1988 NASA launches the space shuttle Discovery on the first crewed U.S. mission since the 1986 Challenger explosion. The shuttle carries a replacement communications satellite for the one lost onboard Challenger.

May 4, 1989 Astronauts dispatch a planetary probe from the shuttle for the first time. The Magellan radar mapper is bound for Venus.

Nov. 15, 1989 The Soviets launch their space shuttle Buran, which means snowstorm, on its debut flight. There is no crew onboard, and unlike the U.S. shuttle, no engines to help place it into orbit. Lofted into orbit by twin Energia heavy-lift boosters, Buran circles Earth twice and lands. Buran never flies again.

Apr. 24, 1990 NASA launches the long-awaited Hubble Space Telescope, the cornerstone of the agency's "Great Observatory" program, aboard space shuttle Discovery. Shortly after placing the telescope in orbit, astronomers discover that the telescope's prime mirror is misshapen.

Dec. 2, 1993 Space shuttle Endeavour takes off for one of NASA's most critical shuttle missions: repairing the Hubble Space Telescope. During an unprecedented five space walks, astronauts install corrective optics. The mission is a complete success.

Feb. 3, 1994 A Russian cosmonaut, Sergei Krikalev, flies aboard a U.S. spaceship for the first time.

Mar. 16, 1995 NASA astronaut Norman Thagard begins a three and a half month mission on Mir—the first American to train and fly on a Russian spaceship. He is the first of seven Americans to live on Mir.

Mar. 22, 1995 Cosmonaut Valeri Polyakov sets a new space endurance record of 437 days, 18 hours.

June 29, 1995 Space shuttle Atlantis docks for the first time at the Russian space station Mir.

Mar. 24, 1996 Shannon Lucid begins her stay aboard space aboard Mir, which lasts 188 days—a U.S. record for spaceflight endurance at that time.

Feb. 24, 1997 An oxygen canister on Mir bursts into flames, cutting off the route to the station's emergency escape vehicles. Six crewmembers are onboard, including U.S. astronaut Jerry Linenger.

June 27, 1997 During a practice of a new docking technique, Mir commander Vasily Tsibliyev loses control of an unpiloted cargo ship and it plows into the station. The Spektr module is punctured, The crew hurriedly seals off the compartment to save the ship.

Oct. 29, 1998 Senator John Glenn, one of the original Mercury astronauts, returns to space aboard the shuttle.

Nov. 20, 1998 A Russian Proton rocket hurls the first piece of the International Space Station into orbit.

Aug. 27, 1999 Cosmonauts Viktor Afanasyev, Sergei Avdeyev, and Jean-Pierre Haignere leave Mir. The station is unoccupied for the first time in almost a decade.

Oct. 31, 2000 The first joint American-Russian crew is launched to the International Space Station. Commander Bill Shepherd requests the radio call sign "Alpha" for the station and the name sticks.

Mar. 23, 2001 The *Mir* space station drops out of orbit and burns up in Earth's atmosphere.

Apr. 28, 2001 Russia launches the world's first space tourist for a week-long stay at the International Space Station. NASA objects to the flight, but is powerless to stop it.

Irene Brown

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Animals

A

In the early days of space travel, scientists wanted to ensure that animals could survive spaceflight before they attempted to send humans. During these first animal flights, scientists were able to test how a living organism would react to the unique environment of spaceflight—including such factors as **cosmic radiation**, the high rate of acceleration during the flight, and the effects of reduced gravity, also known as microgravity, on the body's cells and vital organs (e.g., the heart and lungs). The evaluation of animals in space also gave scientists information on how the brain would behave in microgravity.

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

Dogs Lead the Way

The first animal was launched from the Holloman Air Force Base in New Mexico on June 14, 1949. Albert 2 was a monkey, and he traveled 134 kilometers (83 miles) above Earth in a V-2 **rocket**. His heart rate, blood pressure, and respiratory rate were analyzed, but he died on his way back to Earth when the rocket's parachute failed to open. The first successful live-animal spaceflight happened on September 20, 1951, when the Soviet Union sent a monkey and eleven mice into space and back in a rocket. Then on November 3, 1957, the Soviets sent a dog named Laika in a special animal compartment on Sputnik 2. Laika became the first animal to **orbit** Earth, although she died after four days in space.

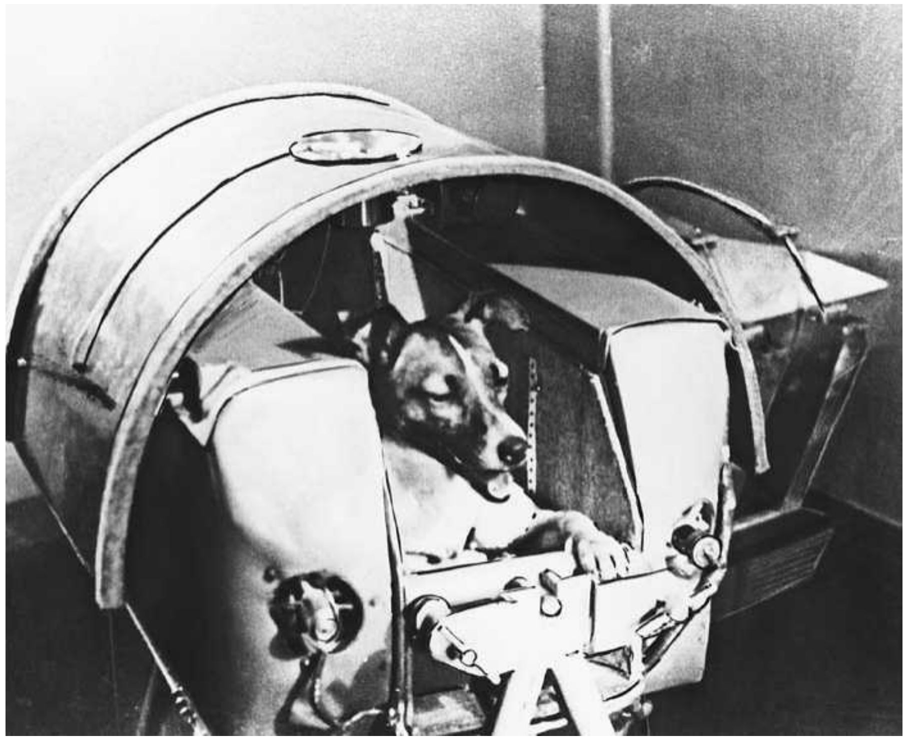
rocket vehicle (or device) especially designed to travel through space, propelled by one or more engines

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

On August 19, 1960, the Russians sent up two dogs, Strelka and Belk, on Sputnik 5. These two animals survived fifteen orbits, returned to Earth, and later gave birth to litters of healthy puppies. The following year, two Soviet missions, Sputniks 9 and 10, each carried dogs that survived the flight and returned home. After these and other successful dog flights, scientists began sending monkeys and chimpanzees, because their bodies most closely resembled the human body. These missions paved the way for human space travel because they proved that vital organs, such as the brain, heart, and lungs, could function in microgravity.

The Neurolab Shuttle Mission: How the Brain Works in Space

In April 1998, animals played an important role on the Neurolab mission aboard space shuttle flight STS-90. This mission was dedicated to studying



Laika, the first living creature to go into orbit, was launched into space on November 3, 1957 aboard Sputnik 2.

the effects of weightlessness or microgravity and other aspects of the space environment on the nervous system. Researchers were interested in how microgravity affects an animal's sensory systems. Signals from the sensory systems relate to balance, vision, and muscle movement and allow an animal to maintain stable vision, posture, coordination, and motion. A variety of species were on Neurolab, including rats, mice, swordtail fish, toadfish, crickets, and snails. Such experiments help scientists develop computer models so they can study how living organisms change while in space, including how their development and growth are affected. Studies on the brains, bones, muscles, and hearts of animals in space help scientists keep track of the effects that the space environment has on humans.

NASA Pulls Out of Bion Mission

In the United States, animals used by the National Aeronautics and Space Administration (NASA) are protected under regulations outlined in the "Principles for the Ethical Care and Use of Animals." In the mid-1990s, NASA was criticized by animal rights activists for participating in the Bion 11 and Bion 12 missions. The Bion programs were cooperative ventures between the United States, Russia, and France, and were intended to study the effects of low gravity and space radiation on primates such as monkeys. Activists claimed, however, that these studies were unnecessary because humans were already safely spending extended periods of time in space.

In December 1996, the Bion 11 satellite sent two rhesus monkeys into space, and they returned to Earth safely two weeks later. But the day after their return, one of the monkeys died after it had an adverse reaction to anesthesia when researchers where trying to surgically remove bone and muscle tissue samples. The second monkey also had an adverse reaction, although it survived. The Bion missions were the first that involved placing animals under anesthesia immediately upon returning to Earth after spending extended periods of time in a low-gravity atmosphere.

NASA investigated the Bion mission and determined that the monkeys were at a great risk when exposed to the anesthesia so soon after returning to Earth. Because of this risk, NASA declared that the United States would not participate in Bion 12 or any other future Bion missions. SEE ALSO LIFE SUPPORT (VOLUME 3); PRIMATE, NON-HUMAN (VOLUME 3).

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Apollo

Project Apollo followed Projects **Mercury** and **Gemini** as the final phase in meeting President John F. Kennedy's ambitious aim, which was stated in a speech on May 25, 1961: "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the Earth." This was at the height of the Cold War, and the United States was behind in the space race with the Soviet Union. Forty-three days before the speech, the Soviet Union had put the first person in space, Yuri Gagarin, who made one **orbit** of Earth in a 108-minute trip.

Mercury the first American-piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963.

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

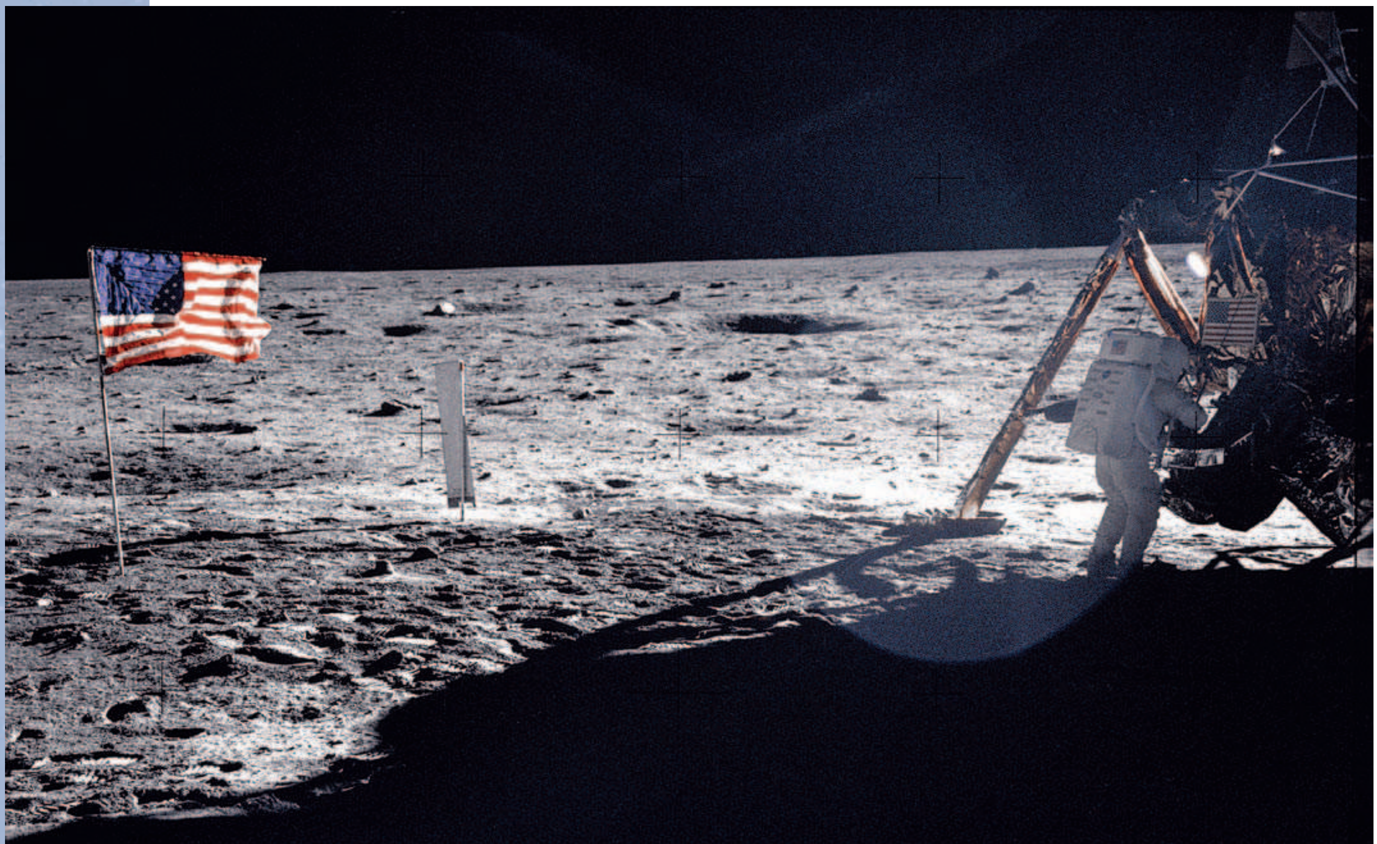
orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Flight Mode

One of the key technological decisions of the early Apollo program was the flight mode used to travel to the Moon and back. Early plans focused on direct ascent (DA) and Earth-orbit rendezvous (EOR). In DA a single vehicle would launch from Earth, travel to the Moon, land, take off again, and return to Earth. This mode had the advantage of simplicity but the disadvantage of requiring an enormous and expensive vehicle that could carry the fuel needed to make a soft landing on the Moon and relaunch from the lunar surface. As an alternative, National Aeronautics and Space Administration (NASA) **rocket** scientist Wernher von Braun advocated EOR, which involved separate launchings—two or more—of a propulsion stage and a piloted spacecraft into Earth orbit for assembly in orbit. The assembled vehicle would travel to the Moon, land, take off, and travel back to Earth. An advantage of EOR was that smaller rockets could be used to lift components and fuel into Earth orbit. It also would have provided the beginnings of a **space station**, which would be useful as part of a long-term strategy of exploration of space beyond the Moon. The United States was in a race, however, and the EOR process was inherently slow, given

rocket vehicle (or device) especially designed to travel through space, propelled by one or more engines

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period



On July 20, 1969, astronaut Neil A. Armstrong, Apollo 11 mission commander, became the first human on the Moon. Here he is pictured at the modular equipment storage assembly of the Lunar Module "Eagle" on the historic first extravehicular activity on the lunar surface.

the multiple launches. It had the additional disadvantage of component parts that had to be brought together and assembled in space, a feat that had never been done before.

A third possible mode, lunar-orbit rendezvous (LOR), was championed by NASA engineer John Houbolt, but initially dismissed by most planners because it seemed even riskier. Failure would strand astronauts in orbit around the Moon. Perceived safety issues aside, however, LOR was an elegant solution because unneeded pieces of the spacecraft would be discarded along the way, reducing mass and fuel needs. A small, specially designed vehicle could make the descent to and launch from the lunar surface and rejoin a mother ship in lunar orbit for the trip back to Earth. Houbolt argued that LOR was even safer than EOR because the mass of the lander would be much smaller and there were no atmosphere or weather concerns in lunar orbit. The matter was effectively settled in June 1961, when von Braun recognized that LOR offered "the highest confidence factor of successful accomplishment within this decade." Lunar-orbit rendezvous was selected as the flight mode in early 1962.

Apollo Crews, Rockets, and Spacecraft

Apollo missions consisted of crews of three astronauts. Earth-orbiting Apollo missions were launched by Saturn 1B rockets, and the lunar missions were launched with the larger Saturn V rocket. Launches were made from the Kennedy Space Center at Cape Canaveral, Florida. The third and final stage of the Saturn V, the S-IVB, was **jettisoned** after propelling the spacecraft out of Earth orbit and toward the Moon. The Apollo spacecraft had three sections: the Command Module (CM), the Service Module (SM), and the Lunar Module (LM). The CM served as the crew's quarters as well as flight control. The SM contained propulsion and support systems. For most of the Earth-Moon trip, the CM and SM were linked and designated the Command-Service Module (CSM). After achieving lunar orbit, two crew members (the LM pilot and the commander) entered the LM, which transported them to the lunar surface and back and provided habitat and support while they were on the surface. The third crew member (the CM pilot) remained in the CSM, orbiting the Moon. When the LM launched from the Moon, it left behind its descent stage, which consisted of rockets and supports for a soft landing on the Moon. The ascent stage, essentially the crew cabin with small rockets, rejoined the CSM in lunar orbit (rendezvous). After the crew reentered the CSM, the LM was jettisoned to crash onto the Moon. The CSM made the return trip to Earth. Before entering Earth's atmosphere, the SM was also jettisoned. The CM with its occupants parachuted into the ocean to be retrieved by the U.S. Navy.

jettisoned ejected, thrown overboard, or gotten rid of

Before July 1969

The first launch of the Apollo program was designated AS-201 ("AS" standing for "Apollo-Saturn"), an unpiloted, suborbital flight of the Saturn booster on February 26, 1966. Unpiloted AS-203 followed on July 5 and AS-202 on August 25. AS-204 was scheduled to be the first piloted Apollo flight. During a preflight test on January 27, 1967, a fire broke out in the CM, killing astronauts Virgil I. Grissom, Edward H. White II, and Roger B. Chaffee. The fire resulted from a short in an electrical panel that ignited flammable materials in the 100-percent-oxygen atmosphere. NASA renamed the scheduled mission Apollo 1 and redesigned the CM. There were no flight missions designated Apollos 2 and 3. Apollo 4, an unpiloted mission launched on November 9, 1967, was the first flight involving all three stages of the Saturn V rocket. On January 22, 1968, the engines of the LM were test-fired in Earth orbit on the unpiloted Apollo 5. Apollo 6, launched on April 4, was another unpiloted test of the Saturn V and the first Apollo mission to carry a camera pointed toward Earth.

The first Apollo mission to take humans into space was Apollo 7, which launched on October 11, 1968. Astronauts Walter M. Schirra Jr., Donn F. Eisele, and R. Walter Cunningham tested the functionality and livability of the CSM for more than ten days while they orbited Earth 163 times. Although the LM was not flown on the mission, the astronauts assessed the capability of the CSM to rendezvous with the LM by separating from and reapproaching an orbiting S-IVB. Apollo 8, the first mission to bring humans to the vicinity of the Moon, was launched two months later on December 21. Astronauts Frank Borman, James A. Lovell Jr., and William A. Anders made ten orbits of the Moon and photographed prospective landing sites. They also provided some of the most memorable photos of Earth from space, including the famous photo of Earth rising over the lunar horizon.✶ Apollo 8 astronauts provided live television broadcasts of their activities and views from space. Their reading from the Bible's Book of Genesis

✶**This image, known as "Earthrise," can be seen in the article "Earth—Why Leave" in Volume 4.**

On August 13, 1969, a ticker tape parade in New York City welcomed the Apollo 11 astronauts home from their successful lunar landing.

on Christmas Eve while in orbit around the Moon was heard by millions of people around the world.

Apollo 9 was launched on March 3, 1969, and orbited Earth for ten days with astronauts James A. McDivitt, David R. Scott, and Russell L. Schweickart. The mission was the first flight of an entire Apollo lunar **payload** and the first test of undocking and docking of the LM and CSM in space. Schweickart left the LM for a thirty-seven-minute **extravehicular activity** (EVA). In a dress rehearsal for the lunar landing, astronauts Eugene A. Cernan, John W. Young, and Thomas P. Stafford took Apollo 10 to the Moon and back on a mission lasting from May 18 to May 26, 1969. They tested LM-CSM undocking and docking and LM navigation in lunar orbit by taking the LM to within 14 kilometers (9 miles) of the lunar surface.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

extravehicular activity a space walk conducted outside a spacecraft cabin, with the crew member protected from the environment by a pressurized space suit

July 1969 and After

Apollo 11 was launched on July 16, 1969, with astronauts Neil A. Armstrong, Michael Collins, and Edwin E. "Buzz" Aldrin Jr. The LM Eagle made history by safely landing on the Moon's Mare Tranquillitatis four days later. Armstrong and Aldrin spent twenty-two hours on the lunar surface during which they did one EVA of two and a half hours, took photographs, and collected 22 kilograms (48.5 pounds) of rock and soil samples from around the LM.

Apollo 12 was launched four months later with crew members Charles "Pete" Conrad Jr., Richard F. Gordon Jr., and Alan L. Bean. On November 19, in one of the most impressive technical achievements of the cold war era, Conrad landed the LM Intrepid within walking distance, about 160 meters (525 feet), of the unpiloted **Surveyor** 3 spacecraft, which had landed in Oceanus Procellarum two and a half years earlier. In two EVAs of almost eight hours, and totaling about 1.5 kilometers (0.9 mile) of walking, Con-

Surveyor a series of spacecraft designed to soft-land robotic laboratories to analyze and photograph the lunar surface; Surveyors 1, 3, and 5–7 landed between May 1966 and January 1968 rad and Bean deployed a package of surface experiments, retrieved parts from Surveyor 3, and collected 34 kilograms (75 pounds) of samples.

Apollo 13 (April 11–17, 1970), carrying Lovell (who had previously flown on Apollo 8), John L. Swigert Jr., and Fred W. Haise Jr., was intended to be the third lunar landing. About fifty-six hours into the mission and most of the way to the Moon, one of the two oxygen tanks exploded, causing the other one to also fail. The normal supply of electricity, light, and water to the CM was gone, with the craft about 300,000 kilometers (200,000 miles) from Earth. The lunar landing was aborted. Relying on power and oxygen from the LM, advice from Earth-based support experts, and their own ingenuity and stamina, the crew returned to Earth safely.

The near-tragedy delayed the program almost a year, but Apollo 14 was launched on January 31, 1971, with astronauts Alan Shepard (Mercury 3), Stuart A. Roosa, and Edgar D. Mitchell. In two EVAs totaling nearly nine and a half hours, Shepard and Mitchell deployed various instruments, walked about 3.5 kilometers (2.2 miles), and collected 42 kilograms (92.5 pounds) of samples from the Fra Mauro Formation, a deposit of **ejecta** from the Imbrium basin. The astronauts used a hand cart to transport tools and samples.

ejecta the pieces of material thrown off by a star when it explodes; material thrown out of an impact crater during its formation

Apollo 15 (July 26 to August 7, 1971) brought Scott (Apollo 9) and James B. Irwin to the edge of Mare Imbrium at the base of the Apennine Mountains. The mission was the first to carry and deploy the lunar roving vehicle (LRV), a 210-kilogram (460-pound) electric car with four-wheel drive. The rover allowed the astronauts to travel much farther, 28 kilometers (17 miles), and collect more samples than on previous missions. In three EVAs the astronauts deployed scientific experiments and collected 77 kilograms (170 pounds) of samples. From orbit, CM pilot Alfred M. Worden operated **spectrometers** to detect **X rays** and **gamma rays** emitted from the Moon and a laser altimeter to measure topography.

spectrometer an instrument with a scale for measuring the wavelength of light

X rays high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

Apollo 16 (April 16–27, 1972) went to the Central Highlands. Astronauts Young (Apollo 10) and Charles M. Duke Jr. used a second LRV to traverse 27 kilometers (17 miles) and collect 96 kilograms (212 pounds) of samples in three EVAs totaling twenty hours. In the CM, Thomas K. Mattingly II photographed the Moon and took measurements with various instruments.

Apollo 17 was launched on December 7, 1972. The crew consisted of Cernan (Apollo 10), Ronald E. Evans, and Harrison H. Schmitt, who was a geologist and the first scientist-astronaut. On three EVAs totaling twenty-two hours, Cernan and Schmitt used the LRV to traverse 30 kilometers (18.6 miles) in the Taurus-Littrow Valley of Mare Serenitatis and collect 110.5 kilograms (244 pounds) of samples. On December 13, 1972, Cernan climbed into the LM for the return trip, becoming the last person on the Moon. The political and technical ends achieved, the program, which cost about $20 billion, ran into budgetary reality.

After the lunar landings, Apollo spacecraft and crews were used in Earth orbit for three missions to the Skylab space station in 1973 and 1974 and the Apollo-Soyuz Test Project in 1975 (Apollo 18). In total, there were nine crewed missions to the Moon, each with three astronauts. Three astronauts (Lovell, Young, and Cernan) made the trip twice, so twenty-four humans made the trip to the Moon and back. Twelve of those astronauts landed and worked on the surface of the Moon. SEE ALSO Apollo I Crew (volume 3); Apollo Lunar Landing Sites (volume 3); Apollo-Soyuz (volume 3); Armstrong, Neil (volume 3); Astronauts, Types of (volume 3); History of Humans in Space (volume 3); Humans versus Robots (volume 3); Kennedy, John F. (volume 3); Lunar Rovers (volume 3); NASA (volume 3); Oxygen Atmosphere in Spacecraft (volume 3); Schmitt, Harrison (volume 3); Shepard, Alan (volume 3); Space Centers (volume 3); Space Suits (volume 3); Tools, Apollo Lunar Exploration (volume 3); Vehicle Assembly Building (volume 3); Why Human Exploration? (volume 3); Young, John (volume 3).

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Apollo I Crew

Shortly before 1 o'clock on the afternoon of January 27, 1967, three men rode a noisy metal elevator to the top of a steel tower at Launch Complex 34-A at Cape Canaveral, Florida. Virgil I. "Gus" Grissom, Edward H. White II, and Roger B. Chaffee would shortly become the first Americans to perish while performing duties directly associated with spaceflight.

The task before these three men and their 1,000 support personnel was known as a plugs-out test. Spacecraft 012 was scheduled to ride a Saturn IB into space on mission AS-204, the first piloted flight, the following month. The plugs-out test was designed to verify that the spacecraft and launch vehicle could operate on internal power only, after all electrical, environmental, and ground checkout cables had been disconnected.

At the time of the AS-204 test Grissom was a veteran space traveler. He had flown the second suborbital flight of the Mercury Program in the Liberty Bell 7 and the highly successful Gemini II mission with Astronaut John Young. Born on April 3, 1926, in Mitchell, Indiana, Grissom was the oldest of four children. After finishing high school he enlisted in the Army Air Force in 1944 but was discharged in November 1945 after the end of World War II. Grissom completed a bachelor of sciences degree in mechanical engineering at Purdue University in 1950 and then reenlisted in the Air Force and earned his pilot's wings. He served in the Korean conflict, flying 100 missions in an F-86 Sabre-jet. After several training assignments he became a test pilot at Wright-Patterson Air Force Base and then was selected to be one of the original seven Project Mercury astronauts.

Edward H. White II was born on November 14, 1930, in San Antonio, Texas. When he was twelve years old, his father, Major General Edward White, took him up for a flight in a trainer and allowed him to fly the plane. After graduating from the United States Military Academy at West Point, New York, White joined the United States Air Force in 1952 and flew the F-86 Sabre and F-100 SuperSabre aircraft. He graduated from the University of Michigan with a master of sciences degree in aeronautical engineering in 1959. He then won test pilot credentials and was transferred to Wright-Patterson Air Force Base. There he flew big cargo planes through the parabolic arc that induced the sensation of weightlessness, and John Glenn and Donald K. "Deke" Slayton were among his passengers. In September 1962 White was selected to join the National Aeronautics and Space Administration's (NASA) second group of astronauts.

Roger Bruce Chaffee was born on February 15, 1935, in Grand Rapids, Michigan. At the age of seven he was treated to his first flight on a short trip above Lake Michigan. Chaffee and his father spent hours building model airplanes from scratch. While growing up he became an Eagle Scout and developed an interest in music, electric trains, and target shooting. He received a bachelor's degree in aeronautical engineering from Purdue University on June 2, 1957 and won his gold Navy pilot's wings early in 1959. During his career he flew photo **reconnaissance** missions out of Jacksonville Naval Air Station, many over Cuba during the Cuban Missile Crisis, as well as some over Cape Canaveral to support its buildup as part of the piloted space program. Chaffee was chosen to be a member of NASA's third class of fourteen astronauts on October 18, 1963.

reconnaissance a survey or preliminary exploration of a region of interest

Apollo I astronauts (left to right) Virgil "Gus" Grissom, Edward White, and Roger Chaffee pose in front of Launch Complex 34. On January 27, 1967, all three men were killed in a training accident on the launch pad.

The three men had been training together for almost a year and had followed their spacecraft along the production line. They became intimately familiar with all eighty-eight subsystems and with the positions of hundreds of switches and controls in the cockpit. They requested that many changes be made in the vehicle. For example, a pyrotechnic device to blow off the Crew Access Hatch in the event of an emergency was deleted. Also, they insisted that many Velcro™ panels be placed around the cockpit so that they could hang the checkout lists in plain view. Later, some of the changes they won were found to be contributing factors to the fire.

Almost from the moment the astronauts entered the cockpit the crew and the test team encountered difficulties. A bad odor in the breathing supply, false master alarms, and communications problems caused the test to drag on into the early evening hours. At 6:31 P.M., as the team prepared to pick up the test in earnest, one of the astronauts almost casually announced over the communications circuits: "Fire. I smell fire." Two seconds later White insistently repeated: "Fire in the cockpit!" Although several nearby technicians and the astronauts within attempted to open the crew access hatch, the three men were overcome by smoke and died.

The investigation that followed led to thousands of design changes and revisions. An explosively actuated hatch was installed in all future Apollos. The use of flammable materials in the cockpit was limited. New nonflammable materials were designed into every system possible. The ground atmosphere in the capsule was changed from pure oxygen to an oxygen-nitrogen mixture.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

After a delay of a year and a half, the Apollo 4 mission was launched to check out the entire system in **low Earth orbit**. The test went smoothly, and America was once again on the way to the Moon. The AS-204 mission was renamed Apollo I in honor of the crew. SEE ALSO Apollo (volume 3); Emergencies (volume 3); Escape Plans (volume 3); Gemini (volume 3); Launch Sites (volume 3); Mercury Program (volume 3); Oxygen Atmosphere in Spacecraft (volume 3).

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Apollo Lunar Landing Sites

The specific locations of the first two Apollo landing sites were selected mainly for reasons related to safety and orbital timing and partly for political reasons. In later missions, scientific objectives became an increasingly important factor. To enable direct communications and maximize safety, all six piloted Apollo landing missions were on the continuously Earth-facing side of the Moon because the farside terrain was not well known and because there were no relay satellites to enable continuous contact for a farside landing. The Apollo landing sites were located relatively near the equator within what was known as the "Apollo Zone." This area had been studied extensively with telescopic images, and a near-equatorial landing would be most favorable for return-to-Earth **trajectories**. Landings had to be made during the lunar day on the near side in a way that would be favorable for the particular launch and orbital configuration and that would allow alternate site selection in the event of a launch delay. This combination of factors restricted the possible landing sites.

Both the Apollo 11 and Apollo 12 missions were targeted to land on smooth, flat **mare** surfaces deemed to have low numbers of **impact craters**. An eastern site was preferred for Apollo 11, which would leave a western site for backup, but too far east would require a night splashdown on the return to Earth. Mare Tranquillitatis was the only suitable landing site. The Apollo 12 site was selected to investigate a western mare region and, specifically, to land at a previous **Surveyor** site to demonstrate pinpoint landing accuracy. Apollo 12 landed within 160 meters (525 feet) of the Surveyor 3 spacecraft, within walking distance, and provided a clear demonstration of U.S. superiority in the space race with the Soviet Union.

Apollo 11: First Manned Landing

The landing sites, once selected, were studied carefully beforehand using the results of **Ranger**, Surveyor, **Lunar Orbiter**, and previous Apollo missions, and each had specific scientific goals. The Apollo 11 landing site would answer questions about the origin and composition of an old mare surface. Although the landed mission consisted of only one brief two and one-half

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

mare dark-colored plains of solidified lava that mainly fill the large impact basins and other low-lying regions on the Moon

impact crater bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

Surveyor a series of spacecraft designed to soft-land robotic laboratories to analyze and photograph the lunar surface; Surveyors 1, 3, and 5–7 landed between May 1966 and January 1968

Ranger a series of spacecraft sent to the Moon to investigate lunar landing sites; designed to hard-land on the lunar surface after sending back television pictures of the lunar surface; Rangers 7, 8, and 9 (1964–1965) returned data

Lunar Orbiter a series of five unmanned missions in 1966 and 1967 that photographed much of the Moon at medium to high resolution from orbit

extravehicular activity a space walk conducted outside a spacecraft cabin, with the crew member protected from the environment by a pressurized space suit

basalt a dark, volcanic rock with abundant iron and magnesium and relatively low silica common on all of the terrestrial planets

breccias mixed rock composed of fragments of different rock types; formed by the shock and heat of meteorite impacts.

plagioclase most common mineral of the light-colored lunar highlands

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

bright rays lines of lighter material visible on the surface of the Moon and caused by relatively recent impacts

Imbrium Basin impact largest and latest of the giant impact events that formed the mare-filled basins on the lunar near side

impact-melt molten material produced by the shock and heat transfer from an impacting asteroid or meteorite

hour **extravehicular activity** (EVA), during which 22 kilograms (48 pounds) of rock and soil samples were collected, the information contained in the samples was enormous. The dark materials that make up the mare were shown to be **basalt**, a common volcanic rock on Earth, and the ages of the basalts were found to be about 3.7 billion years old. The soils contained diverse rock types, including **breccias**, volcanic and impact glasses, and fragments of **plagioclase**-rich rock that were likely brought to the site by meteorite impacts into distant highlands. From these samples, it was deduced that the highlands were made of a rock type rich in plagioclase feldspar. These first lunar samples confirmed the Moon to be without water and lifeless. Surface experiments included setting up a **solar-wind** catcher, a seismometer to detect moonquakes, and a laser-ranging reflector for accurate determination of Earth-Moon distances.

Apollo 12: Another Mare Site

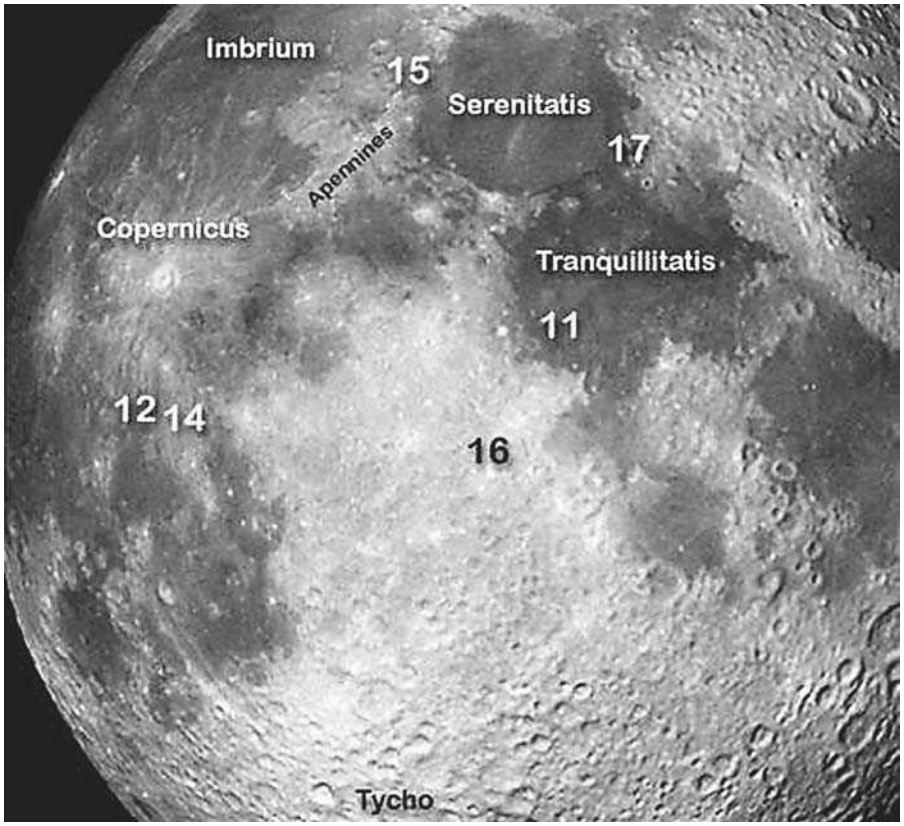
The Apollo 12 (Surveyor 3) site was selected because it appeared to contain basalts of a different type and age. The site lay on one of the **bright rays** from the crater Copernicus, offering the chance to sample some of the ray material. The mission included two EVAs on foot and the setup of the first Apollo Lunar Surface Experiment Package, which included instruments to detect moonquakes, magnetic fields, **solar wind**, and atmosphere. From analysis of the samples brought back from this mission, the basalts were found to be 3.15 to 3.35 billion years old, KREEP (material rich in K, REE, P, and other trace elements) was discovered, and the age of the crater Copernicus was determined to be about 800 million years.

Apollo 14: The Fra Mauro Highlands

An area on the rough highlands north of Fra Mauro Crater was chosen as the Apollo 14 site. The intent was to investigate the Fra Mauro Formation, thought to be material ejected by the **Imbrium Basin impact**. This material would potentially provide a date for the Imbrium event and a sample of rocks from deep within the Moon's crust. Two EVAs were conducted on foot, 43 kilograms (95 pounds) of samples were collected, and an active seismic experiment was accomplished. Most of the rocks found during this mission are complex **impact-melt** breccias, likely formed by the Imbrium impact, and most of the rock ages indicate that the Imbrium event occurred 3.85 billion years ago.

Apollo 15: Imbrium Basin, Volcanic Features, and Ancient Highlands

The Apollo 15 site was located at the edge of Mare Imbrium at the foot of the mountains forming its main topographic ring. This geologically complex site provided for investigation of Mare Imbrium, the Apennine Mountains, and a long channel-like feature called Hadley Rille. Apollo 15 brought along the first Lunar Roving Vehicle (such vehicles were also used during the Apollo 16 and 17 missions). This site was the farthest north of the six landed missions, and it provided the third leg of a triangle for the seismic and laser-ranging arrays. The dark rocks were found to be volcanic basalt,



Base image: Clementine 750 nm mosaic superimposed on an image of shaded relief.

not impact melt, and their 3.2 billion year ages meant that they were not caused directly by the Imbrium impact and did not fill the basin for nearly 600 million years after the basin formed. The **rille** was determined to be an ancient lava channel. Green volcanic glass beads, formed hundreds of kilometers deep in the lunar mantle, were found at the site, and the first large rock sample of **anorthosite**, the so-called genesis rock, 15415, was collected. Seismic data indicated a crustal thickness of 50 to 60 kilometers (31 to 37 miles).

rille lava channels in regions of maria, typically beginning at a volcanic vent and extending downslope into a smooth mare surface

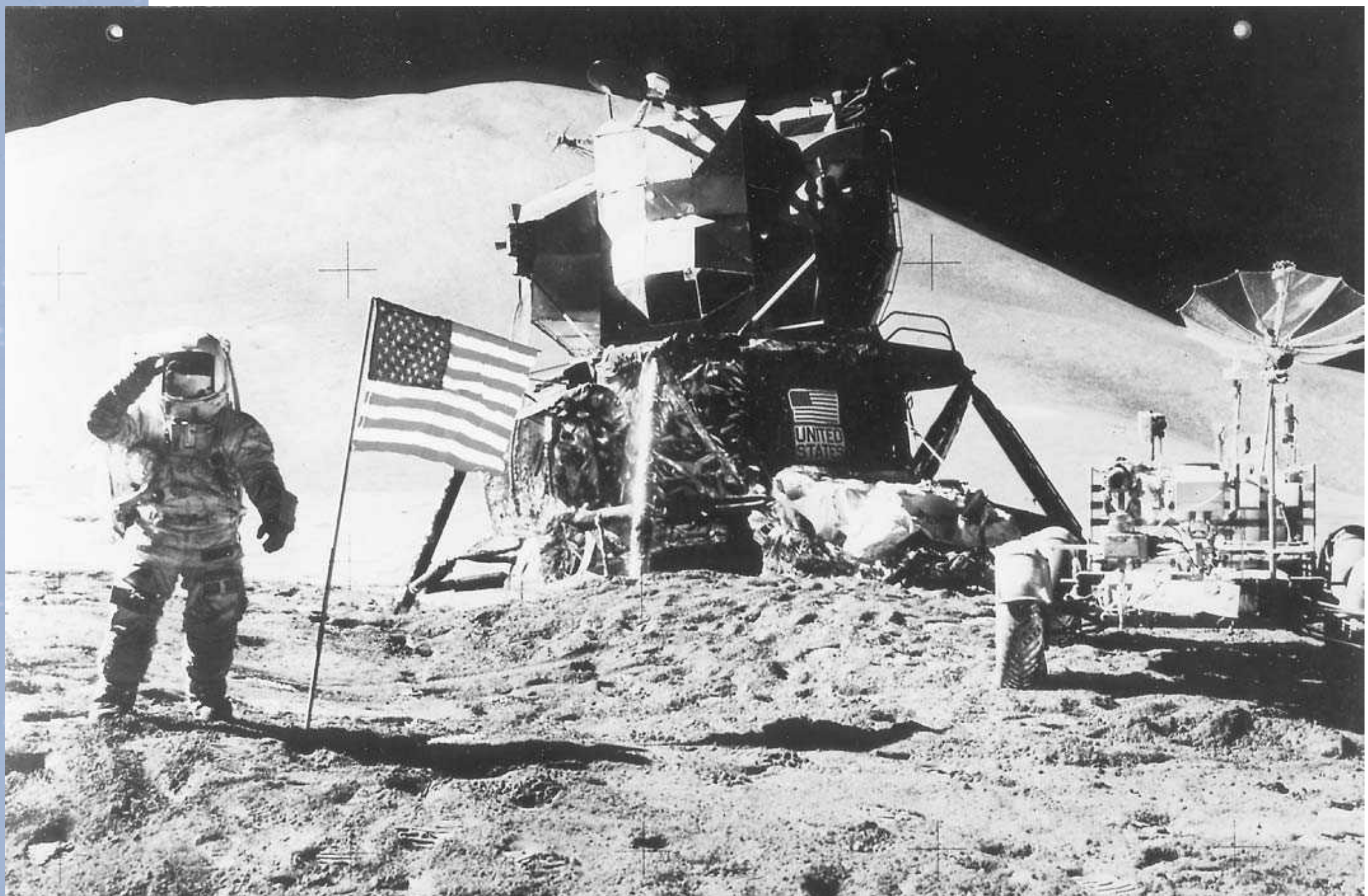
anorthosite a light-colored rock composed mainly of the mineral feldspar (an aluminum silicate); commonly occurs in the crusts of Earth and the Moon

Apollo 16: Young Volcanic Rocks?

Apollo 16 targeted the lunar highlands, away from the basalt-filled basins. The main objectives were to determine the age of the highlands and whether they were volcanic. A site was selected along the edge of the smooth Cayley Plains adjacent the Descartes Mountains so as to explore and sample both features. The site contained two small, fresh craters that penetrated the surface formations and that provided natural drill samples of the underlying materials. To the surprise of mission planners, none of the samples were volcanic; most were complex breccias, formed by numerous, large impact events. Although the breccias dated from 3.8 to 4.2 billion years, they contained pieces of very ancient anorthosites from the earliest lunar crust.

Apollo 17: The Taurus Littrow Valley

The Apollo 17 landing site, like the Apollo 15 site, was chosen to be at the interface between a mare and a highland region. The Taurus Littrow



Astronaut James Irwin, the Lunar Module pilot on Apollo 15, salutes the American flag during one of the ten-plus hours of EVA (extravehicular activity) performed by the crew on the lunar surface.

secondary crater crater formed by the impact of blocks of rock blasted out of the initial crater formed by an asteroid or large meteorite

Tycho event the impact of a large meteoroid into the lunar surface as recently as 100 million years ago, leaving a distinct set of bright rays across the lunar surface including a ray through the Apollo 17 landing site

ejecta material thrown out of an impact crater during its formation

Valley, along the southeastern edge of Mare Serenitatis, was selected to investigate the age of the basin, the different kinds of highland landforms surrounding the basin, the basalts that filled the basin, and the dark mantling materials thought potentially to be young volcanic ash deposits. Also, craters in the Taurus-Littrow Valley floor were thought to be **secondary craters** from the **Tycho event**, providing the possibility of sampling Tycho **ejecta** and dating the impact.

Exposure ages of the central valley craters indeed indicated a "young" age of about 109 million years, apparently corresponding to the Tycho event. The highland mountains were found to be a mixture of older **feldspathic** crustal materials and impact melt formed by the Serenitatis impact, about 3.87 to 3.9 billion years ago. The close dates of the major impact basins suggested that the Moon experienced a late, heavy bombardment of large impactors around 3.8 to 4 billion years ago. Orange and black volcanic ash deposits, 3.5 billion years old, were found in the regolith and were observed by the astronauts in the surrounding regions from orbit. Evidence of young volcanism was not found, but some of the oldest crustal rocks, **dunites** and **troctolites** with ages between 4.3 and 4.5 billion years, were discovered along with the impact breccias. SEE ALSO Apollo (volume 3); Armstrong, Neil (volume 3); Astronauts, Types of (volume 3); Emergencies (volume 3); History of Humans in Space (volume 3); Humans versus Robots (volume 3); Lunar Rovers (volume 3); NASA (volume 3);

Schmitt, Harrison (volume 3); Shepard, Alan (volume 3); Space Suits (volume 3); Why Human Exploration? (volume 3); Young, John (volume 3).

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feldspathic rock containing a high proportion of the mineral feldspar

dunites rock type composed almost entirely of the mineral olivine, crystallized from magma beneath the Moon's surface

troctolites a type of rock composed of the minerals plagioclase and olivine, crystallized from magma

Apollo-Soyuz

Apollo-Soyuz (officially called the Apollo-Soyuz Test Project, or ASTP) grew from a series of cooperative agreements between the United States and the Soviet Union in the 1960s. In March 1970, U.S. President Richard Nixon declared international cooperation a prime objective of the National Aeronautics and Space Administration (NASA). The U.S. space agency and Soviet space officials agreed in October 1970 to study a common **docking system** that would allow each country to rescue the other's space travelers. Nixon and Soviet Premier Alexei Kosygin, taking advantage of a spirit of reconciliation (detente) between the United States and the Soviet Union, signed the Space Cooperation Agreement in Moscow on May 24, 1972, formally creating the ASTP.

docking system mechanical and electronic devices that work jointly to bring together and physically link two spacecraft in space

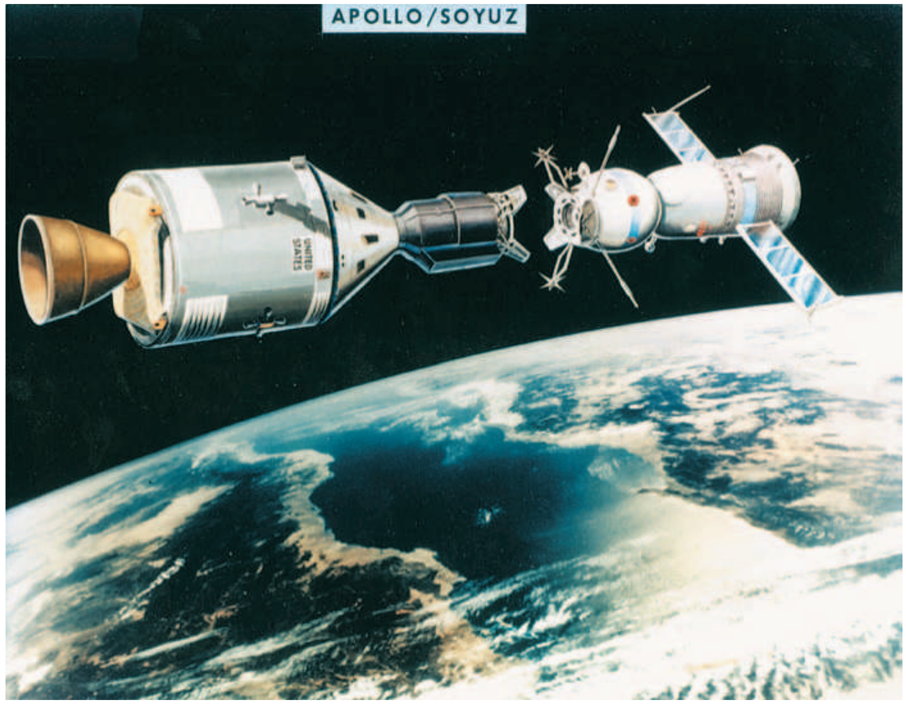
On January 30, 1973, NASA introduced astronauts Thomas Stafford, Donald Slayton, and Vance Brand as its prime ASTP crew. In May, the Soviets tapped Alexei Leonov and Valeri Kubasov as its ASTP prime cosmonauts. The crews trained together in Houston, Texas, and in Moscow and learned each other's language. The Moscow and Houston mission control centers also learned to work together. Meanwhile, Soviet and American engineers worked to make the ASTP spacecraft compatible.

Docking System and Spacecraft Modifications

The common docking unit, the Androgynous Peripheral Docking System (APDS), was based on a U.S. design. Unlike previous docking units, the APDS could play both passive and active roles in docking. To play the active role, motors extended the APDS unit. Spade-shaped guides aligned the APDS units so latches could hook them together. In the U.S. APDS, shock absorbers absorbed impact; the Soviet unit used a gear system. The active APDS then retracted to lock the ships together and create an airtight tunnel for crew transfers.

ASTP Apollo (unofficially designated "Apollo 18") was a stripped-down Apollo lunar spacecraft. In keeping with its short-duration Earth-orbital mission, it carried few supplies and little propellant, making it the lightest Apollo ever flown (12,731 kilograms [28,008 pounds]). A two-stage Saturn IB rocket launched ASTP Apollo into Earth orbit. A second Apollo was prepared as a backup.

The Docking Module (DM), built by the United States, allowed movement between the incompatible Apollo and Soyuz atmospheres by acting as



An artist's rendition of the U.S. Apollo spacecraft docking with the Soviet Soyuz in 1973.

hyperbaric chamber compartment where air pressure can be carefully controlled; used to gradually acclimate divers, astronauts, and others to changes in pressure and air composition

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

a medical **hyperbaric chamber** where astronauts and cosmonauts could adjust their bodies. Apollo had a low-pressure pure oxygen atmosphere, whereas Soyuz replicated Earth's atmosphere (an oxygen-nitrogen mixture at three times Apollo pressure). The 2,012-kilogram (4,426-pound) DM included an Apollo-type docking unit at one end and the U.S. APDS docking system at the other. The DM reached orbit under the Apollo spacecraft, on top of the Saturn IB second stage.

The Soviets committed five Soyuz to ASTP. Two unpiloted Soyuz, Cosmos 638 (April 3–13, 1974) and Cosmos 672 (August 12–18, 1974), as well as the piloted Soyuz 16 (December 2–8, 1974), tested Soyuz modifications for ASTP. Modifications included replacing the standard Soyuz docking system (designed for docking with Salyut space stations) with the Soviet APDS; adding electricity-generating **solar arrays**; and making life support upgrades so Soyuz cosmonauts could host two visiting Apollo astronauts.

The Mission

The Soviet ASTP spacecraft, Soyuz 19, lifted off from Soviet Kazakhstan on July 15, 1975. A backup Soyuz stood by on a launch pad in case the first Soyuz could not launch on time. Seven hours later, ASTP Apollo lifted off from Florida. After separating from the Saturn IB second stage, Apollo turned around and docked with the DM. Stafford, Slayton, and Brand then set out in pursuit of Soyuz 19. Docking occurred on July 17 with Apollo maneuvering and its APDS docking unit playing the active role.

The crews conducted four transfers between their spacecraft over the next two days. During these, much attention was given to television coverage and symbolism. They shared a meal, heard from U.S. and Soviet leaders Gerald Ford and Leonid Brezhnev, and exchanged plaques, flags, and

American commander Thomas P. Stafford (foreground) and Soviet commander Alexei A. Leonov making their historic handshake in space during the Apollo-Soyuz mission on July 17, 1975.

certificates. Leonov and Kubasov gave the American public a television tour of Soyuz 19, and the Americans reciprocated. Though science was of secondary importance, the crews performed twenty-seven experiments, some using a furnace in the DM.

Apollo and Soyuz 19 undocked on July 19 and redocked with Soyuz maneuvering and its APDS docking unit playing the active role. They undocked again, then Apollo maneuvered to block the Sun, creating an artificial solar eclipse, which Soyuz 19 photographed. Soyuz 19 landed on July 21, and ASTP Apollo landed on July 24.

After ASTP

NASA considered a second ASTP mission in 1977, but worried that it would interfere with space shuttle development. The Space Cooperation Agreement was renewed in 1977, calling for a shuttle-Salyut docking in 1981, but the spirit of detente that made ASTP possible evaporated following the 1979 Soviet invasion of Afghanistan. The United States dropped APDS development, but the Soviet Union continued; in the 1990s, NASA equipped the space shuttle with Russian-built APDS units for the shuttle–Mir and International Space Station program dockings. SEE ALSO Apollo (volume 3); Astronauts, Types of (volume 3); Cosmonauts (volume 3); History of Humans in

Space (volume 3); International Cooperation (volume 3); International Space Station (volumes 1 and 3); NASA (volume 3); Zero Gravity (volume 3).

David S. F. Portree

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Armstrong, Neil

American Astronaut; First Human on the Moon
1930–

When Neil Armstrong became the first human on the Moon, he uttered the famous words: "That's one small step for man . . . one giant leap for mankind."

Born in Wapakoneta, Ohio, on August 5, 1930, Neil Alden Armstrong became a naval aviator in 1949. He received a bachelor of science degree in aeronautical engineering from Purdue University in 1955 and a master of sciences degree in aerospace engineering from the University of Southern California in 1970. Armstrong received an honorary doctorate in engineering from Purdue in 1970 and has been awarded additional honorary doctorates by various universities since that time.

In 1955 Armstrong became a research test pilot for the National Aeronautics and Space Administration (NASA) assigned to the X-15 rocket plane program. NASA selected Armstrong to be an astronaut in 1962. On March 16, 1966, Armstrong and Dave Scott were launched in Gemini 8 to conduct the first two-craft linkup in space, docking with a target satellite named Agena. Apollo 11 astronauts Armstrong, Edwin "Buzz" Aldrin, and Mike Collins left for the Moon on July 16, 1969. Armstrong and Aldrin landed their lunar module "Eagle" in the Moon's Sea of Tranquility four days later, on July 20. Armstrong stepped onto the surface and became the first human to set foot on the Moon.

Armstrong left NASA in 1971 and became a professor of aeronautical engineering at the University of Cincinnati, where he taught until 1981. He is currently the chairman of Computing Technologies for Aviation, Inc. (CTA). see also Aldrin, Buzz (volume 1); Apollo (volume 3); Apollo Lunar Landing Sites (volume 3); History of Humans in Space (volume 3).

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Astronaut Candidates *See Career Astronauts (Volume 1).*

Astronaut Corps *See Career Astronauts (Volume 1).*

Astronauts, Types of

Astronauts are persons trained to fly or operate systems aboard a spacecraft. "Astronaut" is the term typically applied to those who fly on U.S. spacecraft, whereas "cosmonaut" refers to crewmembers who have flown on Russian space vehicles. The National Aeronautics and Space Administration (NASA) selected the first American astronauts in 1959 to pilot the single-seat **Mercury** spacecraft. These "Original 7" were all chosen from the ranks of military test pilots.

Qualifications for these first astronauts were extremely high. Not only were the Mercury and **Gemini** astronauts professional test pilots, but they also had to meet strict standards for eyesight, health, and physical size (because of the tight confines of the spacecraft cockpits). In advance of the **Apollo** Moon landings, six scientists were selected for astronaut training in 1965, but only one made it to the lunar surface (compared with eleven former test pilots) before the Apollo program ended in 1972.

NASA drew up new qualifications for astronauts in 1978, with the advent of the space shuttle. The shuttle cabin could handle crews of up to seven astronauts, and its varied missions required a broader mix of skills from an array of technical backgrounds. Scientists, engineers, and physicians were now eligible for selection, and prior flying experience was no longer mandatory. Current shuttle astronaut candidates apply for one of two career positions: pilot astronaut or mission specialist astronaut.

Pilot astronauts have primary responsibility for guiding the space shuttle safely to and from orbit. Pilot astronaut candidates must have professional test piloting experience; most gain that skill in the military. Shuttle pilots monitor the controls during liftoff, maneuver the spacecraft in orbit, guide the shuttle to dockings with the **space station**, and fly the shuttle back to a precision runway landing. Pilot astronauts fly first as a copilot and, with experience, advance to command of a shuttle mission.

Mission specialist astronauts train to operate the space shuttle's experiment **payloads** and conduct a variety of activities in orbit. They have primary responsibility for science tasks and assist the pilots with spacecraft operations. Mission specialists maneuver the shuttle's robot arm to release or retrieve satellites. They also conduct space walks for satellite repairs or space station construction. Experienced mission specialists serve as "payload

Mercury the first American-piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963.

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

Apollo American spacecraft designed to take astronauts to the Moon. Eleven Apollo missions, each carrying three astronauts, were launched between 1968 and 1972

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Mission specialists conduct a range of activities in orbit. Pedro Duque of the European Space Agency checks his notes during the activities of flight day 1 onboard the space shuttle Discovery.

commanders," responsible for controlling a major scientific payload or suite of experiments.

A typical shuttle crew is composed of two pilots and anywhere from three to five mission specialists, depending on the mission's complexity. The crew trains intensively as a team for a year or more to prepare for a mission. The crew may include a "payload specialist," a scientist or engineer from outside the astronaut corps, selected to operate a specific experiment aboard one or two shuttle flights.

Space station crews consist of a commander and two or more flight engineers, with the role of the latter being similar to that of mission specialists. Station crewmembers are drawn from the astronaut corps of the United States, Russia, and the other countries that are international partners. Another category of astronaut—one involved in commercial activities—may soon go to work aboard the International Space Station. SEE ALSO Career Astronauts (Volume 1); Careers in Spaceflight (Volume 3); Cosmonauts (Volume 3); Mission Specialists (Volume 3); Payload Specialists (Volume 3).

Thomas D. Jones

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B

Backpacks, Portable *See Life Support (Volume 3).*

Bell, Larry

American Space Architect, Professor, and Entrepreneur
1938–

Larry Bell is well known internationally for his contributions to the design of space habitats and systems, including the International Space Station. He founded and heads the Sasakawa International Center for Space Architecture (SICSA) at the University of Houston, where he has taught since 1978.

Bell is a licensed architect and urban planner, and was a successful industrial designer for years before moving to Houston. His entrepreneurial nature has made him a key figure in the drive toward private exploration of space rather than through federally-funded programs. One of the companies he co-founded evolved into Veridian, a high-tech company, which employs more than 6,000 people.

In 1987, Bell founded SICSA with a $3 million gift from a Japanese philanthropic organization. SICSA is an important gathering place for the next generation of space architects, who have taken on several projects for NASA and leading aerospace companies.

Bell's main challenge is designing for extreme conditions that do not exist on Earth. "It requires some imagination to be a space architect," he said. "I encourage my students to develop their fundamental thinking skills, which are even more important than technical training. If we can learn to plan for the extreme conditions of space, we might be able to prevent our entire planet from becoming an extreme environment." SEE ALSO Habitats (volume 3).

Chad Boutin

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Biosphere

Earth's biosphere is the sphere of life around the planet. Its organisms interact with their environment and each other, maintaining conditions on the planet conducive to life. Light from the Sun causes plants and **algae** to **photosynthesize** and thereby produce the oxygen that animals and microbes need. As a by-product of their respiration, animals and microbes in turn provide carbon dioxide, which plants require to grow. The oxygen atoms are used over and over again within the biosphere's oxygen cycle. There are many such cycles in a biosphere, with many creatures depending on other creatures for their survival.

algae simple photosynthetic organisms, often aquatic

photosynthesis a process performed by plants and algae whereby light is transformed into energy and sugars

Why Build a Biosphere for People?

At current estimates, it would cost around $22,000 to launch a medium pepperoni pizza to the International Space Station. For short space missions of

Biosphere 2, an enclosed ecosystem located in Tucson, Arizona, was intended to duplicate the conditions needed to settle another planet.

less than two years it is cost effective to take along everything that is needed, as if one were embarking on a camping trip. But longer missions require that the crew grows their own food and that all the oxygen, water, and waste is recycled. The longer the mission away from Earth, the more complete the recycling has to be.

On the space shuttle and the International Space Station, everything that the astronauts and cosmonauts need is taken with them. To maintain a habitable environment within the spacecraft a physical–chemical life support system is used; equipment removes the carbon dioxide and other contaminants from the atmosphere and produces oxygen and water. These systems are efficient and compact, but they require that consumables be brought from Earth. For example, when the carbon dioxide is removed from the atmosphere it is vented to space or stored. This means that the oxygen contained in that carbon dioxide is no longer available for human consumption and that a source of oxygen must be supplied.

bioregenerative referring to a life support system in which biological processes are used; physiochemical and/or nonregenerative processes may also be used

For a mission such as a long-term base on Mars, a life support system is required in which almost everything is recycled and reused and nothing is thrown away—a regenerative system. Systems that use living organisms to perform life support system functions are called **bioregenerative** life-support systems. Earth has such a bioregenerative system—the biosphere.

Biosphere 2

In Arizona, scientists built an artificial biosphere, called Biosphere 2. An eight-person crew lived inside the 1.28-hectare (3.15-acre) hermetically sealed structure for two years from 1991 to 1993. They produced their own food and recycled the atmosphere, water, and waste using a bioregenerative life support system.

Biosphere 2 had a mini rain forest, savanna, desert, marsh, and ocean, as well as a farm and a human habitat. The habitat housed the crew quarters, dining room, kitchen, medical facility, and an analytical laboratory for testing that the air was safe to breathe and that the water was safe to drink. There was also a machine shop for making and repairing equipment, such as water pumps, and the Command Room, with videoconferencing, Internet connections, phones, and a station to monitor the environment of each area in the biosphere.

Just as Earth's biosphere has cycles, so do bioregenerative life support systems. In Biosphere 2 the crew ate the same carbon molecules over and over again and breathed the same oxygen. Following is an example of how a water molecule might move through the biosphere.

After drinking a glass of water, a crew member excretes the water molecule as urine. The crew member flushes it into the wastewater treatment system, a specially designed marsh lagoon where plants and microbes work together to purify the water. Once the treatment cycle is complete, the water irrigates the farm crops. After soaking into the soil, the water molecule that the crew member drank is absorbed by the roots of a wheat plant and is later **transpired** through its leaves. The water molecule is now in the atmosphere, and after passing through a dehumidifying or condensing heat exchanger that maintains the temperature in the biosphere, the water is removed from the atmosphere and placed in a holding tank. A crew member preparing dinner goes into the kitchen and turns on the faucet. Out comes the water molecule, which becomes part of the evening soup. And so on it goes, around and around and around.

transpiration a process whereby water evaporates from the surface of leaves, allowing the plant to lose heat and to draw water up through the roots

Biosphere 2 was the first attempt at a fully bioregenerative life support system. It demonstrated that such a system could be used to support human life on another planet. Someday people will inhabit other planets, and bioregenerative systems will play a key role in allowing that to happen. SEE ALSO Closed Ecosystems (volume 3); International Space Station (volumes 1 and 3); Living in Space (volume 3); Living on Other Worlds (volume 4); Mars Bases (volume 4).

Jane Poynter

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C

Cabins *See Capsules (Volume 3).*

Capcom

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

Capcom is a term that originated in the days of the Mercury space program when spacecraft were little more than **capsules**. Originally named for "capsule communicator," the capcom position is traditionally a U.S. astronaut or a member of the U.S. astronaut corps, who serves in the Mission Operations Control Center as liaison with the astronauts in space.

The first capcoms were chosen from the initial group of seven astronauts selected for the Mercury project. Three-man operations teams were deployed to tracking stations around the globe. The capcom was the leader of each three-man team, and he was responsible for site mission readiness, real-time mission support, and status reporting to the Mercury control flight director. During the piloted missions, he provided communication with the astronaut in the capsule. Since there were thirteen tracking stations and only seven original astronauts, one of whom would be making the flight, the other six astronauts were sent to man the tracking stations designated as mission critical, while the most remote stations were run by recent college graduates.

THE RIGHT STUFF

The Mercury space program ran from 1958 to 1963 and involved six piloted flights. Author Tom Wolfe detailed the men involved in the program in his book *The Right Stuff* (1978), which was later made into a film starring Dennis Quaid as Gordon Cooper, Ed Harris as John Glenn, Scott Glenn as Alan Shepard, and Fred Ward as Gus Grissom.

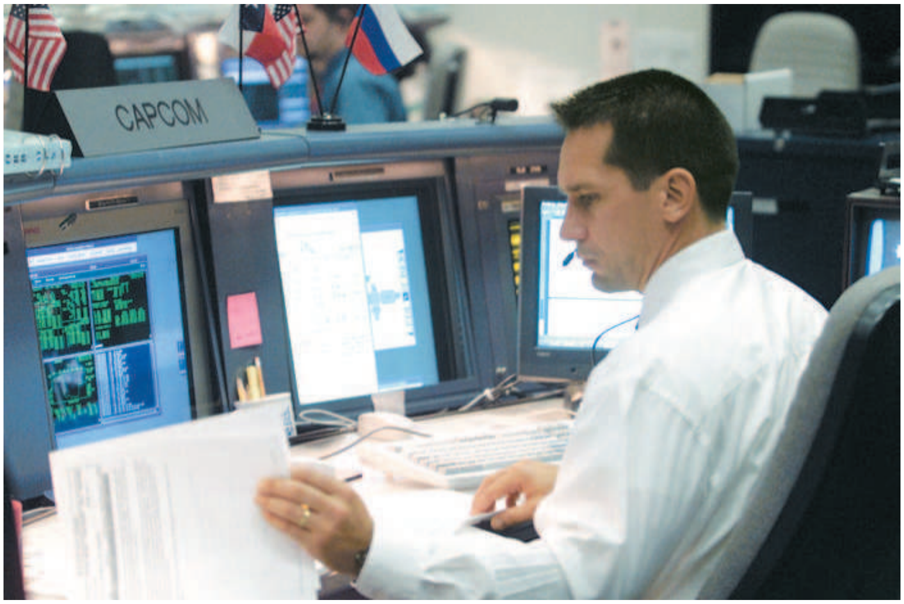
Due to high-risk time-critical decisions, the astronaut corps believed that only astronauts should talk to the astronaut in the capsule. Since the men trained together, the astronaut capcom might recognize the significance of each crew members' tone of voice or speech pattern, which a non-astronaut might miss.

This practice also kept the astronauts who were awaiting their turn in the pilot's seat current on what was happening in the program since they were actual participants in each mission. By the time the Gemini Program had begun, there was a second group of astronauts from which to draw. Historically, capcoms were male because women were not selected by NASA to be astronaut candidates until after 1978. Since then, many women have served in this capacity, including the first American woman in space, Sally Ride, and the first female shuttle commander, Eileen Collins.

There have been many memorable quotes uttered by capcoms throughout the history of the space program. It was fellow astronaut Scott Carpenter who said, "Godspeed, John Glenn" at the moment of engine sequence for the lift-off of Friendship 7. Astronaut Mike Collins, later to be the command module pilot for Apollo 11, sent men out of Earth's orbit for the first time with the command, "You are go for TLI" (trans-lunar injection).

Though still in use, the term capcom is now an anachronism as capsules have been replaced by more airplane-like spacecraft. The launch of tracking and data-relay satellites in the 1980s have made it unnecessary to send capcoms to remote sites around the globe. They perform their duties in the relative comfort of the Mission Control Center in Houston, Texas. SEE ALSO MISSION CONTROL (VOLUME 3); TRACKING OF SPACECRAFT (VOLUME 3); TRACKING STATIONS (VOLUME 3); WOMEN IN SPACE (VOLUME 3).

Vickie Elaine Caffey



Capcom is short for "capsule communicator." The astronaut in this position serves as a liaison between Mission Control and astronauts in space.

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Capsules

A capsule is a sealed, pressurized cabin that contains a controlled environment for humans, animals, or equipment during high-altitude flight or spaceflight. Capsules have been used on dozens of historically important missions from the earliest days of the U.S. and Soviet space programs.

The first space capsule orbited was the Soviet Sputnik 2. Launched November 3, 1957, it was only the second human-made object to **orbit** Earth. The capsule weighed 114 kilograms (250 pounds) and carried the dog Laika into space, but it was not designed to be recovered. Laika died in orbit four days later. Most capsules, however, are re-entry vehicles made to bring their occupants back safely to Earth.

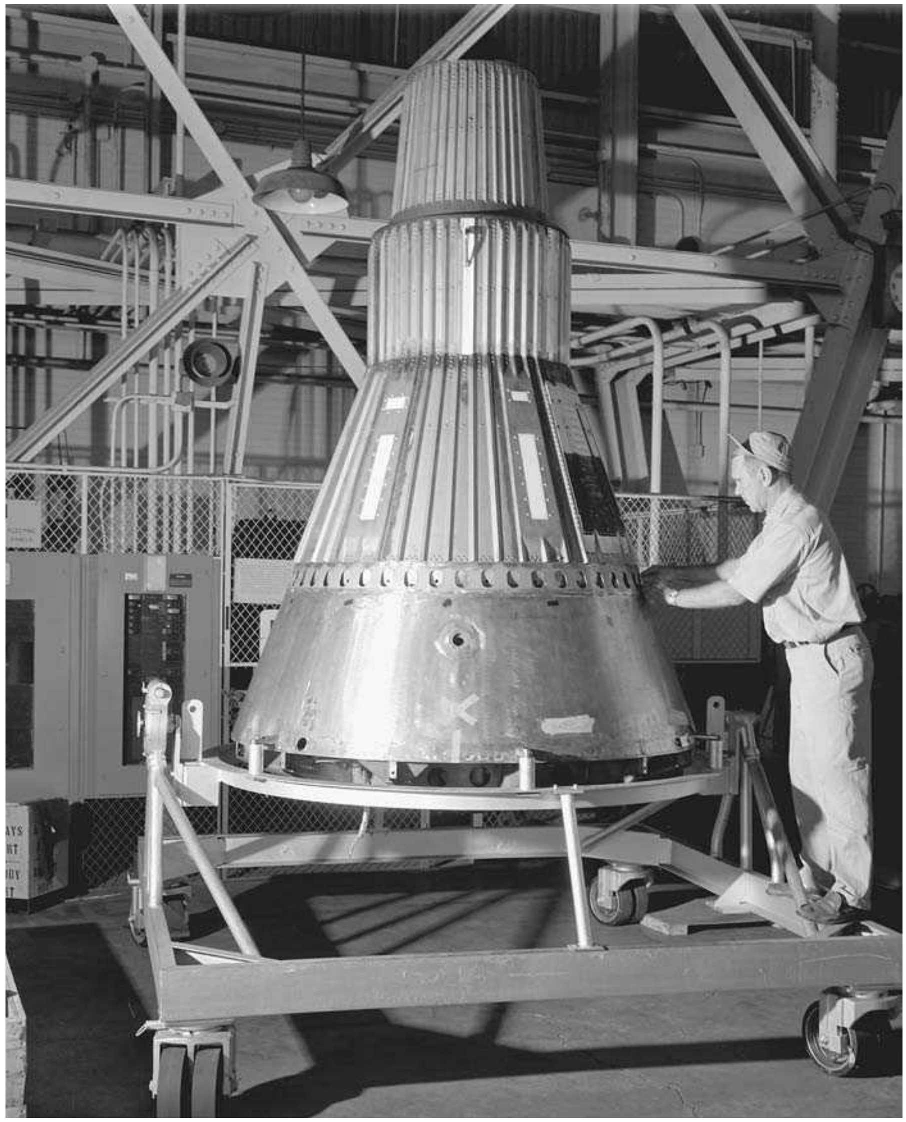
orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Human-Piloted Capsules

The earliest human-piloted capsules were the Soviet Vostok and U.S. Mercury spacecraft. Vostok had a spherical compartment 2.5 meters (98 inches) in diameter with room for a single cosmonaut. It was attached to a cone-shaped equipment module that carried supplies, giving the craft the appearance of a stubby ice cream cone. A Vostok capsule carried Yuri Gagarin, the first human in space, aloft on April 12, 1961. After leaving orbit, the spherical compartment separated from the equipment module and descended through the atmosphere, but it was not designed for a soft landing. The cosmonaut parachuted to safety after ejecting at an altitude of about 6,100 meters (20,000 feet). Five other Vostok missions followed, the last of which carried Valentina Tereshkova, the first woman space traveler.

WHY ARE THEY CALLED "CAPSULES"?

Engineers dubbed the Mercury spacecraft a "capsule" because there was barely enough room to fit the astronaut, 120 controls, fifty-five switches, and thirty-five control levers inside the spacecraft, which was only 2.9 meters (9.5 feet) long and 1.8 meters (6 feet) wide. The name stuck.



Mercury capsule #2 was the first production capsule launched into space.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

Mercury capsules also carried a single passenger. They traveled atop either Redstone **rockets** (for suborbital flights) or the larger Atlas rockets, which were powerful enough to lift the 1,350-kilogram (3,000-pound) capsules into orbit. A Mercury capsule, like subsequent Gemini and Apollo craft, was designed to "splash down" in the ocean after descending by parachute.

Beyond Solo Flight

The Soviet Voskhod capsule was the first designed to carry multiple passengers. It was a modified version of the Vostok spacecraft, with the ejection seat removed to make room for up to three cosmonauts and with an added airlock so that space walks could be performed. Voskhod capsules also had larger parachutes to permit ground landings. Three cosmonauts orbited Earth aboard Voskhod 1 on October 12, 1964. The Voskhod 2 capsule carried Alexei Leonov and Pavel Belyayev into orbit on March 18, 1965; Leonov performed history's first space walk that day, remaining outside of the capsule for twenty minutes.

Conditions were cramped aboard the Voskhod—the three Voskhod 1 cosmonauts were packed into the same volume of space Gagarin had, but without pressure suits or ejection seats for safety—but space aboard Gemini was at a premium as well. The Gemini capsule was made to carry two astronauts but had only 50 percent more interior space than Mercury did. Astronaut John Young compared being inside Gemini to "sitting in a phone booth that was lying on its side." Nevertheless, Gemini provided its crews with valuable space experience. While Mercury could remain in orbit for only a day or so at most, Gemini could sustain two astronauts for up to two weeks. Gemini astronauts had complete control over the motion of their capsules, which they would need to practice the docking maneuvers necessary for later Apollo missions. On December 15, 1965, Gemini 6 and 7 became the first human-piloted spacecraft ever to rendezvous with one another. Five Gemini astronauts also performed space walks; the last, by Buzz Aldrin during Gemini 12, spanned a record-setting five hours, thirty minutes.

Like Vostok, Gemini was a two-section spacecraft. The astronauts rode in the re-entry module, which was attached to an adapter module containing propellant, water, oxygen, and other supplies. The adapter module was **jettisoned** shortly before re-entry.

jettisoned ejected, thrown overboard, or gotten rid of

Rockets to the Moon

The success of the Gemini program gave the United States the experience it needed to pursue human exploration of the Moon. The Apollo lunar program was the last major U.S. space initiative in which astronauts rode in nonreusable capsules. Three astronauts sat abreast inside the Apollo capsule, referred to as the Command Module (CM). The CM, which was about 3.4 meters (11 feet) high and 4 meters (13 feet) wide, had a more regular conic shape and a larger interior (about 6 cubic meters [8 cubic yards]) than Mercury or Gemini capsules; this allowed the crew to remove their bulky space suits after liftoff. Supplies for the journey to lunar orbit and back were kept in the Service Module (SM) behind the CM. The SM was jettisoned before the 5,300-kilogram (11,700-pound) CM returned to Earth. SEE ALSO Apollo (Volume 3); Cosmonauts (Volume 3); Gemini (Volume 3); Rendezvous (Volume 3).

Chad Boutin

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Careers in Spaceflight

Human spaceflight is one of the most exciting professional fields today. Those who work in it are pioneers of an endless frontier filled with challenges,

There are three categories of astronauts: commander/pilot, mission specialist, and payload specialist. Eileen Collins became the first female commander of a space shuttle, the Columbia, in 1999.

adventure, and scientific discovery. Although being an astronaut is the career most commonly associated with human spaceflight, that position accounts for only a small proportion of the jobs in the field. From engineers and physicians to web designers and educators, human spaceflight has career opportunities for anyone who is fascinated by the final frontier.

Human Spaceflight in the Twenty-First Century

Most human spaceflight activity is concentrated in the United States and Russia. Only these two nations have launched people into space, although China is testing a craft that will be capable of supporting human space travelers. Other countries have human space programs, but their astronauts must fly aboard the American space shuttle or the Russian Soyuz vehicle.

The International Space Station (ISS) is the focus of most human space activity. This facility, which is scheduled for completion around 2006, is a collaborative effort of the United States, Russia, twelve European nations, Japan, and Canada. Seven astronauts could eventually live and work aboard the ISS on a full-time basis.

People who are employed in human spaceflight usually work for government agencies such as the National Aeronautics and Space Administration (NASA) or one of the many contractors that support those agencies. Boeing, for example, is the prime contractor on ISS, and the United Space Alliance (USA) oversees the shuttle program for NASA. Many smaller contractors provide goods and services to the government and other contractors.

What Kinds of Jobs Are Available?

There are tens of thousands of jobs in human spaceflight. A comprehensive listing of all of the job categories is beyond the scope of this article. Listed below are several broad categories of the jobs that exist in the early twenty-first century.

Astronauts. This is probably the most visible and interesting job in human spaceflight. It is also one of the most competitive. However, if one has the "right stuff," one can become a star voyager. There are three categories of astronauts: commander/pilot, mission specialist, and payload specialist. Candidates for these positions typically need a bachelor's degree in biological sciences, engineering, physical sciences, or mathematics from an accredited institution. Candidates must be able to pass a rigorous physical examination and be between 64 and 76 inches tall.

Commander/pilot astronauts fly the space shuttle. Candidates must have at least 1,000 hours of experience commanding a jet aircraft. NASA also prefers experience as a test pilot. Many pilots have experience in the military. Mission specialists are responsible for coordinating activities on space shuttle flights, including overseeing experiments, managing **payloads**, and conducting space walks. Payload specialists tend to specific experiments or equipment during a flight. Mission specialists must have at least three years of professional experience in their field of expertise. They may substitute a master's or doctoral degree for part or all of the work requirement. Payload specialists usually must meet similar requirements.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Launch and Flight Operations. NASA and its contractors maintain a small army of engineers and technicians who oversee every aspect of flying the space shuttle. This group includes engineers and technicians who maintain the shuttles, planners who determine mission goals, the launch team that prepares the vehicle for takeoff, and flight controllers who supervise all aspects of the mission. Flight controllers also oversee **space station** operations.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

Payload Management. Payload management technicians and engineers prepare the payloads that are sent into space. Most payloads launched today on the shuttle consist of modules, equipment, and supplies bound for the ISS.

Training. Astronauts go through extensive training before flying in space. Trainers run simulators that mimic the actions of the space shuttle and the space station. Astronauts also practice in water tanks to simulate the effects of zero gravity.

Support Scientists. Scientific research is a major component of the space program. Astronauts conduct scientific experiments to understand the effects of weightlessness on materials. This research has commercial applications in the areas of new medicines, **semiconductors**, and advanced materials.

semiconductors a group of elements with properties intermediate between the metals and nonmetals

Medical Personnel. Space agencies have doctors and support personnel who monitor the health of astronauts. They also help conduct experiments on the effects of zero gravity and radiation on the human body. This research is considered crucial in preparation for sending humans to Mars.

Engineering and Design. Engineers and technicians improve existing vehicles such as the space shuttle and design new vehicles and space hardware. In 2001 NASA initiated a $4.5 billion program to work with private companies to develop technologies that will lead to a replacement for the space shuttle.

Twenty companies also are competing for the X PRIZE, a $10 million award for the first privately financed space vehicle that achieves suborbital flight and can repeat the flight within ten days to demonstrate reusability and quick turnaround.

Education and Public Relations. Governments and private companies are using the Internet, cable and satellite television, and other multimedia technologies to convey the excitement of human spaceflight to students and the public. These developments are producing job opportunities for journalists, educators, web designers, and editors.

NASA has a major presence on the World Wide Web and an extensive educational outreach program. The NASA Quest Web site (<http://www.quest.nasa.gov>) is an excellent source of information about space careers. The site features profiles and journals that provide visitors with a broad cross section of the personnel who work in human spaceflight. The employees explain their jobs, educational backgrounds, and what inspired them to pursue a career in space.

Support Staff. NASA and aerospace companies are similar to most other organizations in their need for nontechnical personnel, such as office managers, accountants, and administrative assistants. Even without an interest in engineering or science, a person can be a pioneer on the final frontier.

What Education Is Required?

Most jobs in human spaceflight are technical or scientific, requiring four to ten years of college. A four-year bachelor's degree in science or engineering generally is considered the minimum requirement for the majority of entry-level positions in the industry.

Beyond the bachelor's degree, one can choose to obtain a master's or doctoral degree. Master's degrees usually require at least two years of study. Doctoral degrees can require two to four years of work beyond a master's degree.

Government agencies such as NASA and many private aerospace companies have tuition assistance programs that allow employees to earn advanced degrees on a part-time basis. It is common for a person to earn a bachelor's degree, take an entry-level position in industry or government, and then earn an additional degree while working full-time.

Engineers and scientists do not necessarily need a master's or doctoral degree in their field of expertise. Management and business skills are highly valued in any organization and are usually necessary for moving up through the ranks of management. Often a good way to develop these skills is to earn a bachelor's degree in a technical field such as aerospace or mechanical engineering and then obtain a management credential such as a master of business administration (MBA) degree.

In The Future

The ISS will be completed around 2006. Space agencies and aerospace companies around the world are looking beyond the program to two possible futures: human flights to other worlds and space tourism in Earth orbit.

Both of these developments could have a major impact on the types of jobs that will be available in human spaceflight.

Early missions to the Moon and Mars would include the establishment of scientific bases. These jobs would require essentially the same mix of skills for astronauts and engineers that are required by the current space program. Requirements for scientists would be different, however. Astronauts who go to other worlds—and the scientists working with them on Earth—will need backgrounds in a variety of fields, such as life sciences, biology, geology, and atmospheric sciences.

Human settlements could follow initial scientific exploration. Full-scale lunar and Martian colonies eventually would include most of the jobs found on Earth. These colonies would need scientists, technicians, construction workers, bankers, administrators, and journalists, for example.

Space tourism is another possible development during the next twenty years. In early 2001 Dennis Tito became the first space tourist when he spent a week on the ISS. More flights of tourists to the ISS are possible in the coming years. Tourism on Earth is already a megabillion-dollar industry. Advocates believe that space tourism could become an even larger industry. Companies are developing vehicles that could enable tourists to take suborbital flights by 2005. Orbital flights on private spacecraft could follow by 2015. If space tourism develops during the coming decades, it will generate jobs similar to those which exist in the travel industry today. The industry will need pilots, flight attendants, travel agents, baggage handlers, and other employees. SEE ALSO ASTRONAUTS, TYPES OF (VOLUME 3); CAREER ASTRONAUTS (VOLUME 1); CAREERS IN BUSINESS AND PROGRAM MANAGEMENT (VOLUME 1); CAREERS IN ROCKETRY (VOLUME 1); CAREERS IN SPACE MEDICINE (VOLUME 1); MISSION SPECIALISTS (VOLUME 3); PAYLOAD SPECIALISTS (VOLUME 3).

Douglas M. Messier

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U.S. Space Camp. <http://www.spacecamp.com>.

X PRIZE Foundation. <http://www.xprize.org>.

Challenger

Challenger was one of five National Aeronautics and Space Administration (NASA) space shuttle orbiters to fly in space, and the only shuttle as of 2002 lost in an accident. The shuttle was named after a nineteenth-century naval vessel that explored the Atlantic and Pacific Oceans. The orbiter flew in space nine times between 1983 and 1985 on a number of missions. On its tenth flight, STS-51-L on January 28, 1986, a problem with a solid rocket booster led to an explosion that destroyed Challenger and killed its seven crewmembers. The disaster and resulting investigation grounded the shuttle fleet for more than two and a half years, and led to a number of safety improvements to the shuttle fleet.

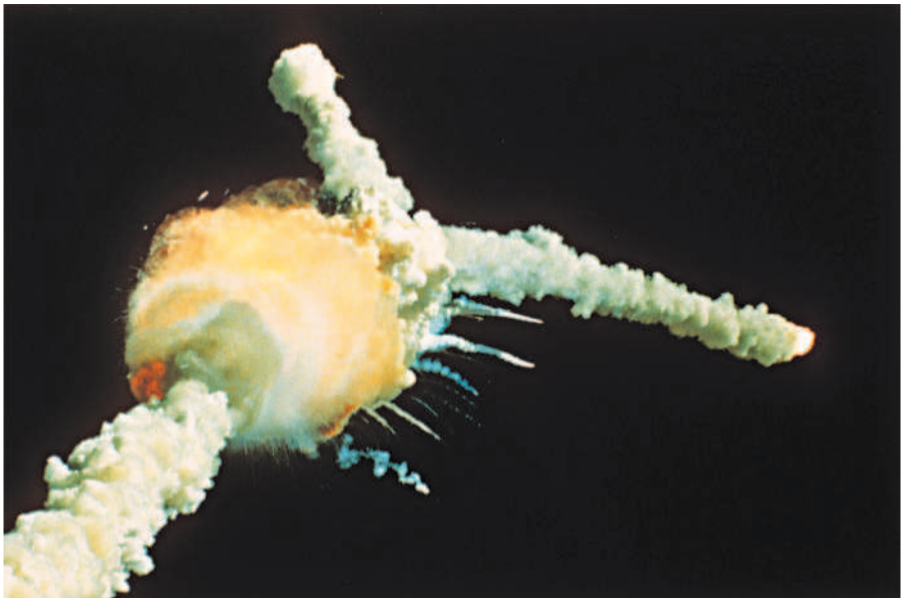
Early History

Challenger's development began in the mid-1970s as a structural test article. The vehicle was not originally planned to fly in space, but instead was meant to allow engineers to study how orbiters would handle the stresses of flight. During these and other tests, NASA concluded that some modifications would be needed to the structure of the shuttle. NASA had planned to refit Enterprise, a shuttle orbiter built for landing tests, to fly in space, but found it would be less expensive to modify Challenger instead. Challenger's conversion into a space-rated orbiter was completed in 1982.

Challenger entered service for NASA in April 1983 on the sixth shuttle flight and the first flight by any shuttle other than Columbia, the first shuttle to fly in space. Challenger completed nine successful flights through November 1985. A summary of those flights is listed in the accompanying table.

Mission 51-L

The tenth flight of Challenger was mission STS-51-L, scheduled for January 1986. This mission attracted considerable pre-launch attention because



The space shuttle Challenger exploded 73 seconds after liftoff from the Kennedy Space Center on January 28, 1986 and claimed the lives of all seven of its crewmembers.

CHALLENGER SHUTTLE MISSIONS

Mission	Launch	Landing	Highlights
STS-6	1983 April 4	1983 April 9	• First mission • Deployed TDRS-1 communications satellite • First spacewalk from shuttle
STS-7	1983 June 18	1983 June 24	• First flight into space by an American woman (Sally Ride) • Deployed Anik C-2 and Palapa-B1 communications satellites
STS-8	1983 August 30	1983 September 5	• First flight into space by an African-American (Guion Bluford Jr.) • Deployed Insat-1B communications and weather satellite
STS-41-B	1984 February 3	1984 February 11	• First untethered spacewalks • Deployed Westar-VI and Palapa-B2 communications satellites • First shuttle landing at Kennedy Space Center
STS-41-C	1984 April 6	1984 April 13	• Retrieved and repaired the Solar Max satellite • Deployed Long Duration Exposure Facility
STS-41-G	1984 October 5	1984 October 13	• Deployed Earth Radiation Budget satellite • First spacewalk by an American woman (Kathryn Sullivan)
STS-51-B	1985 April 29	1985 May 6	• Spacelab-3 tested materials processing and fluid mechanics in weightlessness.
STS-51-F	1985 July 29	1985 August 6	• Shuttle main engine #1 shut down 5 minutes, 45 seconds after launch, forcing “abort to orbit” • Spacelab-2 performed a number of astronomy and life sciences experiments
STS-61-A	1985 October 30	1985 November 6	• German Spacelab D-1 mission performed experiments on materials science, life science, and technology • Crew included two German and one Dutch astronauts

its seven-person crew included a civilian—Christa McAuliffe, a New Hampshire teacher who had been selected from more than 10,000 applicants to become the first teacher in space. The mission also featured the deployment of the TDRS-2 communications satellite as well as studies of Comet Halley.

The launch of Challenger on STS-51-L was originally scheduled for January 22, 1986, but postponed until January 28 because of the delayed launch of the previous shuttle mission, bad weather, and technical glitches. The morning of January 28 was very cold at Kennedy Space Center in Florida, with temperatures well below freezing. The launch was delayed two hours to allow ice on the launch pad to melt as well as to fix an unrelated technical problem. Challenger finally lifted off at 11:38 A.M. Eastern Standard Time. The launch appeared to be flawless until an explosion took place 73 seconds after liftoff, destroying the shuttle and its external fuel tank, and raining debris over the Atlantic Ocean. The two solid rocket boosters (SRBs) attached to the external tank flew free from the explosion for several seconds before launch controllers issued self-destruct commands to prevent them from crashing into populated areas. Challenger and its seven astronauts were lost in the accident, the worst in the history of the space program.

In February 1986 U.S. President Ronald Reagan established a presidential commission to investigate the disaster and recommend changes to prevent such occurrences from happening again. The commission was led by William Rogers, former secretary of state, and included a number of past and present astronauts, engineers, and scientists. The commission concluded that the disaster was caused by the failure of a rubber O-ring in a joint in one of the SRBs. The O-ring was designed to act as a seal and prevent hot gases from escaping, but the O-ring lost its flexibility in the cold temperatures the night before launch and failed to fit properly, allowing hot gases to escape. The hot gases formed a plume that, 72 seconds after launch, caused a strut connecting the SRB to the external tank to fail. A second later, this led to the structural failure of the external tank, igniting the liquid hydrogen and oxygen it carried into a fireball. The fireball itself did not cause the destruction of Challenger; instead, severe aerodynamic loads created by the external tank explosion broke the shuttle apart.

The commission recommended a number of changes to the shuttle program to improve the safety of future launches. First and foremost, the SRBs were redesigned with improved joints to prevent hot gas from leaking from them during a launch. Other improvements were made to the shuttle's main engines and brakes, and an escape system was installed that would allow astronauts to leave the shuttle while in flight in some cases. NASA also changed how it managed the shuttle program, and improved communications between engineers and managers.

The Challenger disaster grounded the shuttle fleet for more than two and a half years while the required improvements were made to the remaining orbiters. The shuttle program returned to flight with the launch of Discovery on mission STS-26 on September 29, 1988. SEE ALSO CHALLENGER 7 (VOLUME 3); HISTORY OF HUMANS IN SPACE (VOLUME 3); HUMAN SPACEFLIGHT PROGRAM (VOLUME 1); SOLID ROCKET BOOSTERS (VOLUME 3); SPACE SHUTTLE (VOLUME 3); TEACHER IN SPACE PROGRAM (VOLUME 3); WOMEN IN SPACE (VOLUME 3).

Jeff Foust

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Challenger 7

On January 28, 1986, space shuttle Challenger was destroyed by a technical malfunction approximately 72 seconds after lift-off. The explosion took the lives of all seven crew members: Francis R. Scobee, Michael J. Smith, Judith A. Resnik, Ellison S. Onizuka, Ronald E. McNair, Gregory B. Jarvis,

When space shuttle Challenger exploded shortly after liftoff on January 28, 1986, the tragedy claimed the lives of all seven of its crewmembers: (left to right) Sharon "Christa" McAuliffe, Gregory Jarvis, Judy Resnik, Dick Scobee, Ronald McNair, Michael Smith, and Ellison Onizuka.

and Sharon Christa McAuliffe. This was the worst National Aeronautics and Space Administration (NASA) disaster since Apollo 1.

Mission Commander Francis R. (Dick) Scobee was born on May 19, 1939. Scobee received a bachelor of science degree in aerospace engineering from the University of Arizona in 1965. He obtained a commission in the Air Force in 1965 and, after receiving his wings in 1966, completed a number of assignments. In August 1979 he completed a one-year training and evaluation period that made him eligible for assignment as a pilot on future space shuttle flights. He first flew as the pilot of the Discovery mission, which launched from Kennedy Space Center in Florida on April 6, 1984. With the completion of this flight he had logged a total of 168 hours in space. His next assignment was flight mission 51-L aboard the Challenger in 1986.

Pilot Michael J. Smith was born on April 30, 1945. He received a bachelor of science degree in naval science from the United States Naval Academy in 1967 and a master of science in aeronautical engineering from the U.S. Naval Postgraduate School in 1968. He completed Navy aviation jet training at Kingsville, Texas, receiving his aviator wings in May 1969. In May 1980 he completed the one-year training and evaluation period. The Challenger mission was to be the first voyage into space for Captain Smith.

Mission specialist Judith A. Resnik was born on April 5, 1949. She received a bachelor of science degree in electrical engineering from Carnegie-Mellon University in 1970 and a doctorate in electrical engineering from the University of Maryland in 1977. She was a senior systems engineer in product development with Xerox Corporation before her selection by NASA in 1978. She completed the one-year training and evaluation period in August 1979. Resnik first flew as a mission specialist aboard Discovery, which launched from Florida on August 30, 1984. With the completion of that flight she had logged 144 hours and 57 minutes in space. The Challenger mission was to be her second spaceflight.

Mission Specialist Ellison S. Onizuka was born on June 24, 1946. In 1969 he received a bachelor of science degree. Later that year Onizuka earned a master of science degree in aerospace engineering from the University of Colorado. Onizuka began active duty with the U.S. Air Force in January 1970 after receiving a commission at the University of Colorado. He joined NASA in 1978 and completed the one-year training and evaluation period in August 1979. He first flew as a mission specialist aboard Discovery, the first space shuttle Department of Defense mission, which launched from Kennedy Space Center on January 24, 1985, logging 74 hours in space. Challenger was to be his return to space.

Ronald E. McNair, the third mission specialist, was born on October 21, 1950. McNair earned a bachelor of science in physics from North Carolina A&T State University in 1971 and a doctorate in physics from the Massachusetts Institute of Technology in 1976. After his graduation from MIT in 1976, he became a staff physicist with Hughes Research Laboratories in Malibu, California. He qualified as a mission specialist astronaut in August 1979 and flew as a mission specialist aboard Challenger (Mission 41-B) on February 3, 1984. With the completion of that flight he had logged 191 hours in space. His flight on Challenger was to mark his return to space.

Born on August 24, 1944, Gregory B. Jarvis was a payload specialist. He received a bachelor of science degree in electrical engineering from the State University of New York at Buffalo in 1967. Additionally, he earned a master's degree in electrical engineering and completed the course work for a master's in management science at Northeastern University in Boston and West Coast University in Los Angeles, respectively. He was selected as a payload specialist candidate in July 1984. The Challenger mission was to be his first spaceflight.

Sharon Christa McAuliffe, born on September 2, 1948, was the second payload specialist. She received a bachelor of arts degree from Framingham State College and a master's degree in education from Bowie State College in Maryland in 1970 and 1978, respectively. She taught various classes for grades nine through twelve in Maryland and New Hampshire. As the primary candidate for the NASA Teacher in Space Program, she was to make her first spaceflight aboard Challenger. SEE ALSO ASTRONAUTS, TYPES OF (VOLUME 3); CHALLENGER (VOLUME 3); EMERGENCIES (VOLUME 3); EXTERNAL TANK (VOLUME 3); HISTORY OF HUMANS IN SPACE (VOLUME 3); SPACE SHUTTLE (VOLUME 3); TEACHER IN SPACE PROGRAM (VOLUME 3); WOMEN IN SPACE (VOLUME 3).

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Civilians in Space

Within a few years of the space shuttle's debut in 1981, the National Aeronautics and Space Administration (NASA) declared the spaceships operational and set about fulfilling an ambitious flight schedule. The space agency hoped to demonstrate that in addition to deploying commercial satellites, flying military **payloads**, and conducting research, the shuttles were safe enough for ordinary people to fly in.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

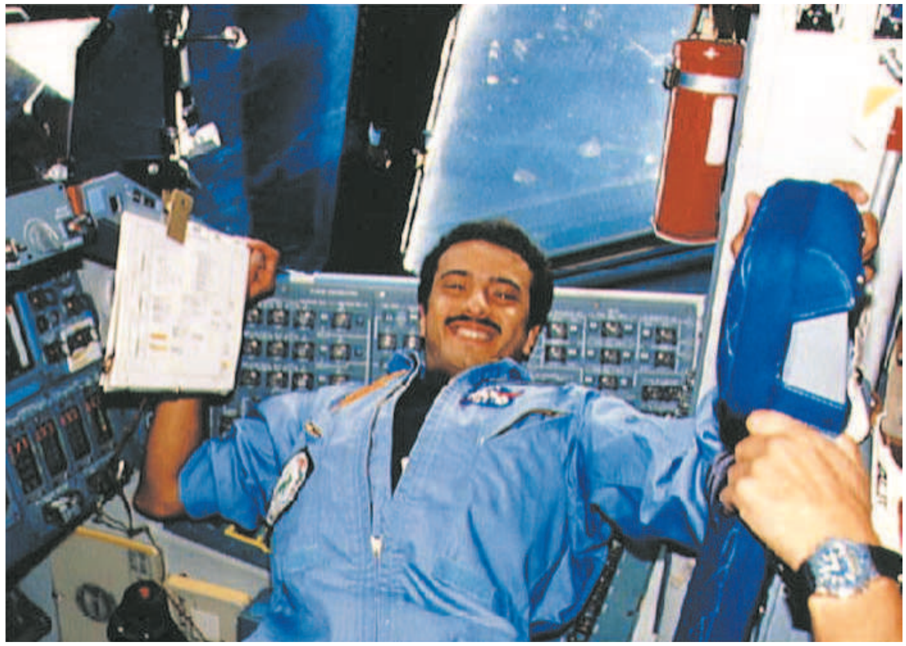
The first guest astronaut invited into the shuttle's crew cabin was a U.S. senator, Jake Garn of Utah, who chaired a NASA oversight committee. Garn, flying as a "congressional observer," made a seven-day flight in April 1985. While his crewmates dispatched two satellites into orbit and conducted science experiments, Garn took part in an informal quasi-educational "Toys in Space" study.

A twenty-eight-year-old Saudi Arabian prince followed Garn into orbit a few months later. On June 17, 1985, Prince Sultan Salman Abdelazize Al-Saud accompanied a crew of six into space for a weeklong mission. The prince was a member of the Saudi royal family and a pilot in the Saudi Air Force. His flight on the shuttle was ostensibly tied to one of the shuttle's payloads: an Arabsat communications satellite. Arabsat was one of three communications satellites launched by the shuttle during that mission, which also involved the deployment and retrieval of an astronomy spacecraft. Another U.S. congressman, Representative Bill Nelson of Melbourne, Florida, flew in January 1986 on the last successful shuttle mission before the Challenger accident.

The Challenger crew, which blasted off on their ill-fated flight on January 28, 1986, included another guest astronaut, the finalist of the agency's Teacher in Space Program, Christa McAuliffe. Her death, along with the loss of five career astronauts and a scientist, brought a quick end to the guest astronaut program.

In the months following the accident, the agency not only ordered equipment redesigns and management changes but also shifted its thinking about the shuttle's operational status. NASA canceled plans to fly a journalist in space and put the Teacher in Space Program on hold.

In 1998 the agency made a slight exception to its ban on nonprofessional astronauts aboard the shuttle. The agency approved former Mercury Seven astronaut John Glenn's petition to fly on the shuttle for geriatrics research. Glenn, who was retiring from the U.S. Senate, was seventy-seven years old when he flew. He served as a research subject for a variety of experiments sponsored by the National Institutes of Health.



Civilian pilot Sultan Salman Abdelazize Al-Saud accompanied an Arabsat communications satellite in June 1985.

In announcing Glenn's flight on the shuttle, NASA Administrator Daniel Goldin also created a new position in the elite astronaut corps—the educator-astronaut—and selected McAuliffe's backup, Barbara Morgan, to fill the position. Morgan joined the astronaut corps that year and completed a mandatory one-year training program. In 2002, NASA announced that Morgan would fly to the International Space Station, possibly in 2004, as the first educator in a new educator mission specialist program.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

Guest astronauts may not be flying on the shuttle anytime soon, but the agency has been unable to prevent its Russian partners in the International Space Station program from selling seats on its Soyuz **rockets** bound for the orbital outpost. On April 28, 2001, Dennis Tito, an American businessman, became the world's first paying space tourist. Tito reportedly paid the Russians about $20 million for a weeklong stay in space. South African Mark Shuttleworth made a similar trip on April 25, 2002, and others were set to follow. SEE ALSO Challenger (volume 3); Glenn, John (volume 3); Teacher in Space Program (volume 3); Space Tourism, Evolution of (volume 4); Tourism (volume 1); Toys (volume 1).

Irene Brown

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Closed Ecosystems

Thermodynamically speaking, humans as living creatures are open systems. To maintain their physical structure, people exchange matter and energy with their environment. Humans live in a closed terrestrial life support system known as the biosphere. The biosphere is a basically closed system in terms of matter but an open system in terms of energy. For spaceflight purposes, the goal is to develop techniques to ensure the biological autonomy of humans when isolated from the terrestrial biosphere.

WHAT ARE THE LAWS OF THERMODYNAMICS?

The term "thermodynamics" refers to the behavior of energy. The first law of thermodyamics states that energy can be transferred from one form into another form but is never created or destroyed. The second law states that no process involving energy transformation can occur unless there is degradation of energy from a concentrated form into a dispersed form.

Life Support Systems

Onboard any spacecraft, **space station**, or planetary base, a controlled and physiologically acceptable environment for the crew is provided by a life support system. The traditional components of life support are air, water, and food. Since the beginning of human space missions, these supplies have been launched from Earth along with the crew or sent as dedicated supply missions. Waste was typically stored and returned to Earth. These open-loop life support systems are very useful and efficient for short-duration space missions. As space missions get longer, however, the supply load gets heavier and becomes prohibitive. Therefore it will be essential to recycle consumables and, consequently, to introduce closed-loop life support technologies on future long-duration space missions. The selection of a suitable life support system in space depends mainly on the destination and duration of a mission and the available technologies.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

bioregenerative referring to a life support system in which biological processes are used; physiochemical and/or nonregenerative processes may also be used

Closed-loop technologies that provide regenerative functions can use physicochemical and/or biological processes. Systems that include both physicochemical and biological processes are called hybrid life support systems. Physicochemical processes include the use of fans, filters, physical or chemical separation, and concentration. Biological or **bioregenerative** processes employ living organisms such as plants or microbes to produce or break down organic molecules. Physicochemical processes are typically well understood, relatively compact, and low maintenance and have quick response times. However, these processes cannot replenish food stocks, which still must be resupplied. Biological processes are less well understood. They tend to be large volume and power- and maintenance-intensive, with slow response times, but they have the potential to provide food.

Whereas the water and oxygen loops of a life support system can be closed through the use of both physicochemical and bioregenerative processes, the carbon loop (most human food is based on carbon compounds) can only be closed by using biological means. If all three loops are closed using bioregenerative means, a closed ecosystem is obtained. In this type of closed life support system, all metabolic human waste products are regenerated and fresh oxygen, water, and food are produced.

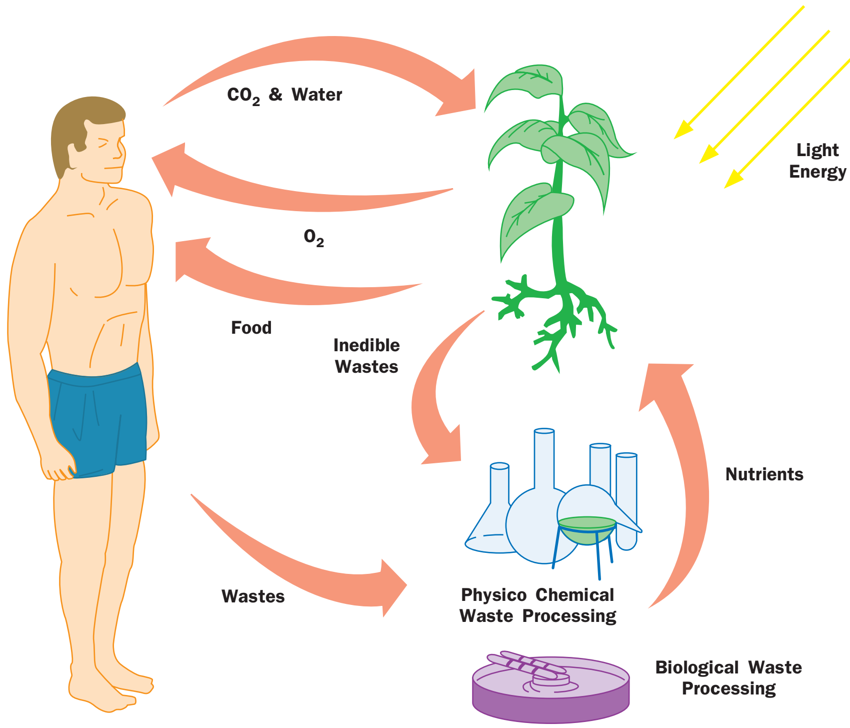
Designing a Closed Ecosystem for Space Missions

Engineering a scaled-down version of the complex terrestrial biosphere into a spacecraft or planetary colony is a difficult task. An efficient biological system requires the careful selection of organisms that can perform life support functions while being ecologically compatible with other organisms in the system and with the human crew. In the absence of natural terrestrial forces, maintaining the health and productivity of the system requires stringent control of system processes and interfaces.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Although closed ecosystems in space are theoretically feasible, they will not become a reality in the very near future. This is due to the fact that there are extreme environmental conditions in space, such as **microgravity**

PRINCIPLE OF A CLOSED ECOSYSTEM



and ionizing radiation. In addition, there is a high degree of complexity, and therefore manifold feedback processes, in such a system.

The main challenges in the design of closed ecosystems are:

- harmonization of mass and energy fluxes;
- miniaturization; and
- stability.

All of these problems are due mainly to the comparatively small size of space ecosystems. Whereas on Earth almost unlimited buffering capacities exist, these capacities are not available in small artificial ecosystems. For example, a problem area in attempts at miniaturization involves mass flow cycles: the mass turnover of the subsystems (producers, consumers, **detruents**) that have to be adjusted because large reservoirs cannot be installed. Thus, turnover processes are accelerated and volume is decreased. Because of the lowered buffering capacity, the whole system loses stability and the capacity for self-regulation, and the danger of contracting an infection increases. Finally, in small ecosystems the equilibrium has to be maintained by monitoring and control systems that detect and correct deviations.

detruents microorganisms that act as decomposers in a controled environmental life support system

Current Research

To enable the development of a closed ecosystem in space within the next few decades, a comprehensive research program on bioregenerative life support systems has been established by the National Aeronautics and Space Administration (NASA). The site of this research program is the BioPlex facility at the NASA Johnson Space Center in Houston, Texas. Bioplex is a ground-based life support test facility that contains both physicochemical and bioregenerative systems. Long-duration tests with humans are to be conducted in the future. SEE ALSO Biosphere (volume 3); Environmental Controls (volume 3); Food (volume 3); Food Production (volume 4); Life Support (volume 3); Living in Space (volume 3).

Peter Eckart

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Collins, Eileen

American Shuttle Commander, Pilot, and Mathematician
1956–

Eileen Collins became the first female shuttle commander in 1995.

Space shuttle Columbia (STS-93) lifted off in July 1999 under the command of Eileen Collins, the first woman shuttle commander. Collins graduated from the Air Force Undergraduate Pilot Training program at Vance Air Force Base in Oklahoma in 1979 and remained there as a T-38 instructor pilot until 1982. She then moved to Travis Air Force Base in Colorado, where she was a C-141 aircraft commander and instructor pilot until 1985.

From 1986 to 1989, Collins was an assistant professor of mathematics and a T-41 instructor pilot at the U.S. Air Force Academy. She received two master's degrees during that period: a master of science in operations research from Stanford University in 1986 and a master of arts in space systems management from Webster University in 1989.

Collins became a National Aeronautics and Space Administration (NASA) astronaut in 1991. She has worked in mission control as a spacecraft communicator (CAPCOM) and served as chief of the Shuttle Branch at NASA Johnson Space Center. She became the first woman pilot of the space shuttle when she flew on STS-63 in 1995; that mission marked the first shuttle rendezvous with the Russian space station Mir. Collins returned to Mir a second time as the pilot of STS-84 in 1997, followed by STS-93 in 1999, when as shuttle commander she oversaw the deployment of the Chandra X-Ray Telescope. SEE ALSO Career Astronauts (volume 1); History of Humans in Space (volume 3); Mir (volume 3); Space Shuttle (volume 3); Women in Space (volume 3).

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Communications for Human Spaceflight

The first serious proposal for space-based human communications was in Arthur C. Clarke's famous article titled "Can Rocket Stations Give Worldwide Radio Coverage?", which appeared in the October 1945 issue of the British magazine *Wireless World*. In this article, Clarke made the case for manned space stations in **geosynchronous orbit**. In addition to conducting research, these stations were to be used to relay radio signals back and forth from Earth's surface. Clarke's article is generally recognized as the origin of today's communications satellites.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis; an object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Early Communications Systems

During the first piloted spaceflight in April 1961, Yuri Gagarin was able to maintain voice communications with Moscow Ground Control throughout his 108-minute trip. As well as being the first human in orbit, he was the first to communicate from space to Earth. On this spaceflight, telemetry, defined as a constant stream of data, was sent back to Earth from his capsule, Vostok 1. Gagarin used radios that transmitted via the very high frequency (VHF), high frequency, and shortwave bandwidths. He tried to maintain communications with a network of six or seven ground stations, all based inside the borders of the Soviet Union.

Later, the Soviets would build and deploy a small fleet of massive radio-relay ships equipped with huge dish antennas. These ships would allow them to maintain constant worldwide communications with their spacecraft without relying on land-based antennas. For the Mercury and later programs, the Americans were able to set up a network of thirteen large antennas in friendly and/or neutral nations, especially Bermuda, Spain's Canary Islands, Nigeria, Zanzibar, Australia, Canton Island, and Mexico; on U.S. territory, in the Hawaiian Islands, California, and Florida; and on ships.

Types of Signals and Antennas

Since Gagarin's flight, piloted spacecraft transmit three main types of signal to ground stations: voice, television, and telemetry, also referred to as data. One of the best-known forms of telemetry is biomedical monitoring where sensors attached to an astronaut's body send an uninterrupted flow of data concerning heartbeat, breathing, and blood pressure to medical personnel on the ground. Other signals used by spacecraft include interferometry for measuring microwaves, **radar**, and automated beacons that provide mission control with the capsule's precise location in space. Recovery beacons are for use during and after landing back on Earth.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Early Russian piloted spacecraft transmitted mostly in the AM and FM bandwidths, while later ones also used more sophisticated pulse compression techniques. To this day, Russian spacecraft tend to use separate antennas for each communications function. Thus, their vehicles tend to be festooned with whip antennas.

In contrast, the Americans either integrate their antennas into the skin of their spacecraft or use small blade antennas, such as the VHF scimitar ones on the Apollo service module. For Apollo's long-range communications needs, the National Aeronautics and Space Administration (NASA) installed a steerable, S-band, 2-gigahertz high-gain antenna. This assembly, composed of four small (78-centimeter [31-inch]) parabolic dish antennas attached to a boom, was more difficult to design and build than all of Apollo's other communications gear combined. This antenna group was deployed as the Command and Service Module docked with the Lunar Excursion Module.

The TDRS System

For the space shuttle, NASA designed and built a series of tracking and data relay satellites (TDRS; pronounced T-dress). The TDRS series is the backbone of the U.S. space communications system in the early twenty-first century. Ground stations are used almost entirely as backups. There are currently seven TDRS spacecraft in equatorial geosynchronous orbit 35,786 kilometers (22,300 miles) above Earth. The first of the series, TDRS-A (now referred to as F-1), was launched by the space shuttle Challenger in April 1983. TDRS-B was onboard the Challenger when it blew up in January 1986. TDRS-C was launched in September 1988, TDRS-D (F-4) in March 1989, and TDRS-E in August 1991. They have been joined by TDRS-F (F-5), TDRS-G (F-6), and the first of a new generation built by Hughes, TDRS-H, launched in June 2000. TDRS-H provides Ka band service for NASA's international partners.

The TDRS system operates in the C, the S, the high-capacity Ku, and the Ka radio bands. The system is controlled from the White Sands Ground Terminal in New Mexico. A support ground station has been built on Guam. The TDRS does not process any data by itself. It is strictly a relay system. The two principal antennas are 4.9 meters (16 feet) in diameter, parabolic, and dual-feed S band/Ku band, and they are held together by a set of umbrella-like ribs. The S-band multiple access **phased-array antennas** can simultaneously receive signals from five spacecraft while transmitting to one.

The TDRS system provides service to a wide range of orbiting spacecraft, both those with crews and those without. Spacecraft supported by this

phased-array antennas radar antenna designs that allow rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

The TDRS-1 helps improve data relay services and communications between such diverse projects as the International Space Station, the Hubble Space Telescope, and the space shuttle.

system include the space shuttle, the International Space Station (Alpha), and the Hubble Space Telescope; Earth observation satellites, which help monitor and control pollution; and astrophysical satellites, such as the X-Ray Timing Explorer, which are showing scientists some of the wonders of the universe. On March 8, 2002, Atlas IIA launched the TDRS-I. Due to a problem with one of the propellant tanks it failed to achieve the proper orbit. Boeing, the prime contractor, has said that eventually they will succeed in getting it to its proper slot in geosynchronous orbit. SEE ALSO COMMUNICATIONS, FUTURE NEEDS IN (VOLUME 4); GROUND INFRASTRUCTURE (VOLUME 1); GUIDANCE AND CONTROL SYSTEMS (VOLUME 3).

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Computers, Use of

The earliest human spaceflights were guided by navigational computers on the ground; there was no onboard computation. But starting with project **Gemini**, computers have been an essential part of every space mission. When the first piloted Gemini flew in 1965, most computers were the size of a room, and so it was a remarkable technological achievement to shrink a computer down to a size (2 cubic feet) that could fit into the small capsule. Onboard computing power enabled Gemini to carry out tasks such as rendezvous and docking even though the computer was underpowered by today's standards. It contained 4,000 words of memory, about a thousandth the size of a handheld personal digital assistant today. The Apollo computer that controlled the lunar landing had only 32,000 words of memory.

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

Early Spaceflight Computers

The computers used in spaceflight have always been a mixture of leading and lagging technology. The fast chips used in desktop and laptop computers on Earth would never survive in space because cosmic gamma ray radiation would deposit electrical charges on the chips, and cause data loss or other failures. Therefore, many chips used in space are custom-designed with redundant circuitry: three circuits instead of one so that the three can vote on the correct answer and ignore a single incorrect result caused by **cosmic radiation**. In other cases standard chips can be protected from radiation with special metal shielding, but even then the onboard chips are typically ten or twenty times slower than Earth models.

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

The experience of the National Aeronautics and Space Administration (NASA) on the Apollo program changed the way people thought of software as a component in a large system and ultimately led to great advances in the software development process. In 1966 NASA was concerned that the software might not be ready by the scheduled launch of Apollo 1. Until that time software had been thought of as a minor add-on to large projects. Now

Computers give astronauts real-time information about the space shuttle, as well as predict upcoming Earth observation targets for the crew.

it appeared that software development delays were threatening the space race with the Soviet Union. NASA and its partner, the Massachusetts Institute of Technology (MIT), were forced to develop better practices of software requirements analysis, documentation, verification, and scheduling. Eventually they were successful, and many of the practices they developed remain in effect. The Software Engineering Laboratory at NASA's Goddard Space Flight Center is still a leader in the field.

The Uses of Computers in Spaceflight

Computers are used in spaceflight for three purposes: to reduce costs, reduce risks, and increase capability. The most significant form of cost reduction lies in minimizing ground operations. For example, scientists at NASA's Ames Research Center developed an artificial intelligence program to automate scheduling of the space shuttle ground processing, a task with roughly 10,000 steps. The program saved time and money, and led to the spinoff of a successful company that provides software to constantly monitor manufacturing variables, such as customer demand and resource availability, thereby helping Fortune 500 companies optimize their factory operations.

The speed and reliability of computers have enabled complex space missions and maneuvers such as bringing the space shuttle back from orbit to take place with a reduced risk of failure. However, computers also play an important role in risk reduction before a mission is even launched. During the design stage, computer simulations search for problems and computerized failure analysis techniques estimate the probability of failure and point out areas to improve.

Computers enable human spaceflight but also diminish the need for it. When Wernher von Braun first imagined space travel, he thought that an orbiting space station would be staffed by about eighty scientists observing the weather and performing other tasks. He did not foresee that unmanned robotic satellites would perform most of those tasks more efficiently and less expensively. Astronauts are so expensive that robots are preferred wherever possible, and are relied on exclusively for all exploration beyond **low Earth orbit** and the Moon.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

There are two kinds of robotic control: telerobotic and autonomous. In telerobotic control a human guides the movements of a robot in another location via radio signals. A fascinating example is Robonaut, a human-sized robot with two arms and hands, a head, a torso, and one leg. Under development at NASA's Johnson Space Center, Robonaut is designed to carry out space walks under the control of a human in the safe environment of the space station or on the ground. Robonaut has hundreds of sensors, giving the human operator a feeling of actually "being there."

Autonomous control is used when a telerobotic link would be too slow or too expensive to maintain. For example, Mars is typically about twenty minutes away from Earth by radio communication, and so **rovers** on the Martian surface are designed to have some autonomous control over their own actions. For more ambitious missions, such as the Mars sample return mission currently scheduled for 2014, more capable autonomy using artificial intelligence will be required. Autonomous robots are also useful as assistants to humans. An example is the Personal Satellite Assistant, a softball-sized robot designed to float in the weightless environment of the space station. It is designed to propel itself by using ducted fans, take pictures, analyze temperature and gas levels, and communicate by voice control. It can check on the status of the station and assist astronauts in doing experiments, using a combination of autonomous and telerobotic control.

rovers vehicles used to move about on a surface

The best uses of computers combine the three attributes of cutting costs, reducing risks, and increasing capability. An example is the Remote Agent program, which controlled the experimental Deep Space 1 mission in 1999. Using technology similar to the space shuttle's ground processing scheduler, Remote Agent allows ground controllers to send a high-level command such as "take pictures of this star cluster" rather than detailed low-level commands such as "open valves 3A and 4B, then burn the engine for three seconds." The program comes up with the best plan for achieving the high-level goal and then executes the plan, all the while checking to see whether something goes wrong, and if it does, figuring out how to fix it.

NASA administrator Daniel Goldin has stated: "When people think of space, they think of rocket plumes and the space shuttle, but the future of space is information technology." Advanced computer technology will continue to contribute to this future. SEE ALSO Humans versus Robots (volume 3); Robotic Exploration of Space (volume 2); Robotics Technology (volume 2); Simulation (volume 3); Telepresence (volume 4).

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Cosmonauts

Cosmonauts are the Russian counterparts to American astronauts. During the early years of the "space race" between the two superpowers, the United States and the Soviet Union, it was the Soviet Union who took the lead. Cosmonauts achieved the records for sending the first human into space, the first space walk, and the first woman in space, Valentina Tereshkova. Yuri Gagarin, the first man in space, was honored by the Soviet Union as a hero, and a cosmonaut training center was named after him.

The first cosmonauts underwent similar training, as well as scrutiny, that American astronauts endured. Tests were conducted on everything from stamina to eyesight. Each candidate was required to be in good physical and mental condition. Training itself was strenuous, including simulators for zero-g and spacecraft controls.

Just as many astronauts were selected from the military, most of the early cosmonauts were selected from the Russian Air Force. The first twenty cosmonauts were male and were jet pilots who had passed rigorous medical tests. Later, five female parachutists who passed the same medical tests were admitted to cosmonaut training.

Training programs in the United States and Russia simulate **microgravity** environments, thrust felt during liftoff, and working in space. Astronauts and cosmonauts both train under water, and train on planes flying parabolas to experience weightlessness. But even though the basic engineering concepts are similar, technology varies. This was apparent when the historical docking and handshake occurred between the astronauts and cosmonauts on an Apollo and a Soyuz spacecraft.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Cosmonaut training before the mission occurs at the Baikonur launch site. Here, cosmonauts perform their final test runs and prepare themselves in simulators. After the training is complete, the cosmonauts will launch inside on a Soyuz spacecraft. These spacecraft are similar to the module-style spacecraft that the United States used during the Apollo space missions. Originally, the destination of the Soyuz transport vehicles was the Mir space station. Soyuz modules are now used for transporting people and equipment to the International Space Station (ISS).

As Russia began to have more problems funding their ISS participation, the first space tourists have been paying millions of dollars and receiving cosmonaut training to visit the ISS. By paying the Russian Space Agency a reported $20 million, American Dennis Tito was able to take a Soyuz spacecraft up to visit the ISS in April, 2001. South African Mark Shuttleworth became the second cosmonaut tourist to visit the ISS the following year.

Cosmonauts Yuri V. Lonchakov and Yury V. Usachev, onboard the Zvezda Service Module of the International Space Station, hold a photo of late cosmonaut Yuri Gagarin, commemorating the fortieth anniversary of first human spaceflight. On April 12, 1961 Gagarin became the first person to travel in space.

SEE ALSO Apollo-Soyuz (volume 3); Civilians in Space (volume 3); Gagarin, Yuri (volume 3); Leonov, Alexei (volume 3); Mir (volume 3); Tereshkova, Valentina (volume 3).

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Crystal Growth

Among the most productive areas of space-based research have been the investigations into growing protein crystals. Proteins are complex biological molecules in all living things, critical for a variety of functions, such as transporting oxygen and chemicals in the blood, forming the major components of muscle and skin, and fighting diseases. Research efforts are focused on understanding the structure of individual proteins, how the structure affects the protein's function, and the design of drugs to interfere with or enhance the protein's function. The human body alone contains more than 100,000 proteins. Scientists, however, know the structure of only about 1 percent of them.

Many diseases involve proteins, such as toxins secreted by invading organisms, or proteins an invading organism needs to survive and spread. Angeogenin, for example, is a protein produced by tumor cells to help lure blood vessels toward the tumor. Cells infected with the HIV virus need the protein HIV protease to replicate. Studying these proteins helps pharmaceutical researchers design drugs to fight the diseases. Protein crystal studies also benefit other areas of biotechnology, such as the development of disease-resistant food crops and basic biological research.

The first step to understanding how proteins function is to produce crystals that are big enough and uniform enough to provide useful structural information upon analysis. Protein crystals are cultivated by moving large molecules through a fluid. Gradually, the concentration of the protein solution is increased so that the growing protein molecules contact each other and form a complex crystal. Temperature, salt concentration, pH balance, and other factors all affect the protein crystal's formation.

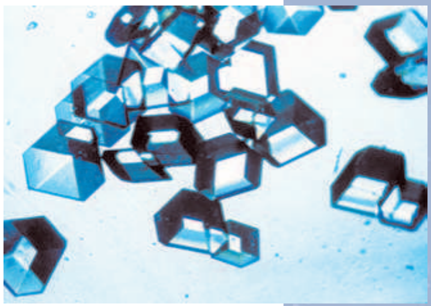
On Earth, protein crystal growth is hampered by convective flows, as molecules **diffuse** from the surrounding solution and join the growing crystal structure. The solution bordering the crystal then contains a lower protein concentration than the remainder of the solution, and therefore, a lower density. This less-dense solution tends to rise, and the denser solution sinks under the influence of gravity, creating eddies next to the crystal. These convective currents are harmful because they alter the orientation of the protein molecules as they hook onto the **crystal lattice**.

Earth-grown crystals also are adversely affected by sedimentation. Once crystals have grown large enough, the suspending solution can no longer support its mass and the crystals fall on top of each other and grow together. Proper analysis of the protein crystals requires individual molecules.

Space-grown crystals tend to be larger and better organized than their terrestrial counterparts. The **microgravity** environment minimizes sedimentation and the effects of **convection** on the crystal, resulting in a more uniform, highly ordered molecular structure. The space-grown crystals thus have fewer defects than Earth-grown crystals.

The National Aeronautics and Space Administration (NASA) has flown dozens of protein crystal growth experiments on the space shuttles and plans to continue the investigations aboard the International Space Station. The delicate space crystals, which are about the size of a grain of salt, are returned to Earth for analysis. A process called X-ray **crystallography** is used to reveal the inner structure of the protein. Unlike dental **X rays**, this technique does not produce a shadow image, but a diffraction pattern, as the X rays bounce through the crystal structure. The scattered X rays are recorded on photographic film or **electron** counters. This data is then fed into a computer, which can perform precise measurements of the intensity of the X rays scattered by each crystal, helping scientists to map the probable positions of the atoms within each protein molecule.

The cleaner the structure of the protein, the more defined the diffraction patterns will be. Once the protein is mapped, researchers look for receptor sites and active areas on the protein where it will connect with other



Researchers are using the microgravity environment in space to produce large near-perfect protein crystals, which are then used to develop new and improved treatments for diabetes.

diffuse spread out; not concentrated

crystal lattice the arrangement of atoms inside a crystal

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

convection the movement of heated fluid or gas caused by a variation in density

crystallography the study of the internal structure of crystals

X rays high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

electron a negatively charged subatomic particle

> **WHAT KINDS OF PROTEINS HAVE BEEN GROWN IN SPACE?**
>
> Proteins that have been successfully cultivated in space include the following:
>
> - Gamma interferon, which is important in antiviral research and for treatment of certain types of cancer
> - Human serum albumin, which is the most abundant protein in human blood, which is responsible for distribution of many different drugs, including aspirin, to various body tissues
> - Elastase, which is a key protein known to cause the destruction of lung tissue in patients suffering from emphysema
> - Factor D, which is important in inflammation and other immune system responses
> - Isocitrate lyase, which is important for the development of antifungal drugs
> - Canavalin, which is isolated from edible plants whose structure is of interest because the information can be used to genetically engineer more nutritious plants
> - Proline isomerase, which is important in and used as a drug for diabetes

molecules, somewhat like a lock and key. From this information, drugs can be designed to aid protein interaction or block it, without affecting the rest of the body. SEE ALSO International Space Station (volumes 1 and 3); Made in Space (volume 1); Microgravity (volume 2); Space Shuttle (volume 3); Space Walks (volume 3).

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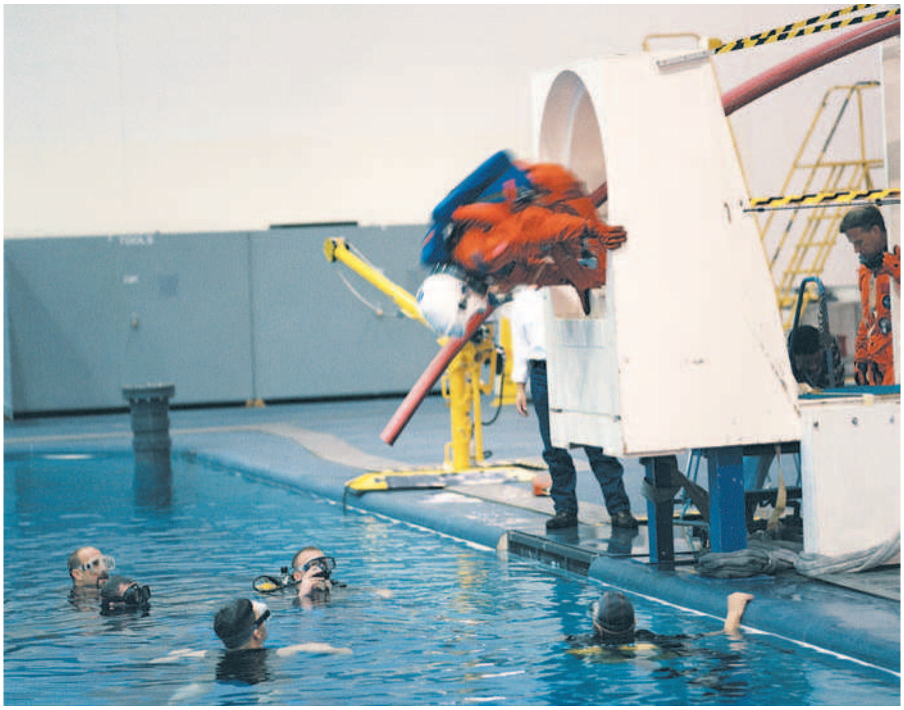
Docking ***See Apollo-Soyuz (Volume 3); International Space Station (Volume 3); Mir (Volume 3); Rendezvous (Volume 3); Space Shuttle (Volume 3).***

Emergencies

Even after forty-five years of experience, traveling to and living in space is a risky proposition. Both of the world's major spacefaring nations, the United States and Russia, have had close calls and catastrophes.

American Incidents

On the American side, an early emergency in space occurred during the **Gemini** program. Neil Armstrong, who would later become the first per-



An astronaut simulates an ejection into a body of water during an emergency bailout training session

son to set foot on the Moon, had to abort his mission when a stuck thruster sent his spaceship tumbling. Close to losing consciousness, Armstrong fired his maneuvering engines to leave orbit and landed safely in the ocean.

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

A few years later, the National Aeronautics and Space Administration (NASA) nearly lost the Apollo 13 crew when an oxygen tank exploded, crippling the spacecraft. The mission to the Moon was quickly aborted, and NASA now had a single goal: bring back the crew alive. The module designed to land on the Moon was refashioned into a crude lifeboat as engineers struggled to come up with a way to bring the spacecraft back to Earth. They finally succeeded. Exhausted and freezing, the crew splashed down in the Pacific Ocean on April 17, 1970. NASA later determined that a design flaw had caused the oxygen tank to overheat and explode.

During launch of a space shuttle in 1985, one of the orbiter's three main engines shut down early. Without enough power to lift the spacecraft to its intended orbit, the shuttle pilots carried out an **abort-to-orbit procedure** and were able to successfully conduct their mission after some hasty replanning by NASA ground control teams. If the shuttle's engine had shut down any earlier, the crew would have been forced to attempt a risky touchdown at one of the shuttle's transatlantic emergency landing sites. In 104 flights of the shuttle, five times engine failures have triggered last-minute launch aborts while the shuttle was still on the ground.

abort-to-orbit procedure emergency procedure planned for the space shuttle and other spacecraft if the spacecraft reaches a lower-than-planned orbit

Early the following year, the space shuttle Challenger exploded shortly after liftoff, claiming the lives of seven astronauts in an accident that was not survivable. The shuttle's solid rocket booster, which triggered the explosion, was subsequently redesigned, but the first two minutes of flight, when the boosters are burning and cannot be shut down, still present the most risk to the shuttle and its crew.

Russian Incidents

Russia suffered fatalities during two missions in the early years of human spaceflight. On April 23, 1967, cosmonaut Vladimir Komarov was killed when the parachute of his Soyuz spacecraft failed during the return to Earth. On June 30, 1971, three cosmonauts returning from a twenty-four-day mission on the Salyut 1 space station died during re-entry when the air leaked out of their spaceship through a faulty valve.

Another emergency occurred in 1984, after two Russian cosmonauts climbed aboard their Soyuz spacecraft for a ride to the Salyut 7 space station. Two minutes before liftoff, a fuel line valve failed to close and propellant spilled out and ignited. Flames engulfed the rocket. Ground controllers worked frantically to send radio commands to **jettison** the crew compartment. An escape rocket fired with just six seconds to spare, carrying the cosmonauts to safety as their launcher exploded on the pad.

jettison to eject, throw overboard, or get rid of

During its final years in orbit, the Russian space station Mir suffered a number of mishaps. Among these were two emergencies—occurring within a period of four months—involving fire and depressurization, two of the most dangerous things that can happen to a spacecraft in orbit. In February 1997, a faulty oxygen candle caused a fire to break out. The blaze blocked the route to one of the station's escape vehicles, but quick action by the crew saved the ship. The next Mir crew had an even more hazardous experience in space. An unpiloted Progress resupply craft crashed into Mir, puncturing its hull. The crew had to work frantically to seal off the damaged module. SEE ALSO Apollo (volume 3); Challenger (volume 3); Cosmonauts (volume 3); Escape Plans (volume 3); Mir (volume 3).

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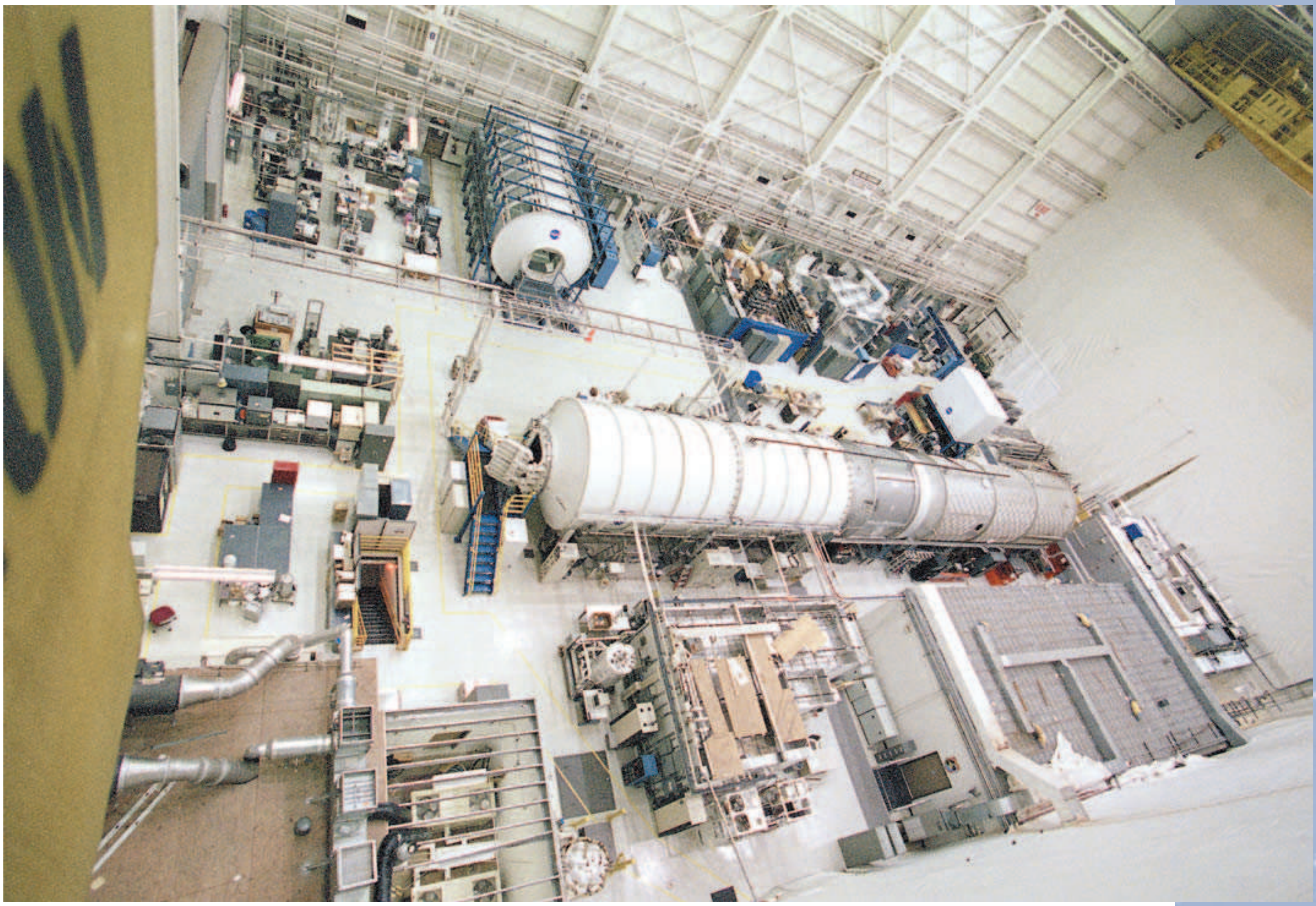
Environmental Controls

When astronauts travel to space, they need to carry along basic life support elements from Earth, such as the ability to produce food, purify their water, regenerate oxygen, and remove harmful microbes and elements from the air. The environmental control systems (in addition to other life-support systems) on the space shuttle and the International Space Station perform these functions, which keep the passengers and crew onboard alive.

Space Shuttle Climate

Temperature, which is controlled by an air revitalization system (ARS), is vital for the operation of a space shuttle, but heating and cooling systems need to be delicately monitored because some portions of the shuttle need cool air to operate, whereas others need warm air. The ARS maintains a



This Internal Thermal Control System Test Facility at the Marshall Space Flight Center is one of the sites for the development and testing of the Environmental Control and Life Support Systems.

relative humidity level of between 30 percent and 75 percent, in addition to keeping the carbon dioxide and carbon monoxide at safe levels. The ARS also regulates temperature, ventilation, and pressure in the crew compartment, in addition to providing cool air to the crew compartment and various flight-deck and mid-deck electronic mechanisms.

Environmental Controls Onboard the International Space Station

Technological advances in the field of environmental controls are a significant part of the International Space Station (ISS). These advances were designed by the National Aeronautics and Space Administration's Marshall Space Flight Center in Huntsville, Alabama, and are collectively called the Environmental Control and Life Support Systems (ECLSS). The ECLSS consists of an ARS, waste collection systems, and water purification systems. Innovations will enable the space crew to not only survive but also to live and work on the ISS for months and maybe years.

Water recycling and oxygen generation are two of the most important aspects of the ECLSS, because water and oxygen are the two basic necessities for life. One of the initial aims of the ECLSS is to recycle wastewater (including urine) to produce purified water for drinking. This recycled water will also be used to produce oxygen for the flight crew. The systems also need to remove dangerous gases from the cabin atmosphere. These gases may be generated only in trace amounts, but they can still be dangerous. In addition, gases such as nitrogen, oxygen, carbon dioxide, methane, and hydrogen must be kept at specific pressures to ensure the safety of the crew and shuttle. Because ventilation and air distribution are also important, the environmental control systems ensure that all air circulates properly through the ISS modules. SEE ALSO Closed Ecosystems (Volume 3); Life Support (Volume 3).

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Escape Plans

Safety considerations in a piloted spacecraft must take into account the possibility of an emergency at any stage of the flight, starting with the prelaunch countdown and ending with the vessel's return to Earth. Following the Challenger disaster in 1986, the crew compartment was found in the Atlantic Ocean. It appeared that at least some crewmembers survived the initial explosion and were alive before the impact with the water. But the seven astronauts had no way to escape, and their cloth uniforms offered no protection or survival capabilities. The National Aeronautics and Space Administration (NASA) proceeded to implement changes to the crew module and the astronauts' uniforms, making emergency evacuation and survival more likely during specific periods in the shuttle's mission.

In the event of an emergency on the launch pad, the astronauts can evacuate the shuttle up to 30 seconds before launch. The shuttle launch gantry is equipped with seven 1,200-foot-long sliding wires, each attached to a basket similar to those used for hot-air ballooning. Each basket can carry up to three people. The baskets descend steeply and rapidly down the wires to the ground, where the crew will proceed to a special bunker designed to shield them from a possible explosion on the launch pad.

Should the shuttle come in for a landing, but cannot reach a runway, the crew can evacuate while the orbiter is in the air. The side hatch on the shuttle can be discarded. A pole is then lowered from the hatch opening, and crewmembers can hook themselves to the pole. The astronauts will slide down the pole past the left wing, and slide off the pole into a freefall. The special suits worn by astronauts during launches and landings contain parachutes that will allow the crew to return safely to Earth.

Mercury the first American-piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963.

The side hatch on the shuttle is similar in principle to the explosive hatches used on the **Mercury** spacecraft, starting with Gus Grissom's Liberty

If an emergency evacuation from the space shuttle is needed on the ground, astronauts can escape through a side hatch, as simulated here.

Bell. Mild explosives sever the hinges on the hatch, just the way the Mercury hatches worked. Hatch thrusters propel the hatch on the shuttle away from the main shuttle body.

When the shuttle is on the ground, an emergency evacuation can be achieved through the side hatch opening using an inflatable slide. A secondary emergency opening is through one of the overhead windows on the flight deck. Once that window has been opened, the astronauts climb special steps up to the opening and lower themselves to the ground over the side of the shuttle.

The current escape systems described above are considered inadequate in many scenarios involving catastrophic engine failure or a Challenger-like explosion. NASA has been studying additional emergency escape systems for the space shuttle. Among the options being considered are ejection seats and a detachable crew compartment with its own separation rockets. These systems are not new to human spacecraft. Ejection seats were used on the Gemini spacecraft, and on many Soviet spacecraft, as well as the first four shuttle missions. The Mercury and Apollo space vehicles were equipped with a launch escape tower—a tower bearing a rocket that could carry the crew capsule away from a burning launch pad or a fiery booster during launch, similar to the proposed detachable crew module for the shuttle.

Any upgrades to the safety systems will require major and expensive changes to the current space shuttle design. The space shuttle is scheduled to operate at least until 2012, and probably longer. Independent safety experts consider safety upgrades past due, given the planned life span of the shuttle program. SEE ALSO Apollo (volume 3); Challenger (volume 3); Emergencies (volume 3); Space Shuttle (volume 3).

Adi R. Ferrara

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EVA *See Space Walks (Volume 3).*

External Tank

Propelling the space shuttle into orbit requires a lot of fuel—more than 2 million liters (525,000 gallons) are used during every launch—and a very large tank to hold it. The biggest and heaviest element of a fully fueled space shuttle is the rust-colored, bullet-shaped external fuel tank, which the National Aeronautics and Space Administration (NASA) calls an ET.

Stretching 46.9 meters (153.8 feet) long and spanning 8.4 meters (27.6 feet) in diameter, the external tank forms the structural backbone of the shuttle during launch, absorbing most of the 2.7 million kilograms (6 million pounds) of thrust generated during blastoff. The primary job of the external tank, however, is to feed pressurized fuel to the shuttle's three hydrogen-burning main engines during the eight-and-a-half-minute ride into space. The engines consume more than 242,000 liters (64,000 gallons) of propellants every minute.

Carrying that much fuel into space is difficult enough—about 25 percent of the shuttle's 2-million-kilogram (4.4-million-pound) launch weight is the weight of the fuel itself. But adding to the complexity is the unusual nature of the fuel, which is only remotely similar to the petrochemicals used in most automobiles.

The external tank contains liquid hydrogen and liquid oxygen, supercold substances that have to be kept well below freezing in the usually warm weather found at the shuttle's Florida launch site. The external tank is coated with many layers of a special foam insulation to keep ice from forming on the outside of the tank during the final hours before launch. Any ice on the shuttle could break off during launch and damage the spaceship.

The external tank actually contains three tanks: one at the top for liquid oxygen, one in the middle to house electronics, and a large container in the rear to hold the liquid hydrogen. The oxygen must be kept at –183°C (–297°F), and the hydrogen at –253°C (–423°F)—just a bit shy of absolute zero, the point at which there is a complete absence of thermal energy.

jettison to eject, throw overboard, or get rid of

The external tank is the only part of the space shuttle that is not reusable. The tank is attached to the underside of the orbiter at three locations. When the shuttle is almost in orbit and the fuel tank nearly empty, small explosives are fired to break the tank's connective bolts and **jettison** it from the spaceship. The tank breaks into pieces as it reenters the at-

The external tank of a space shuttle is taller than the Statue of Liberty without its base.

mosphere, and any debris splashes down into a remote area of the Indian or Pacific Oceans.

Several proposals have been made over the years to turn the shuttles' spent fuel tanks into mini space stations and other orbital platforms, but so far the tanks, which cost NASA about $43 million apiece in 2001, have never been recycled. SEE ALSO Rocket Engines (volume 1); Rockets (volume 3); Solid Rocket Boosters (volume 3); Space Shuttle (volume 3).

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F

Faget, Max

American Engineer and Designer
1921–

Maxime (Max) Allan Faget was born in Stan Creek, British Honduras, on August 26, 1921. He received a bachelor of sciences degree from Louisiana State University in 1943 and later was given honorary degrees by the University of Pittsburgh and Louisiana State University. He has done research in manned spaceflight, propulsion, re-entry aerodynamics, life support systems, guidance and control, engineering and space systems development, and technical management. He worked at the National Aeronautics and Space Administration (NASA) Langley Research Center in Hampton, Virginia, from 1946 to 1958; as director of engineering and development at NASA Manned Spacecraft Center, Houston, from 1961 to 1981; as vice president and director of Eagle Engineering from 1981 to 1984; and as the founder, president, and chief executive officer of Space Industries from 1982 to 1992.

Faget has contributed many publications to the field of spaceflight and has been granted numerous patents. He has received many awards, including the Athhur S. Fleming Award, 1959; Golden Plate Award for Academic Achievement, 1962; Daniel and Florence Guggenheim Award, 1973; NASA Goddard Space Flight Center Astronaut Award, 1979; William Randolph Lovelace II Award, American Astronautical Society, 1971; Space Flight Award, 1976; Lloyd V. Berkner Award, 1987; Gold Medal, American Society of Mechanical Engineers, 1975; Albert F. Sperry Medal, Instrument Society America, 1976; Harry Diamond Award, Institute of Electrical and Electronics Engineers, 1976; and the Jack Swigert Memorial Award, 1988. SEE ALSO Guidance and Control Systems (volume 3); History of Humans in Space (volume 3); Life Support (volume 3).

E. Julius Dasch

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Flight Control

The control of a space vehicle can be divided into two parts. The most obvious part includes the rockets and airfoils that directly steer the vehicle and control its speed. Less apparent are the computer systems that control the rockets and airfoils. These systems rely on measurements from various instruments, as well as knowledge of the vehicle's planned route, to determine how the rockets and airfoils should be used.

In a way, these computer systems act collectively like a car driver who relies on what she knows and senses to make decisions about car speed and direction. The driver then uses the steering wheel, gas pedal or brakes to act on these decisions, just as the computer systems would use the rockets or airfoils of a space vehicle. Similarly, while a car driver can refer to landmarks and street signs to determine if the car is off course, the flight con-

William Foster monitors flight data in the Shuttle Flight Control Room of Johnson Space Center's Mission Control Center.

trol computer systems depend mainly on inertial guidance to make this determination.

The inertial guidance system calculates the vehicle's speed, direction and location, and issues control commands. "Inertial" means that it is based on measurements of acceleration. The system consists of a computer and an inertial measurement unit (IMU) comprising three accelerometers mounted on a gyroscopically stabilized platform. Accelerometers are mechanical devices that respond to acceleration. Acceleration can be felt when a car changes speed or makes a turn. If these accelerations could be monitored and split into northward, eastward and upward directions, then the location and speed of the car at any given moment could be determined. In a similar way, a rocket's inertial guidance system measures acceleration along three principal directions. To keep the accelerometers always pointing in these same principal directions, gyroscopic devices sense changes in direction and move the IMU platform to counter them.

Once the inertial guidance computer decides a course change is needed, it issues control commands to the space vehicle's rockets and airfoils. Airfoils are useful only when the vehicle travels through air, during launch, for example. Typically, moveable flaps on fins serve as airfoils. Just as a rudder steers a boat by diverting water flow, an airfoil steers the vehicle by diverting the flow of air.

Rocket-based control can be used during both launch and in space. It relies mainly on diverting the direction of the rocket's exhaust, and on controlling the amount of exhaust. The most direct form of rocket-based control swivels the rocket motor or its nozzle to steer the vehicle's direction. This is one of the methods used to control the space shuttle during launch.

Another method employs moveable flaps in the rocket motor to divert the exhaust flow direction. A variation of this uses a stream of gas or liquid in the rocket nozzle to divert the exhaust flow. Auxiliary engines and gas can provide the delicate control sometimes needed in space because valves can slow and even stop the exhaust of the liquid fuels or gas propellants whenever it is needed. In contrast, solid fuel, like that used to launch the shuttle, must burn until used up. SEE ALSO Guidance and Control System (Volume 3); Gyroscopes (volume 3); Inertial Measurement Units (Volume 3); Space Shuttle (volume 3).

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Food

Astronaut Brian Duffy samples a beverage during a food evaluation session.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth and 1972

Proper nutrition is central to the maintenance of good health. The primary purpose of a diet, whether on Earth or in orbit, is to provide adequate levels of essential nutrients and energy. However, nutritional requirements change under **microgravity** conditions and diets need to reflect these changes. There are a number of physical constraints on the presentation and preparation of foods during piloted space missions. These include issues of weight, volume, preparation time, and waste generation. The psychosocial benefits of mealtime on motivation and morale also must be considered.

Food products for spaceflight need to be safe, easy to prepare and consume, compact, and produce little waste. For short-term missions of two weeks or less, such as those of **Apollo** and the space shuttle, foods are stored at room temperature. Food products are **thermostabilized**, freeze-dried, or specially packaged to prevent microbial spoilage. Water is plentiful on spacecraft that use fuel cells, so dried foods are easily rehydrated for consumption. Many of the precooked foods are commercially available canned or foil-packaged products.

Longer missions, such as Skylab and the International Space Station, are provided with refrigerated- and frozen-food storage units. Short-duration missions are characterized by intense workloads for the crew. Little time is available for food preparation and meals. Many of the food products available require no preparation and are provided as individual portions. Early missions used food products packaged in tubes that could be squeezed into the mouth. Apollo used hot water (about 65°C [150°F]) to warm foods. The space shuttle has a small **convection** oven to warm foods at temperatures of 145 to 185°C [293 to 365°F]. No cooking is done during spaceflight. For longer missions, more preparation time and effort is acceptable.

Lifting materials into orbit and beyond is costly, making weight and volume considerations important. Dehydrated foods help to limit these costs. The consumption of foods is made simpler in a microgravity environment by providing bite-sized products or by using special packaging. Crumbs and splatters disperse throughout the cabin on orbit, so their generation must be minimized. Given the closed environment of the spacecraft, food odors also should be minimized.

M&Ms float into the mouth of NASA astronaut Loren J. Shriver onboard the space shuttle Atlantis. The majority of space food consists of precooked and dehydrated substances.

Space Diets

Space shuttle astronauts meet with dieticians well before the start of their mission to design a suitable diet. Menus are chosen from a list of more than 100 foods and beverages. Many of these are prepackaged, widely available, and familiar food products. Fresh fruits can be included. Tortillas act as a bread substitute to limit the generation of crumbs. Beyond the menu chosen by each astronaut, a communal pantry is stocked with a variety of snack foods and an extra two-day supply of food. Astronauts aboard the International Space Station can choose from an even richer variety of foods. Approximately one-quarter of the foods are ethnic or international in origin. The menu rotates through a twenty-eight-day cycle. The station also has a "salad machine" to grow fresh lettuce and salad greens onboard. This technology has been tested and used on the space shuttle and on the Mir space station.

thermostabilized designed to maintain a constant temperature

convection the movement of heated fluid or gas caused by a variation in density

The Impact of Diet During Short-Duration Missions

For short-duration missions, nutritionists follow the basic U.S. National Research Council recommended daily allowance guidelines. Additional considerations are necessary for long-duration missions. Studies have found that individuals who consume the space shuttle diet on the ground obtain proper energy intakes and no loss of lean body mass. However, during shuttle missions adequate energy intake is an issue, mainly because of decreased food consumption. In part this can result from space adaptation syndrome, which causes malaise, vomiting, and the loss of fluids and **electrolytes**. A more prevalent cause may be the excitement of spaceflight and the demanding work schedule. Astronauts simply do not take the time to eat proper meals while on orbit. During spaceflight, liquid intake is generally too low. Microgravity causes bodily fluids to redistribute. It is possible that thirst is not triggered in the same way under these altered physiological conditions.

electrolytes a substance that when dissolved in water creates an electrically conducting solution

Changes in Nutritional Needs During Longer Missions

Over the course of longer missions, studies have identified a variety of physiological changes that may reflect changes in nutritional needs. The most striking changes are the loss of minerals from the bones and a decrease in muscle mass. There are changes in the metabolism of calcium that leads to bone loss. The cause is unclear, but may be due to reduced load on the bones in the absence of gravity, reduced Vitamin D production in the absence of **ultraviolet**-rich sunlight, and changes in fluid balances and **endocrine** function. Nitrogen balance also is affected during long-duration spaceflight, and this, combined with changes in energy metabolism due to endocrine alterations, may be responsible for the loss of muscle mass that has been observed.

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

endocrine system in the body that creates and secretes substances called hormones into the blood

The Challenges of Very-Long-Duration Missions

Very-long-duration flights, covering years, such as a human expedition to Mars, pose unique challenges. As the length of the voyage extends past several months, it becomes increasingly cost-effective to grow foodstuffs in the spacecraft rather than launching with a full supply of foods. Closed ecological life support systems would provide the crew with oxygen and remove carbon dioxide, as well as provide food and potable water. Vegetarian diets are under consideration that include a limited number of hydroponic crops such as rice, wheat, potatoes, and soybeans. Fewer crops are easier to manage, but a diet lacking in variety is less palatable. It will be important to develop the means to create a variety of food products from each crop. Soybeans can provide soy milk, tofu, tempe, and other products. Extensive use of spices also can be helpful.

As mission lengths increase, it is likely that the crew's emphasis on food and mealtimes will increase, a phenomenon observed at the permanent station at the South Pole and during the two-year enclosure of people in the closed environment of Biosphere 2 in Oracle, Arizona. The psychosocial benefits of feasting are likely to become more important as the distance between the crew and Earth increases and real-time communication and interaction with Earth decreases. In addition, cumulative nutrient deficiencies become more important over long time spans. Food processing can affect nutrient availability and protein digestibility. Cumulative **toxicological** effects may be observed as a result of by-products of food processing, storage, or water recycle. Extensive ground-based testing will need to be performed to ensure a safe food supply for long-duration human space missions. SEE ALSO Biosphere (Volume 3); Communities in Space (Volume 4); Food Production (Volume 4); Living in Space (Volume 3); Living on Other Worlds (Volume 4); Long-Duration Spaceflight (Volume 3); Microgravity (Volume 2).

toxicological related to the study of the nature and effects on humans of poisons and the treatment of victims of poisoning

Mark A. Schneegurt

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G Forces

Astronauts and spacecraft are subject to both the force of gravity and "G forces." Although they are related, these forces are not necessarily the same thing. However, to understand G forces it helps to know something about gravitational force—the force that determines the motion of a planet around a star, the **orbit** of a satellite, or the motion of clusters of galaxies. In the presence of any massive object, such as a planet or star, any other mass experiences a force of attraction called gravitational force. This gravitational force is strictly proportional to the object's mass and the gravitational field, as in the formula $F = m \cdot g$, where g is the gravitational field at any given location, and g exerts a force F on the mass m. The force F is also considered the object's weight.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger objects

At different points in space, the gravitational field generally has a different magnitude and direction. Therefore, the gravitational force acting on an object (its weight) changes as well. Newton's law of gravitation states that the gravitational force that two objects exert on one another also depends on their masses. This explains why astronauts on the Moon, which is much less massive than Earth, weigh only one-sixth as much as they do on Earth.

Besides being called the gravitational field, g is also considered the acceleration due to gravity. In fact, Newton's second law says that the force on an object is strictly related to the object's mass and acceleration—any type of acceleration. This means that if an object is accelerated it will experience G forces regardless of the gravitation force acting upon it. In practice, the term "G force" measures the magnitude of force due to nongravitational accelerations and represents the force of acceleration that pull on an object when it changes its plane of motion. Objects that are decelerated experience negative G forces.

Although G forces and the force of gravity are not synonymous, the force of gravity on Earth is used as a baseline for measuring G forces from acceleration or deceleration. When a person is simply sitting down, the force pressing her or him against the seat is the force of gravity. The intensity of this force is said to be "1G." The G force increases, however, if an astronaut is in a spacecraft that is accelerated. As the astronaut pulls more Gs, her or him weight increases correspondingly. An 80-kilogram (176-pound) astronaut in the space shuttle can experience 3Gs or more during liftoff, and her or him weight would thereby increase to 240 kilograms (528 pounds).

STS-95 mission specialist John Glenn completed two nine-minute training runs in this centrifuge, where he pulled a threshold of three times his body weight, or three G forces.

centrifugal directed away from the center through spinning

An astronaut in an orbiting spacecraft experiences weightlessness (often mistakenly call zero gravity). The cause of weightlessness is not the absence of gravity because gravitational force is still present. But the gravitational force is exactly balanced by the **centrifugal** force of the orbital trajectory, so that the astronaut is pulled with equal but opposite acceleratory forces that cancel each other out. For this reason, the astronaut floats in a state of weightlessness. SEE ALSO FLIGHT CONTROL (VOLUME 3); GRAVITY (VOLUME 2); MICROGRAVITY (VOLUME 3); ROCKET ENGINES (VOLUME 1); ROCKETS (VOLUME 3); SOLID ROCKET BOOSTERS (VOLUME 3); ZERO GRAVITY (VOLUME 3).

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Gagarin, Yuri

Russian Cosmonaut; First Human in Space
1934–1968

On April 12, 1961, at age twenty-seven, Yuri Gagarin, of the Soviet Union, became the first human in space. He completed one orbit of Earth before descending in his Vostok 1 spacecraft and parachuting the last 3 kilometers (2 miles) to the ground. Instantly, this Russian from a collective farm in Klushino became a world hero and household name.

After graduating from high school, Gagarin attended a machinery school to train as an ironworker. He then attended the industrial and technical school in Saratov. While there, he joined a flying club and became an amateur pilot. On the recommendation of an instructor he was accepted into the Orenburg Aviation School in 1955. Gagarin trained as a fighter pilot with the Northern Fleet. Inspired by the Soviet Union's Luna 3 satellite, which was the first to return images of the Moon's farside, he applied to become a cosmonaut and was accepted.

Gagarin's orbital flight in 1961 was a pivotal moment in the "space race" between the Soviet Union and the United States. The United States sent Alan Shepard into space on a suborbital flight three weeks after Gagarin's flight. After his orbital flight, Gagarin made many public appearances and in 1966 began training for a Soyuz flight. Unfortunately, at the age of thirty-four, he and a flight instructor were killed in the crash of their MiG-15 training jet. SEE ALSO COSMONAUTS (VOLUME 3); GOVERNMENT SPACE PROGRAMS (VOLUME 2); HISTORY OF HUMANS IN SPACE (VOLUME 3); SHEPARD, ALAN (VOLUME 3).

Meridel Ellis

Russian Yuri Gagarin became the first person in space when he orbited Earth on April 12, 1961.

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Gemini

The Gemini program was the United States' second human spaceflight program, an interim step designed to bridge the technological gulf between the early **Mercury** flights and the Apollo lunar-landing program. The National Aeronautics and Space Administration (NASA) announced plans for Gemini on December 7, 1961, two months before John Glenn's historic Mercury mission. Like Mercury, the Gemini spacecraft was built by the McDonnell Aircraft Corporation, but unlike its predecessor, Gemini carried a two-person crew. This inspired NASA to name the program after the third constellation of the zodiac, which featured the twin stars Castor and Pollux. Altogether, the Gemini program involved twelve flights, including two unpiloted flight tests of equipment.

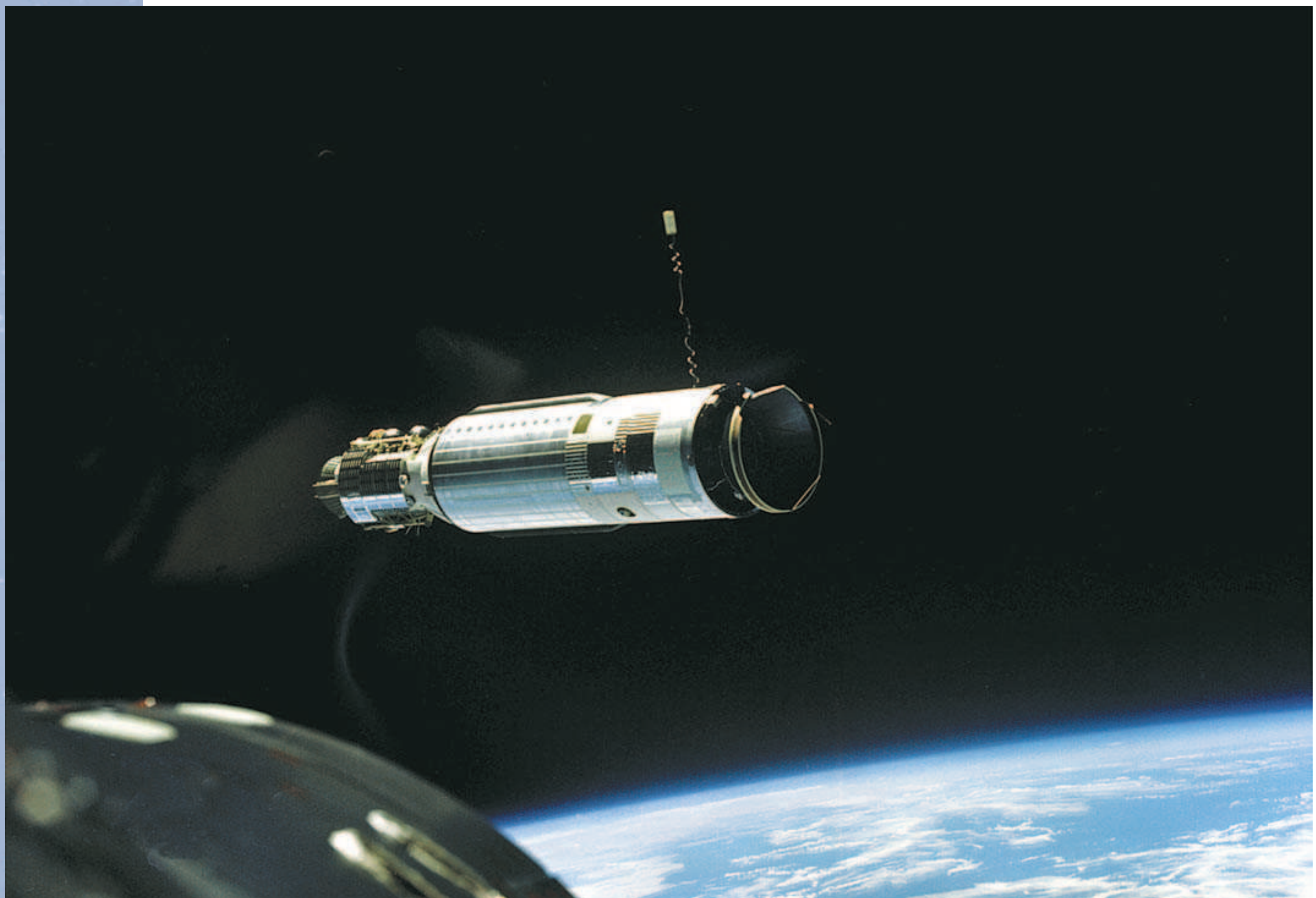
Edward H. White was the first U.S. astronaut to complete extravehicular activity.

Program Objectives and Spacecraft Features

From a pilot's perspective, the Gemini spacecraft represented a major advance over Mercury in design and capability. Gemini was designed to rendezvous and dock with other orbiting vehicles and to maneuver in space. The program also aimed to test astronauts and equipment during long-duration flights as well as **extravehicular activity** (EVA)—a requirement for later trips to the Moon. Other major objectives of the Gemini program included perfecting re-entry and landing at preselected points and gaining information about the effects of radiation and weightlessness on crew members.

Mercury the first American piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963.

Meeting these objectives meant that the new spacecraft had to be large enough to support its two-person crew—5.8 meters (19 feet) long, 3 meters (9.8 feet) in diameter, and about 3,810 kilograms (8,400 pounds) in weight—and have an adapter section attached to the crew cabin to house consumables, carry equipment, and provide propulsion. The onboard propulsion



The Agena Target Vehicle as seen from Gemini 8. This was the first successful docking of two spacecraft.

system, called the Orbit Attitude Maneuvering System, gave Gemini its versatile flight capability, allowing the spacecraft to be maneuvered and docked in orbit and controlled in flight. Engineering advances also simplified the maintenance of Gemini by using independent equipment modules located outside the cabin to allow easy access for engineers and technicians.

extravehicular activity a space walk conducted outside a spacecraft cabin, with the crew member protected from the environment by a pressurized space suit

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

The Initial Gemini Flights

Sometimes referred to as Gemini-Titan for the spacecraft and its launch vehicle (a converted Air Force intercontinental **ballistic** missile), the first piloted Gemini flight, Gemini 3, rocketed into orbit in March 1965 and completed three orbits in four hours, fifty-three minutes. Although the flight was brief, the crew of Virgil "Gus" Grissom and John Young proved that orbital maneuvers were possible and partially achieved a controlled re-entry and landing.

Just over two months later, Gemini 4, the second of the piloted flights, completed sixty-two orbits in four days and two hours, with Edward White spending twenty-two minutes outside the spacecraft during the historic first American EVA. The mission, commanded by James McDivitt, successfully evaluated real-time flight planning and procedures for crew rest and work cycles, but a planned rendezvous with the Titan II's upper stage was canceled because of fuel consumption.

In Gemini 5, Gordon Cooper and Charles "Pete" Conrad tested a prototype fuel cell that became a vital element in future spaceflights. During the mission, problems with the fuel cell precluded rendezvous with a **radar** evaluation "pod," but the astronauts were able to put the spacecraft through a series of orbit changes, aiming at a hypothetical target. Cooper and Conrad splashed into the Atlantic on August 29, 1965. They had flown 120 orbits of Earth in eight days, carrying out sixteen experiments and proving that a round-trip voyage to the Moon was within the physical capability of trained astronauts.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Rendezvous and Docking Operations

Having demonstrated the feasibility of a lunar trip, project Gemini prepared for the next step: rendezvous with an **Agena** target vehicle. The first rendezvous attempt was slated for Gemini 6 with Walter Schirra and Thomas Stafford in the cockpit, but a propulsion failure of the Agena forced the mission to be rescheduled. In its place, Gemini 7 was launched on December 4, 1965. Aboard Gemini 7, Frank Borman and James Lovell completed 206 orbits in thirteen days, eighteen hours, establishing an endurance record for human spaceflight that would stand for years. While in orbit, Gemini 7 served as a passive docking target for Gemini 6, which had finally launched on December 15, 1965, carrying Schirra and Stafford. The two spacecraft approached to within 6 meters (20 feet) of each other and flew in formation for nearly five and a half hours.

Agena a multipurpose rocket designed to perform ascent, precision orbit injection, and missions from low Earth orbit to interplanetary space; it also served as a docking target for the Gemini spacecraft

On the next flight, Neil Armstrong and David Scott successfully docked with an Agena target vehicle six and a half hours after liftoff, but the flight of Gemini 8 was cut short because of problems with Gemini's control system. The crew was forced to undock after thirty minutes and had to regain control of their spacecraft by using the re-entry control system, which prompted an early landing in the Pacific on March 16, 1966. Two months later, however, Thomas Stafford and Eugene Cernan refined rendezvous techniques in Gemini 9, including a simulation of lunar module rendezvous using a backup-docking target lashed together from spare parts. Cernan also performed a two-hour EVA, though his visor became fogged, and he was unable to test a maneuvering unit.

Gemini 10 and 11 provided additional rendezvous and EVA experience. In July 1966 John Young and Michael Collins piloted Gemini 10 to a rendezvous with two Agena target vehicles on separate occasions and used the Agena propulsion system to boost Gemini 10 to a Gemini altitude record of 760 kilometers (471 miles). In addition, during a ninety-minute EVA, Collins used a handheld maneuvering unit to float over to an undocked Agena. Gemini 11, commanded by Charles "Pete" Conrad, was launched in September 1966 and reached a Gemini altitude record of 1,190 kilometers (738 miles) using the Agena's propulsion system after a first-orbit rendezvous and docking. During the mission, Richard "Dick" Gordon completed several EVAs and tethered the Gemini and Agena spacecraft together with a 30-meter (98-foot) line to test whether two spacecraft could be stabilized in a **gravity gradient**.

gravity gradient the difference in the acceleration of gravity at different points on Earth and at different distances from Earth

The last flight in the series, Gemini 12, spent almost four days in orbit practicing rendezvous and docking operations and performing several EVAs. James Lovell and Edwin "Buzz" Aldrin docked with the Agena on the third orbit, largely by visual means, and Aldrin set an EVA record of five and a half hours for a single space walk. Gemini 12 also performed tethered operations with its Agena target vehicle, but docking maneuvers were canceled because of a propulsion anomaly during the target vehicle's insertion into orbit. The splashdown of Gemini 12 on November 15, 1966, marked the operational end of the Gemini program.

As a prelude to Apollo, NASA needed to perfect rendezvous and docking techniques in orbit, learn how to make precision landings, and gain experience with large propulsion systems in space. Astronauts also needed to prove they could conduct EVAs and endure long-duration missions. Over eighteen months, the ten piloted flights of Gemini met all of these goals and many other objectives to provide a solid foundation for the Apollo voyages to the Moon. SEE ALSO APOLLO (VOLUME 3); ASTRONAUTS, TYPES OF (VOLUME 3); CAPSULES (VOLUME 3); HISTORY OF HUMANS IN SPACE (VOLUME 3); MERCURY PROGRAM (VOLUME 3); MISSION CONTROL (VOLUME 3); RENDEZVOUS (VOLUME 3); SHEPARD, ALAN (VOLUME 3); SPACE WALKS (VOLUME 3); YOUNG, JOHN (VOLUME 3); ZERO GRAVITY (VOLUME 3).

John F. Kross

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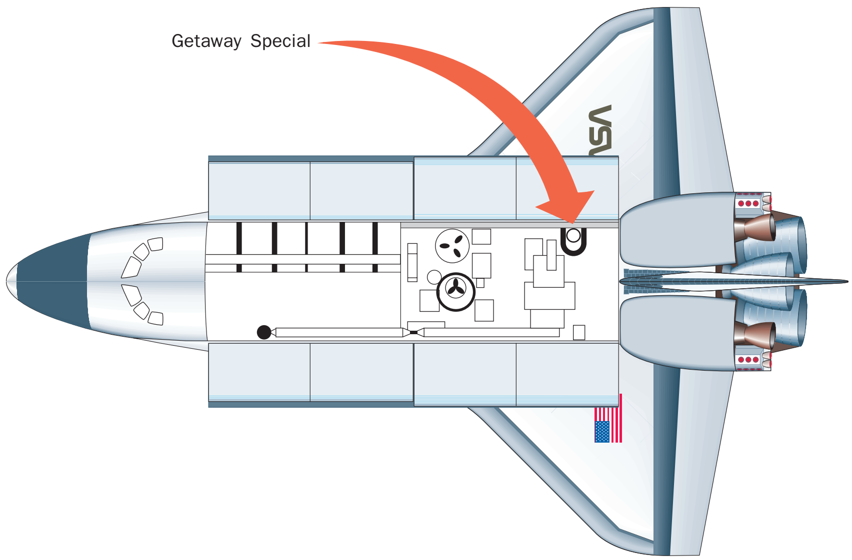
Getaway Specials

Getaway Special (GAS) is the common name for the National Aeronautics and Space Administration's (NASA) small, self-contained payload program. GAS is a project designed to provide easy, low-cost access to space for individuals and organizations that wish to conduct research in a true space environment. Because the space shuttle's huge **payload bay** is not always full, NASA can offer available space for small experiments at reduced prices.

payload bay the area in the shuttle or other spacecraft designed to hold the experiment to be performed or cargo to be launched

NASA classifies the participants in the GAS program into four classes: domestic educational institutions (experiments for the benefit of the students, not faculty or staff); the U.S. government; other U.S. entities (private or commercial); and international entities (governmental, industrial, or educational). Access to GAS flights rotates among these classes to give all potential participants a chance to conduct their experiments. Class I (domestic educational institutions) comes up in the rotation before and after every other class. Within each class applications are processed on a first-come, first-served basis. As long as payloads are available, NASA's rule dictates, "No entity [an individual or organization in any of these classes] may

LOCATION OF GETAWAY SPECIAL
FLIGHT VERIFICATION PAYLOAD ON STS-3



receive more than two out of any twenty consecutive payload opportunities."

The program allows individuals and organizations a free hand in designing experiments that will be carried on the shuttle. There are a few rules that must be adhered to, including the following:

1. The experiment or experiments must fit into a standard NASA GAS container and weigh altogether no more than 91 kilograms (200 pounds). More than one experiment (from the same group or individual) can be put into the same container.
2. The experiment(s) must be peaceful and scientific, educational, or technical. NASA will not fly commemorative items in the GAS program.
3. The experiment(s) should be self-powered.
4. The experiment(s) should require only minimal crew involvement, usually limited to flipping on/off switches.

Utah State University students prepared the first GAS payload. It included ten experiments, testing the effects of **microgravity** on subjects ranging from fruit fly genetic structure to the thermal conductivity of a water-oil mixture. The canister was flown on STS-4 (space shuttle Columbia; launched June 27, 1982). The second payload belonged to the government of West Germany. That experiment looked at the effects of microgravity on a mixture of molten mercury and gallium. The movie director Steven Spielberg donated a GAS payload to the California Institute of Technology for two experiments looking at the effects of microgravity on oil and water separation and the direction in which roots grow.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

The GAS program seeks to further educational goals at all levels and has accepted experiments from high schools and the Boy Scouts of America.

On September 12, 1992, seven experiments belonging to Explorer posts throughout the country flew on Endeavour. The Explorers were invited to submit ideas for experiments in 1978, and of the thirty-eight original proposals, the final seven were selected. These experiments included capillary pumping and crystal growth under conditions of microgravity.

NASA does not require the owners of the experiments to furnish the results to NASA following the flight. However, the results, with few exceptions, should be publicly available within a year after the flight. SEE ALSO Crystal Growth (Volume 3); Education (Volume 1); Made in Space (Volume 1); Payloads (Volume 3); Payloads and Payload Specials (Volume 1); Space Shuttle (Volume 3).

Adi R. Ferrara

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John Glenn became the first American to orbit Earth during the Mercury 6 mission on February 20, 1962. In 1998, at the age of seventy-seven, Glenn returned to space.

Glenn, John

American Astronaut and Senator
1921–

Born in Cambridge, Ohio, on July 18, 1921, John Hershel Glenn, Jr., graduated with a bachelor of science degree in engineering from Muskigum College in 1942. Glenn has received nine honorary doctoral degrees from various colleges and universities.

Through the Naval Aviation Cadet Program, Glenn obtained a commission in the U.S. Marine Corps in 1943. He flew combat missions in World War II and the Korean War. After Korea, Glenn attended Navy test pilot school and joined the Naval Bureau of Aeronautics' Fighter Design Branch in Washington, D.C. In 1957 he set a transcontinental speed record, averaging supersonic speeds in flying from Los Angeles to New York.

In 1959 Glenn was chosen to be a member of the first group of the National Aeronautics and Space Administration's (NASA) astronauts. On February 20, 1962, he became the first American astronaut to orbit Earth aboard Mercury 6. In January 1963, Glenn specialized in the design and development of spacecraft and flight control systems for Project Apollo. He retired from NASA and the Marine Corps as a colonel in 1964 and was elected a U.S. senator from Ohio in November 1974.

On October 29, 1998, at the age of seventy-seven, Glenn returned to space aboard the space shuttle Discovery for a nine-day mission investigating, among other things, the relationship between spaceflight and the aging process. SEE ALSO Aging Studies (Volume 1); History of Humans in Space (Volume 3); Mercury Program (Volume 3); Space Shuttle (Volume 3).

Frank R. Mignone

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Guidance and Control Systems

Guidance and control systems determine and regulate everything from the trajectory of a vehicle to how much fuel it burns and when. Thus, these systems are vital to the performance of satellites, **rockets**, and spacecraft in orbit and when moving through space. Space travel and the use of communications and other types of satellites would be impossible without the thousands of individual components that constitute guidance and control systems.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

Piloted and Unpiloted Guidance

In piloted spacecraft, guidance control is usually an automatic process—that is, controlled by the ground-based support crew. But astronauts also have the capability of guiding their craft, in order to fine-tune their orbit or **interstellar** path, maneuver the spacecraft to a target, and as a fallback system in case of ground-based guidance failure.

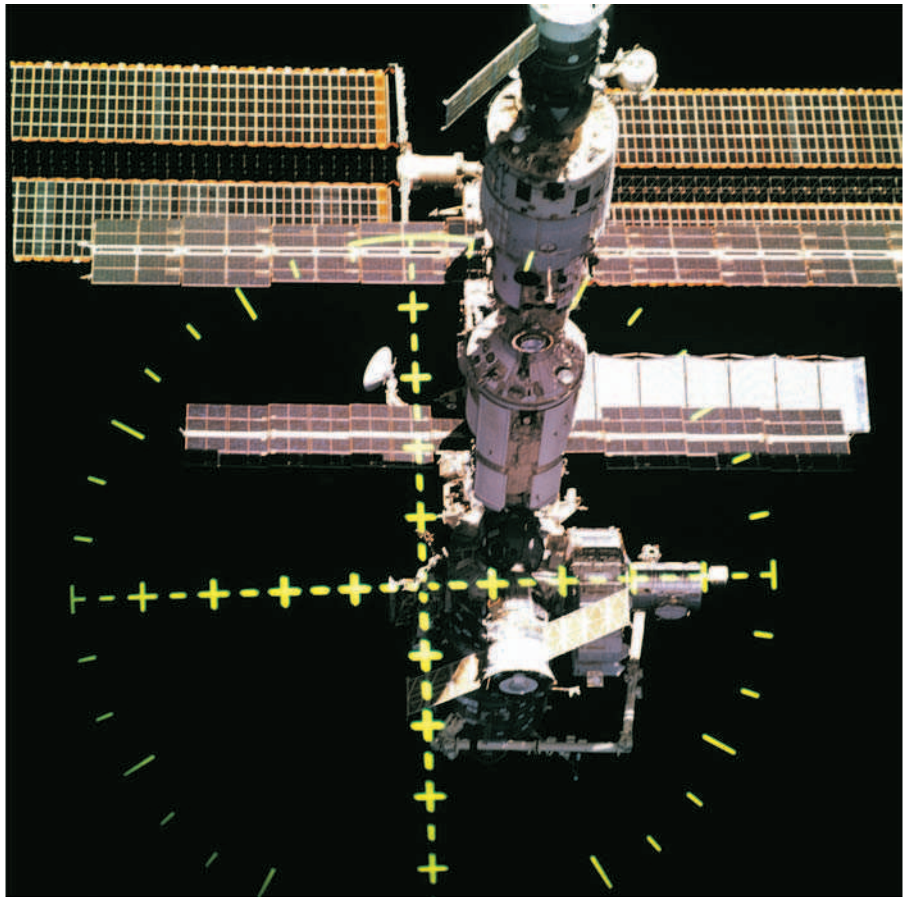
interstellar between the stars

Unpiloted craft, such as a rocket (essentially a tube mounted on an explosive motor), has to be oriented correctly and kept going in the desired direction. Longitudinal and lateral guidance and control processes are important.

Longitudinal guidance, along the long axis of the rocket, prevents potentially catastrophic end-over-end tumbling. Fins are sometimes used for this purpose. Passive fins, which do not move, can be positioned toward the front or, most commonly, towards the rear of the rocket. Passive fins cannot correct for changes from the desired route caused by things such as a cross-wind. Such directional control, which is important in the targeting of military weapons, for example, can be achieved by active fins, which are pivoted in a manner similar to the rudder on an airplane. Proper lateral guidance, or guidance around the cylinder, is ensured by small rockets called thrusters. They are positioned along the side of the craft and help prevent or control spinning.

Satellites

Satellites intended for orbit can have various guidance and control systems, depending on the design of the satellite, the height of the orbit, and the satellite's function. Many satellites are stabilized in their orbits by spinning. Things that spin are naturally stable. Cylindrical satellites often spin slowly, at about one revolution per second, to keep them in their predetermined orbit. If a satellite has a communications dish, the dish must remain stationary to keep pointing at its target on Earth. The satellite has to be designed to



The grid of the Optical Alignment System (COAS) of the space shuttle Discovery can be seen during separation operations while undocking from the International Space Station (ISS).

maintain its stability even with a nonmoving portion present, and the dish must be designed to prevent the satellite from wobbling out of orbit. Satellites with protruding solar panels require another means of guidance and control, which is provided by **gyroscopes** or small spinning wheels—flywheels—that are part of the main body of the satellite. If sensors detect an orbital change, a signal is relayed to the flywheels to spin faster or slower to correct the deviation.

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

Forces associated with Earth, such as gravity and the magnetic field, provide other means of guidance, serving to position the orbiting spacecraft or satellite in a certain orientation or maintain the desired flight path. SEE ALSO FLIGHT CONTROL (VOLUME 3); INERTIAL MEASUREMENT UNITS (VOLUME 3); NAVIGATION (VOLUME 3).

Brian Hoyle

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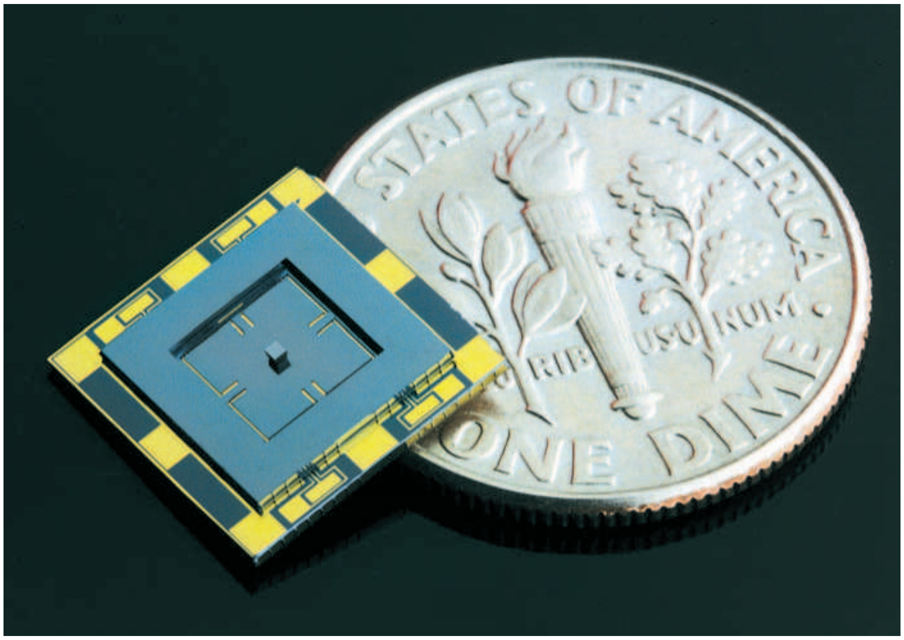
Gyroscopes

Gyroscopes are mounted disks that spin so that their axes can turn freely and maintain a constant orientation in space. Consequently, they play an



The microgyro, which is smaller than a dime, is better performing and cheaper than its larger counterparts.

important role in space travel as they are used to stabilize spacecraft and keep them pointed in a specific direction. Any changes in a spacecraft's orientation detected by onboard gyroscopes can be used by guidance systems to make adjustments. This ability to retain a particular position is vital. For instance, it allows controllers to orient a spacecraft so that a communications antenna is pointed toward a receiving antenna and so that solar panels are pointed toward the Sun.

Gyroscopes are the heart of the space shuttle's Inertial Measurement Units (IMUs). IMUs measure the shuttle's attitude and **velocity**, and this information is used by the shuttle's navigation, guidance, and flight control systems for steering and control.

velocity speed and direction of a moving object; a vector quantity

The basic principle of the way in which gyroscopes provide stabilization for spacecraft has not changed since gyroscopes were invented in the nineteenth century by Jean Foucault. The physics of gyroscopes involves the conservation of **angular momentum**. A spinning top can be used to illustrate how a gyroscope works. If one pushes a spinning top so that it tilts, the top will right itself. This ability to retain position is used in space to ensure that satellites and spacecraft remain in the proper orientation and do not tumble out of control.

angular momentum the angular equivalent of linear momentum; the product of angular velocity and moment of inertia (moment of inertia = mass $\times$ radius^2)

Late in the twentieth century the importance of gyroscopes to space missions was demonstrated on two occasions. In November 1999 the science missions of the Hubble Space Telescope had to be put on hold when one of its three gyroscopes failed. The National Aeronautics and Space Administration (NASA) had to send a rescue mission to the Hubble in which space shuttle astronauts made a special space walk to replace the defective gyroscopes. In June 2000 NASA was forced to perform a controlled reentry of the fully functional Compton Gamma Ray Observatory because a gyroscope had failed in December 1999. The Compton Observatory still had two working gyroscopes, but NASA was concerned that if one of those gyroscopes failed, NASA controllers would not be able to control the descent of the spacecraft. Because the Compton Observatory was one of the largest objects ever placed in space (about 17 tons), NASA felt that it would be prudent to bring Compton down while it was sure it could fully control the observatory's attitude during the deorbiting maneuvers, ensuring that it did not hit populated areas of Earth.

Gyroscopes are essential to any space mission. As with any element of a spacecraft, certain traits—smaller, lighter, longer life span, reduced power consumption—are desirable. This has been a driving force in the development of new gyroscope technology.

The major change in gyroscopes since their discovery has been the shift from mechanical to electronic devices. Nonetheless, gyroscope units used in space can weigh up to 9 kilograms (20 pounds). In 1999 NASA's Jet Propulsion Laboratory developed an experimental gyroscope on a chip. The new device measures 4 millimeters by 4 millimeters (about the size of a shirt button) and weighs less than 1 gram. It will be some years before these devices are used on spacecraft. SEE ALSO Guidance and Control Systems (volume 3); Navigation (volume 3).

Salvatore Salamone

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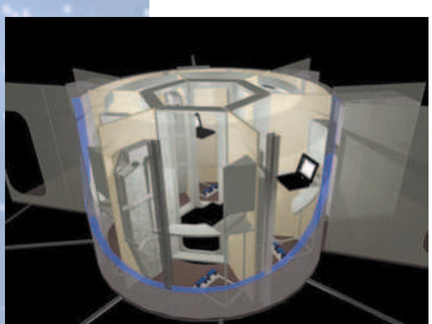
H

Habitats

One of the earliest designs for living in space was clearly a fantasy: an orbiting sphere, 200 feet (61 meters) in diameter, made of 12 million bricks and housing thirty-seven human inhabitants determined to create an ideal society. It was described by Boston religious leader Edward Everett Hale in a short story titled "The Brick Moon" in *Atlantic Monthly* magazine in 1869. It was written as a fable, never meant to be taken seriously. Later, Russian mathematician Konstantin Tsiolkovsky, after seeing France's Eiffel Tower in 1895, was at first obsessed with the idea of building a tower 35,786 kilometers (22,300 miles) into the sky. In his 1920 novel, *Beyond the Planet Earth*, a more mature Tsiolkovsky proposed a **geosynchronous** orbiting space station, with an international crew, greenhouses, and solar power—a remarkable vision very close to modern reality.



This computer-generated close up of the TransHab Module crew quarters is an example of the living space available in such a module.

The First Space Stations

More than eighty years later, with the experiences of the Salyut, Skylab, and the Mir space station, along with the space shuttle behind us, we no longer have to speculate about life in space—we have firsthand knowledge. Astronauts staying in space for extended periods have had to settle for very modest accommodations, often living in cramped, oversized aluminum cans. These "human habitation modules," as they are called, are designed to be rugged, lightweight (hence the aluminum), and functional, but they do not take the human factors of comfort and privacy into account. Skylab housed three astronauts in an aluminum cylinder—essentially one section of a Saturn IVB booster rocket—that was 48 feet (14.6 meters) long and 22 feet (6.7 meters) in diameter for missions lasting as long as 84 days.

geosynchronous remaining above a fixed point above Earth's surface

The International Space Station

In the early stages of the International Space Station (ISS), crews of three astronauts used the Zvezda (the Russian word for "star") module for living quarters. This cylindrical module—originally developed for the Mir 2 station—is 43 feet (13.1 meters) long, and has sleeping quarters for two people; the third person sleeps in a Temporary Sleep Station (TeSS) located in the science laboratory. Zvezda has the necessary toilet and hygiene facilities, a kitchen with a refrigerator and freezer, a table for meals, and a treadmill and a stationary bike for exercise.

NASA's plans for a U.S.-built habitation module have gone through many revisions over the years as budgets for space exploration have been cut back. A habitation module capable of housing up to seven astronauts has recently been scrapped due to cost overruns. For now, Zvezda is the only habitation module available on the ISS.

Future Habitat Designs

In the future, with permanent **space stations**, space hotels, and long voyages to Mars a distinct possibility, larger living quarters will be needed. Tourists staying in a hotel on the Moon will surely require entertainment facilities, luxurious accommodations, privacy, and room to move around. Astronauts on long voyages will need some privacy to escape the constant presence of coworkers, and they will require more comfort than is available in the oversized aluminum cans. But designers have been limited to **payloads** that can be carried by the shuttle, which has severely restricted the size of possible habitation modules.

space stations large orbital outposts equipped to support human crews and designed to remain in orbit for an extended period

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

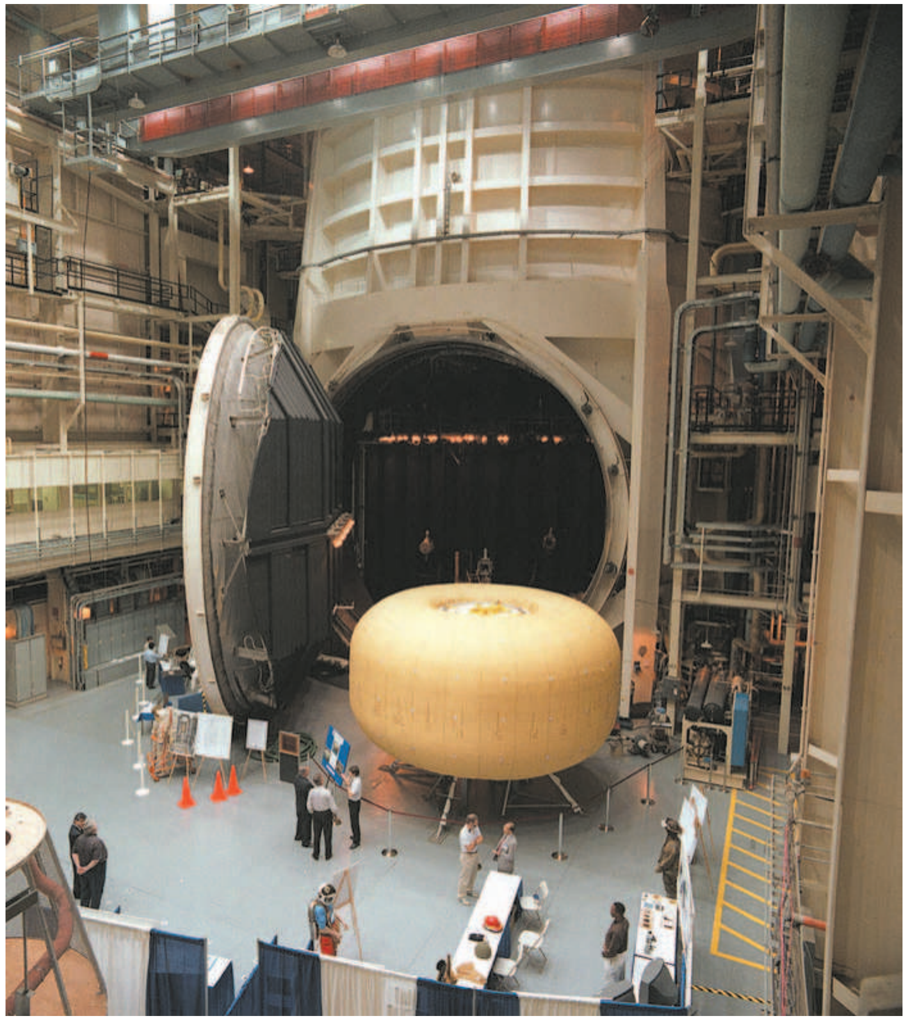
Engineers at the NASA Johnson Space Center in Houston, Texas, came up with a solution to the problem in 1997. The proposed "TransHab" (for transit habitat) module is an inflatable living space made of lightweight, flexible materials stronger than steel. TransHab could be folded during transportation in the shuttle and inflated to its natural size when deployed in space. Like a balloon, the inflated size will be much larger than its collapsed size; living spaces three times bigger than the current aluminum modules will be possible. Using strong, lightweight materials keeps the payload weight down, so the shuttle can carry it. Instead of living inside of a can, astronauts would live in a balloon.

In its current design, TransHab will be a four-level pressurized cylinder with a foot-thick (0.3 meters) outer shell consisting of about two dozen layers of varying materials. Layers of an insulating ceramic material combined with layers of polyurethane foam will protect TransHab from **meteors** or other space debris by absorbing energy and shattering the particle before it causes extensive damage. Kevlar®, the material used in bullet-proof vests, will provide structural support. Three bladders of a polymer material will hold in the air, and a fireproof cloth will line the interior walls.

meteors physical manifestations of a meteoroid interacting with Earth's atmosphere

The internal core of TransHab will be made of lightweight carbon-fiber composite materials. The floors and walls will fold out after TransHab is

The TransHab module is seen here under development in the Space Environment and Simulation Laboratory (SESL) at NASA's Johnson Space Center in 1998. This habitation module has a three-level internal layout and could house all crew activities, from sleep to exercise.



inflated; in some areas, floor panels can be opened as passageways to create a vaulted-ceiling effect. A central passageway will provide access to all four levels of the module. The wardroom and galley area on the first level will have a kitchen with a refrigerator and freezer, a microwave oven, a water dispenser, and a table for twelve that will be used for meals and meetings. An "Earth-viewing" window will provide a scenic area for diners. The crew quarters on the second level will have six individual compartments with 81 cubic feet of space each, so every astronaut will have a private living/sleeping room with a sleeping bag, a computer entertainment center, and storage space for personal items. A mechanical room containing the environmental control and life support systems will encircle the crew quarters. Level three is the crew health care area, with a treadmill, an exercise bicycle, another "Earth-viewing" window, a "space bath" for "showering," and a medical exam room complete with emergency equipment and medical supplies. The fourth level is just a pressurized tunnel to connect TransHab to a space station.

With its roomy living space and provisions for entertainment, exercise, and privacy, TransHab could find many uses beyond the ISS. It could be the perfect vehicle for transporting a crew of astronauts during the long voyage to Mars. Once there, TransHab could transform into a "mobile home" for astronauts while they explore the red planet. Larger units with even more room and luxurious accommodations could become the first hotels in space, whether sitting on the surface of the Moon or floating in orbit at L2, one of the five Lagrangian points in the Earth-Sun system where the gravitational forces balance to provide a stable orbiting location.

Clearly, other types of space habitats are possible, and ideas previously unimagined will emerge. Perhaps huge, environmentally controlled geodesic domes on the Moon or Mars could act as giant greenhouses where humans could live and grow crops for consumption. Rotating cylindrical or ring-shaped spacecraft could produce **centrifugal** forces that simulate gravity for the space tourist. Concept proposals have been developed for a space hotel orbiting 775 miles (1,247 kilometers) above Earth, with a tether connected to a space dock only 160 miles (257 kilometers) above Earth. Passengers would fly to the space dock in a reusable launch vehicle, then ride a space elevator up to the hotel. Maybe Tsiolkovsky's tower idea was not so far-fetched after all. SEE ALSO BIOSPHERE (VOLUME 3); CLOSED ECOSYSTEMS (VOLUME 3); COMMUNITIES IN SPACE (VOLUME 4); DOMED CITIES (VOLUME 4); DYSON SPHERES (VOLUME 4); DYSON, FREEMAN JOHN (VOLUME 4); HOTELS (VOLUME 4); HUMAN FACTORS (VOLUME 3); HUMAN SPACEFLIGHT PROGRAM (VOLUME 1); L-5 COLONIES (VOLUME 4); LIFE SUPPORT (VOLUME 3); LUNAR BASES (VOLUME 4); O'NEILL COLONIES (VOLUME 4); O'NEILL, GERARD K. (VOLUME 4); SETTLEMENTS (VOLUME 4); SPACE ELEVATORS (VOLLUME 4); TRANSHAB (VOLUME 4); TSIOLKOVSKY, KONSTANTIN (VOLUME 3).

centrifugal directed away from the center through spinning

Tim Palucka

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Heat Shields

The term "heat shield" refers primarily to a special structure that protects a re-entry vehicle from the intense heat generated by friction with a planet's atmosphere. Less commonly, it can refer to the insulating material that surrounds the entire spacecraft, protecting the interior from the extremes in temperature encountered during the course of the mission. Heat shields are a vital part of every vehicle designed to return its crew and/or instruments safely to Earth, as the heat of re-entry would easily incinerate a spacecraft without this form of protection.

Space Capsules

The cone-shaped capsules of the early U.S. space program had heat shields attached to their base. These shields were designed to vaporize slowly during

The damage to the heat shield of the Apollo 17 Command Module was caused by the extreme heat of re-entry.

Mercury the first American-piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963.

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

re-entry. The materials used in the heat shield, as they vaporized, would carry excess heat away from the spacecraft and its crew. For example, the **Mercury** and **Gemini** capsules of the early 1960s were protected by heat shields made of silica-fiber resin, while the later Apollo capsules had shields made of phenolic epoxy resin, a form of plastic. Apollo heat shields were nearly 7 centimeters (2.7 inches) thick and weighed 1,360 kilograms (3,000 pounds).

The Space Shuttle

With the development of the space shuttle in the late 1970s came the need for lighter materials that could protect the orbiter on multiple re-entries. The surface of each orbiter is covered by the Thermal Protection System (TPS), an outer layer primarily consisting of more than 24,000 heat-resistant ceramic tiles. These tiles dissipate heat so efficiently that it is safe to touch one by its corners only a few seconds after it is removed from a 1,260°C (2,300°F) oven, the temperature most of the heat shield reaches during re-entry. Most of the orbiter's underside is covered by one of the three types of tile, known as high-temperature reusable surface insulation (HRSI) and distinguished by its black color. These 99.8-percent silica tiles are approximately 15 centimeters (6 inches) square and between 2.5 and 12.5 centimeters (1 and 5 inches) thick. The rest of its underside, primarily the leading edges of the orbiter's nose and wings, reaches temperatures exceeding 1,260°C (2,300°F) during re-entry and must be protected by an all-carbon composite known as reinforced carbon-carbon.

The remainder of the shuttle is covered by low-temperature reusable surface insulation (LRSI) tiles. LRSI tiles have the same basic characteristics as HRSI tiles but are cast thinner (0.2 to 1.4 inches) and in larger, 20 centimeter by 20 centimeter (8 inch by 8 inch), sections. LRSI tiles have a white optical- and moisture-resistant coating made of silica compounds and shiny aluminum oxide, which helps the orbiter control its temperature while in orbit.

Looking to the Future

Despite the advantages of ceramics, the tiles still require heavy maintenance, which adds to the cost of each shuttle flight. Several tiles are shaken loose during each shuttle mission and must be replaced. The National Aeronautics and Space Administration (NASA) is already developing heat shield technology for the next generation of re-entry vehicles. One promising material is a nickel-chromium alloy known as Inconel 617, which was proposed to form the surface panels for the heat shield on the X-33 (an experimental space plane designed to test single-stage-to-orbit technologies; the project was canceled in 2001). Inconel panels for the X-33 were crafted to be highly resistant to corrosion, require only a single waterproofing (unlike shuttle tiles which must be waterproofed frequently), and be more easily removed than ceramic tiles because of a simpler mounting system. SEE ALSO Re-entry Vehicles (volume 3); Solar Particle Radiation (volume 2).

Chad Boutin

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History of Humans in Space

Exploring seems to be a part of the human psyche. But the desire to leave the confines of Earth's gravity could not meet reality until some practical means of transportation could be developed. American physicist Robert H. Goddard's experiments in the 1920s and 1930s showed a practical way to loft objects and people into space: the liquid-fueled rocket. During World War II the German military exploited Goddard's new technology by building the V-2 rocket to carry bombs to targets in England. Larger rockets to carry nuclear bombs on intercontinental flights were developed during the Cold War. By the late 1950s, booster rockets were powerful enough to launch objects into **orbit** around Earth, and by 1960 they were powerful enough to carry humans with their life-support equipment. For the first time, humans had the means to leave their home planet.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Early Space Exploration

Building a vehicle to carry people into space is not something one can do in one's garage. The resources of a nation are required. The Soviet Union's very large booster rockets were the first with that capability. The Soviet Union and the United States were adversaries during the Cold War. One way for each to show off its power was to outdo the other in space achievements, which became known as the "space race." In October 1957 the Soviets launched Sputnik 1, an 83.5-kilogram (184-pound) satellite, into orbit; the following month they launched a second one weighing 500 kilograms (1,100 pounds). This capability surprised and startled the world.

Mae Jemison working in the Spacelab-J module on the space shuttle Endeavour. This mission was a collaboration between the National Space Agency of Japan and NASA. Members of the crew included the first Japanese astronaut to fly aboard a shuttle, the first African-American woman to fly in space, and the first married couple to fly on the same space mission.

reconnaissance a survey or preliminary exploration of a region of interest

In the ensuing years the Soviets launched numerous Earth satellites for communications, weather, **reconnaissance**, and other purposes. In preparation for a piloted spaceflight they also launched at least four spacecraft with dogs as passengers in 1960 and 1961. Then, on April 12, 1961, Yuri Gagarin became the first person to orbit Earth. The single-orbit flight in a spherical capsule named Vostok 1 lasted one hour and forty-eight minutes. On August 6 of that same year, Gherman Titov stayed in space for an entire day, making seventeen orbits.

Well behind the Soviet Union, the United States launched Project Mercury, which used a conical capsule that carried one astronaut. After several test flights carrying monkeys and a chimpanzee, Alan Shepard became the first American in space on May 5, 1961, in a fifteen-minute suborbital flight downrange into the Atlantic Ocean. Finally in February 1962 an American, John Glenn, flew into orbit and circumnavigated Earth three times in just under five hours. When Project Mercury concluded in May 1963, four Americans had flown into orbit for a total of fifty-three hours, a little more than two days. Meanwhile, Soviet cosmonauts had totaled nearly eight days.

The Race to the Moon

On May 25, 1961, only three weeks after Shepard's short suborbital flight, President John F. Kennedy committed the nation to land a man on the Moon and bring him safely home by the end of the decade. This bold commitment, made before an American had even completed one orbit, would galvanize the nation in an effort to surpass the Soviets in space achievements.

Both the United States and the Soviet Union worked to develop, perfect, and practice the necessary procedures for a lunar mission. They had to learn how to rendezvous and dock with another craft in orbit; provide life support for up to two weeks; cope with protracted weightlessness; determine the level of radiation in space that a person could endure; and a myriad of other tasks.

In the United States, Project Gemini was designed to accomplish this preliminary work. The first flight of the two-person Gemini capsule came in March 1965 carrying John Young and Gus Grissom. The Soviets continued to upstage the Americans. In October 1964, three men, a cosmonaut, a doctor, and a scientist, had been on a daylong flight in a Voshkod vehicle. In March 1965, Alexei Leonov made the first space walk while the first piloted Gemini flight was being readied on the launch pad.

Both countries sent robotic spacecraft on reconnaissance missions to the Moon during the 1960s. Some circumnavigated the Moon and photographed its surface; some landed and sent back data about the lunar surface. The Soviets sent a robotic vehicle to move over the lunar surface, and another flight brought lunar soil back to Earth.

There were eleven piloted **Apollo** flights. Two flew to Earth orbit only, three circumnavigated the Moon but did not land, and six landed. The first to land, Apollo 11, touched down on July 20, 1969, before the decade of the sixties was out; President Kennedy's goal for America had been achieved. Neil Armstrong and Edwin "Buzz" Aldrin were the first humans to set foot on the Moon, while Michael Collins remained in orbit around the Moon tending the return vehicle. Ten more astronauts walked on the Moon in five additional missions. Apollo 17 in December 1972 was the last.

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

Apollo 13 was almost a disaster. On April 13, 1970, three days out from Earth, an oxygen tank exploded in the service module of the spacecraft, disabling the Apollo command module. The three astronauts crowded into the two-person lunar lander to ride out a ninety-hour flight back to Earth. Using the lander's power system and rocket engine, the vehicle swung around the Moon and returned toward Earth. As they approached Earth, they fired the lander's engine again to put them on the proper trajectory. Then they moved back into the lifeless command module and cut it loose for a landing. The potential disaster had been avoided with no loss of life.

For many people, the ultimate goal of the world's space programs is to expand human presence into the universe beyond Earth. However, the funding to carry on these programs comes from governments, and political leaders may have other priorities. After the landings on the Moon, many hoped that sending a crew to Mars would be the next step. But more earthly issues took priority among those who controlled the purse strings. Funding for space programs declined, and the last three planned Moon flights were cancelled.

In 1975, in a gesture of international friendship, the United States and the Soviet Union joined together for a joint mission. Apollo hardware carried astronauts Thomas Stafford, Vance Brand, and Donald "Deke" Slayton to rendezvous and dock with cosmonauts Alexei Leonov and Valeri

Kubasov in a Soyuz vehicle on July 17 for two days of camaraderie. They shook hands, exchanged gifts, completed five joint experiments, shared meals, and held a news conference as the world watched.

The Soviet Union never did attempt a piloted flight to the Moon. Their N-1 or SL-15 Moon rocket had forty-three engines in four stages. Engineers had trouble keeping the thrust stable in the thirty engines of the first stage and after four failures they instead turned their attention to space stations.

Space Stations and Shuttles

Salyut 1, the first space station, was in orbit from April to October 1971, and was occupied by three cosmonauts for twenty-two days in June of that year. It was about 15 meters (50 feet) long and 5 meters (17 feet) in diameter at its largest point. The Soviets had space stations in orbit almost continuously for twenty-five years from 1974 to 2000. Salyut 2 failed, but Salyuts 3 to 7 and Mir were extraordinarily successful. Mir, their last, was modular and had space for up to six cosmonauts and six ports for docking spacecraft or other modules. Cosmonauts set new records with stays in Mir of more than a year. Crew on the Salyuts and Mir observed the sky and Earth, studied the growth of weightless plants and animals, conducted science experiments, tried methods of manufacturing, and tested new types of equipment. They learned a great deal about living and working in space, the effects of weightlessness on humans, recycling air and water, designing spacecraft for extended stays, and repairing spacecraft while in orbit.

Meanwhile, the United States used leftover Apollo equipment to launch a space station called Skylab. It was launched completely equipped on a two-stage Saturn V rocket. Three crews of three men each occupied Skylab for a total of 172 days in 1973 and 1974. They carried out numerous scientific experiments, photographed Earth, and studied the effects of weightlessness.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

NASA then turned its attention to developing the space shuttle. The most expensive part of spaceflight is the cost of getting off the ground into **low Earth orbit**. Burned-out booster rockets generally drop into the ocean, and new ones are built for each flight. In an effort to find a cheaper method of access to orbit, the United States developed the space shuttle, a reusable vehicle that launches as a rocket and returns to Earth like an airplane. The booster rockets are also reusable; they are recovered from the ocean and reconditioned for another flight. The first space shuttle flew to orbit in April 1981. One hundred missions had been flown by 2000.

On space shuttle missions, astronauts launch satellites into Earth orbits and send spacecraft to other parts of the solar system; recover inoperative satellites; repair and service the Hubble Space Telescope; carry military **payloads** to orbit; perform **microgravity** experiments; study effects of weightlessness on the human body; test concepts for new spacecraft; and photograph Earth.

Supporting people in space is an expensive proposition. Besides food, air, and water they need a comfortable temperature, room to move around and work, and rest periods. Automatic experiments on robotic satellites require none of these. Nevertheless, if an unforeseen problem occurs, something the robotic experiment was not preprogrammed to handle, the experiment could be lost. An astronaut operating an experiment can adapt to new situations and correct unforeseen problems. The space shuttle has shown this to be true over and over again.

The Soviet Union built a vehicle named Buran that superficially looked like a space shuttle. It was launched, however, on an Energia booster rocket, whereas the space shuttle has rocket engines built into the orbiter that are brought back to Earth for another flight. Buran flew only once on an unpiloted test flight in November 1988.

The idea of a space station with participation from many countries had been considered for many years. With the end of the Cold War the idea came to fruition. The International Space Station, which was approved for development in 1984 by President Ronald Reagan, is a cooperative venture of the United States, Russia, Canada, Japan, and the eleven countries of the European Space Agency. The International Space Station dwarfs all previous space stations. Its main truss is 111 meters (365 feet) long, and in its final design configuration it would have six laboratories, two habitat modules, and two logistics modules to support up to six astronauts and cosmonauts. The modules are being carried to orbit on Russian booster rockets and in the space shuttle and are assembled in orbit. Astronauts and cosmonauts have the space and time to run long-duration experiments, to test out new concepts for space equipment, and to try to solve the problems of the human body in weightlessness. The International Space Station may also act as a base for reaching farther into the solar system.

Astronauts and Cosmonauts

Astronauts and cosmonauts are trained professionals, usually military pilots, engineers, doctors, or scientists. The first woman to orbit Earth was Valentina Tereshkova, on a three-day flight in June 1963. It was nineteen years before another woman, Svetlana Savitskaya, was to venture into space. The first American woman in space was Sally Ride, who was a crew member on a space shuttle mission in June 1983. By 1999, 384 men and women had flown into orbit: 243 from the United States, 89 from the Soviet Union and Russia, eight each from France and Germany, seven from Canada, and the rest from twenty-two other countries. More than thirty guest cosmonauts from more than two-dozen countries were flown to Soviet space stations. After the Cold War ended, American astronauts visited Mir to learn from the long experience of the Soviets and to plan for the International Space Station.

Vladimir Komarov became the first person to die during a space mission when, after successfully piloting the Soviet spacecraft Soyuz 1 to re-enter Earth's atmosphere on April 24, 1967, the vehicle crashed just prior to landing safely.

Spaceflight is a dangerous occupation. Although engineers try to consider all possible potential problems and hazards, accidents do happen and lives have been lost. In January 1967, fire broke out in the pure oxygen atmosphere of the Apollo 1 capsule during a launch rehearsal. Three astronauts died: Virgil "Gus" Grissom, Roger Chaffee, and Edward White, the first American to "walk" in space. Cosmonaut Valentin Bondarenko had perished in a similar accident in March 1961. The first person to die while actually on a spaceflight was Vladimir Komarov. The Soviets reported that on returning from orbit in April 1967 a problem with the parachute caused Komarov's Soyuz spacecraft to hit the ground at high speed. In June 1971, three cosmonauts died when the air leaked out of their Soyuz capsule during their return to Earth following a three-week stay in the Salyut 1 space station.

The space shuttle Challenger disaster in 1986 was perhaps the most devastating to the American space program. Seven astronauts perished when hot exhaust gas leaked from one of the booster rockets, destroying the vehicle less than two minutes into the flight. Shuttle flights were halted for two and a half years. SEE ALSO APOLLO (VOLUME 3); APOLLO-SOYUZ (VOLUME 3); ARMSTRONG, NEIL (VOLUME 3); ASTRONAUTS, TYPES OF (VOLUME 3); CHALLENGER (VOLUME 3); CIVILIANS IN SPACE (VOLUME 3); COLLINS, EILEEN (VOLUME 3); COSMONAUTS (VOLUME 3); EMERGENCIES (VOLUME 3); GAGARIN, YURI (VOLUME 3); GEMINI (VOLUME 3); HUMANS VERSUS ROBOTS (VOLUME 3); MERCURY PROGRAM (VOLUME 3); MISSION SPECIALISTS (VOLUME 3); NASA (VOLUME 3); PAYLOAD SPECIALISTS (VOLUME 3); SKYLAB (VOLUME 3); SPACE SHUTTLE (VOLUME 3); SPACE STATIONS, HISTORY OF (VOLUME 3); TEACHER IN SPACE PROGRAM (VOLUME 3); VOSTOK (VOLUME 3); WHY HUMAN EXPLORATION? (VOLUME 3); WOMEN IN SPACE (VOLUME 3).

Thomas Damon

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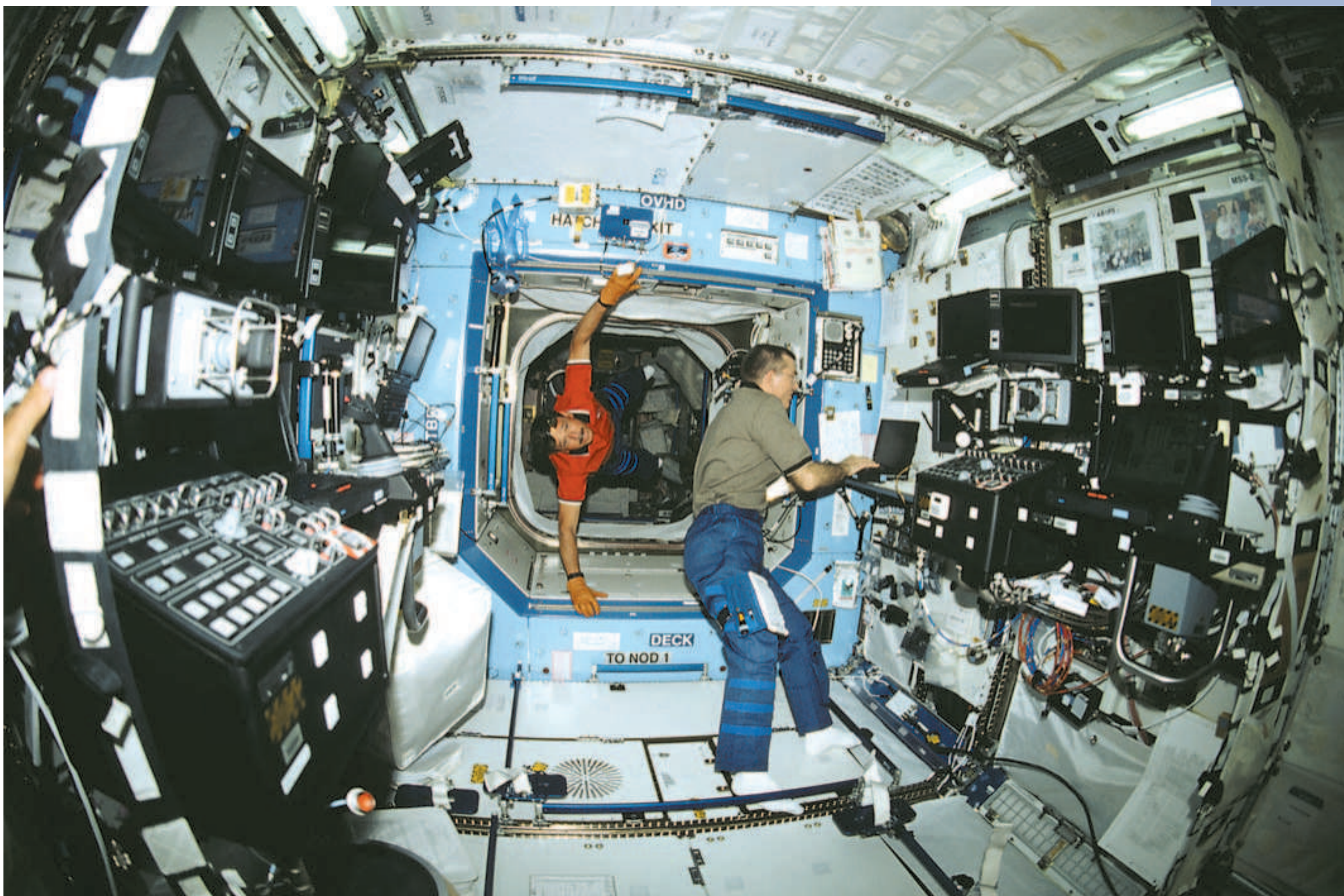
Human Factors

Human factors engineering, a term that is often used synonymously with the word "ergonomics," is the science and design activity that deals with improving how people interact with their environments, tools, and tasks as part of a system; the objective is to make these interactions safe, productive, and comfortable. Or, perhaps better stated from an engineering perspective, human factors engineering is the science and art of designing the environment, tools, and tasks so they interact well with humans as part of a system.

This discipline is difficult to implement in workplaces and homes on Earth. Many problems are technically complicated, as issues of money and scheduling are usually constraints, and the traditionally successful ways of getting things done make the politics of improvement and innovation complex. Allocating tasks along the continuum from manual to machine; taking into account all of the capabilities and the limitations of people (as individuals or teams) and machines; accounting for the dimensions of power, tools, feedback, control, automation, memory, computation, analysis, decision making, and artificial intelligence; and bringing together the sciences and practices of engineering, psychology, biology, communications, and economics are issues that human factors engineers deal with every day.

Stepping off the home planet to the reduced gravity and relative hostility of space adds considerably to the problems addressed by space human



The workstation used here by astronaut James S. Voss was designed to allow the crew to do accurate work as comfortably as possible in the microgravity environment of the International Space Station.

factors engineers, but the discipline is the same. The environment in space is different in regard to factors that go beyond the effects of gravity (no ground reactive support; the need to wear protective yet cumbersome suits); the human body adapts to these changes in different ways over time, and the work that must be done is often specific to space in terms of what has to be done or how it can be done.

Meeting the Challenges of the Space Environment

Microgravity has a direct and immediate effect on the human body. Each cell reacts individually to microgravity, and the body as a whole immediately undergoes changes in chemistry and dimensions. Fluids shift to the upper body, and compression no longer acts on the spine and the soles of the feet. Calcium is lost from the bones, and muscles **atrophy** from lack of use, resulting in diminished strength. A human arm floats up rather than hanging down by the hip. The design of workstations and computers must take into account these differences in stature, posture, biomechanics, and strength. For example, gravity will not keep a computer mouse on the tabletop, and so a different tool must be used to move the cursor. A touch screen was studied, but it was very difficult for a person in space to hold the arm out and maintain contact with the screen without pushing oneself away. Voice control of the computer holds promise, but crewmembers want something much more reliable on the machine side and much more forgiving of

atrophy condition involving withering, shrinking or wasting away human error. The current compromise is a trackball-type device or a joystick. But what if the crewmember floats over to the workstation upside down? How should displays and controls be designed so that procedures are not performed backward?

In orbit, feet are nearly useless appendages after an initial kickoff and moving around is controlled mostly by using handrails. Pushing on a toggle switch is more likely to result in rotating the operator's human body than in repositioning the switch unless the operator is restrained. Mobility aids and force restraints are essential in reducing bruises among people moving and stopping in space. In partial gravity environments, such as on Mars or lunar surfaces, moving from one place to another is very different from the same activities on Earth. Video sequences of humans on the Moon show that they sort of bounce around. Studies in simulated Mars gravity conducted in parabolic flights of National Aeronautics and Space Administration (NASA) research airplanes have demonstrated that a different way of moving comes naturally to the human explorer. Space suits and tools will have to be designed to take into account the way human behavior changes in space.

convection currents mechanism by which thermal energy moves because its density differs from that of surrounding material; convection current is the movement pattern of thermal energy transferring within a medium

Natural **convection currents** do not act without a gravity field, and so hot air does not rise. If an astronaut wants to breathe fresh oxygen in every breath, there have to be fans to circulate the air. The heat from an electrical component such as a laptop does not move away with the air, and so energy must be used for active cooling of every item that dissipates heat, including the human.

Working in a pressurized space suit is difficult, especially for the hands. Controlling telerobots or programming automated machines leaves little room for error, takes a lot of time, and requires special skills. The confined cabin of a spacecraft limits the range and exercise of human senses and perceptions. The isolation from colleagues, family, and friends can alter social relationships, expectations, and support structures. The hostility of the external space environment and the inherent risk of spaceflight add stress to everyday tasks. A mistake or inattention can quickly result in death or mission failure and consequently everything becomes much more important.

The nature of space combined with the new human-designed environments and tools for living and working in space impact the ways in which people do things. Solving cognitive problems; meeting unexpected challenges; maintaining safety; staying attentive and motivated on long, boring flights from planet to planet; and maintaining teamwork, family ties, and a healthy personality are all aspects of the interaction between a human and the designed environment. SEE ALSO COMMUNITIES IN SPACE (VOLUME 4); INTERNATIONAL SPACE STATION (VOLUMES 1 AND 3); LIVING IN SPACE (VOLUME 3); LIVING ON OTHER WORLDS (VOLUME 3).

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Human Missions to Mars

Human flights to Mars will likely be the next major milestone in humankind's expansion into the solar system. Solving the complex problems of Mars' origin and history, such as whether life ever existed there, is likely to require direct scientific exploration by humans. However, sending humans to Mars will not be easy.

Mission Planning

Much of the mission planning for human exploration missions deals with finding appropriate **trajectories** for the trips out to Mars and back to Earth. Earth revolves around the Sun about twice as fast as Mars does. A spacecraft launched from Earth must "lead" Mars, aiming at the place where that planet will be in 5 to 9 months. Opportunities to do this only occur at 26-month intervals. By the time a spacecraft arrives at Mars, Earth has moved and it is necessary to wait for a similar leading trajectory opportunity from Mars to Earth. Trajectory options exist for long travel times (9 months) and short stay times (30 to 60 days) on Mars or somewhat shorter travel times (5 to 8 months) and long stay times (500 days). A total round trip requires 21 to 36 months. It is possible to shorten the transit time by increasing the velocity with which the spacecraft leaves Earth. However, the round trip times will remain about the same because of the need to wait for the correct planetary alignment. Chemical **rockets** using hydrogen and oxygen as well as nuclear rockets have been studied. Nuclear **fission** rockets can provide higher velocities for transit but have not been developed. Even higher-energy propulsion systems, such as nuclear fusion rockets, are being studied but will not be available for a long time.

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

fission act of splitting a heavy atomic nucleus into two lighter ones, releasing tremendous energy

Because of these orbital and propulsion considerations, trip times for human missions will be much longer than any previous missions. In addition, the infrequent mission opportunities will not permit resupply or rescue missions once a spacecraft has been launched from Earth. Human health and safety therefore will be a major consideration on these missions. For example, methods will have to be found to prevent the loss of calcium, deconditioning of the heart, and other detrimental effects of weightlessness that occur in spaceflight. The mechanical systems required for life support and surface activities will also have to be far more reliable than those developed thus far.

Chemical propulsion, which is used in the space shuttle, requires large quantities of propellant. For a spacecraft that is launched from **low Earth orbit** (LEO) to Mars, three times as much propellant is required. Five times a spacecraft's mass in propellant is required for a rocket launched from the surface of Mars into space. Therefore, approximately 15 kilograms (33 pounds) of mass must be launched from LEO to get 1 kilogram (2.2 pounds) of mass back to Earth. Because of this unfavorable relationship, designers have looked for ways to reduce the mass of spacecraft and other materials that must be launched from Earth. Reducing crew size is one possibility; however, considering the range of skills that will be necessary, crew sizes of five to eight are probably minimal. Inflatable habitation systems provide more crew space for the same amount of mass of the hard modules used in the International Space Station. Aerobraking, or using the atmosphere to slow spacecraft down when landing on Mars or Earth, is one way of reducing the

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

In this artist's depiction of a human mission to Mars, an astronaut examines what could be fossil fragments in the Martian rocks for evidence of earlier life.

amount of propellant that is needed in space. Manufacturing propellant from the atmosphere of Mars also could reduce the mass of propellant that must be hauled to Mars. That is the fundamental premise of the Mars Direct mission proposed by Robert Zubrin and has been incorporated into some of NASA's Design Reference Missions.

"Split" mission options are designed to launch a habitat, a power and propellant production system, and a return vehicle twenty-six months before sending humans from Earth. Humans would not be launched until all systems were tested and found to be working well. This strategy allows greater support capability on Mars, although the equipment must be able to work unattended for the twenty-six months during which it awaits the crew.

Exploring Mars

On the surface of Mars, astronauts would conduct several types of activities. Astronauts riding on long-range motorized vehicles, some of which might be able to traverse hundreds of kilometers from an outpost site, would conduct field studies of Martian geology, search for evidence of past or current life, collect rocks, and place geophysical instruments. Automated vehicles operated by astronauts from their Martian control center could explore and collect samples at even greater distances. Astronauts would use an analytical laboratory to study samples. Data would be sent back to Earth, and information from the initial investigations would be used to plan later investigations. The search for a usable source of water would have a high priority. Within the habitat astronauts would conduct plant growth and medical experiments aimed at determining the possibility of establishing permanent settlements on Mars. They would also select and package samples that would be returned to Earth for more detailed analysis. While they were accomplishing their scientific mission, the astronauts would carry out the operations and maintenance required to keep the systems and themselves fit and productive.

The search for existing life on Mars and for usable resources will focus on looking for liquid water beneath the surface. Drilling for water and analyzing its organic and inorganic constituents will be a major task for the human crews. The need to prevent terrestrial organisms from invading Martian water deposits and to protect astronauts from exposure to Martian organisms will be one of the most difficult technical challenges of a human exploration mission.

Many of the questions surrounding the design of the first human missions to Mars can be addressed by using automated missions that precede humans. These missions should include **reconnaissance** surveying activities (images and surface properties) and the return of samples that can be used to determine whether surface materials might be detrimental to astronauts' health. SEE ALSO Apollo (Volume 3); Human Factors (Volume 3); Humans versus Robots (Volume 3); International Space Station (Volumes 1 and 3); Life Support (Volume 3); Living in Space (Volume 3); Long-Duration Spaceflight (Volume 3); Lunar Rovers (Volume 3); Microgravity (Volume 2); Mir (Volume 3); NASA (Volume 3); Nuclear Propulsion (Volume 4); Weather, Space (Volume 2); Why Human Exploration? (Volume 3).

reconnaissance a survey or preliminary exploration of a region of interest

Michael B. Duke

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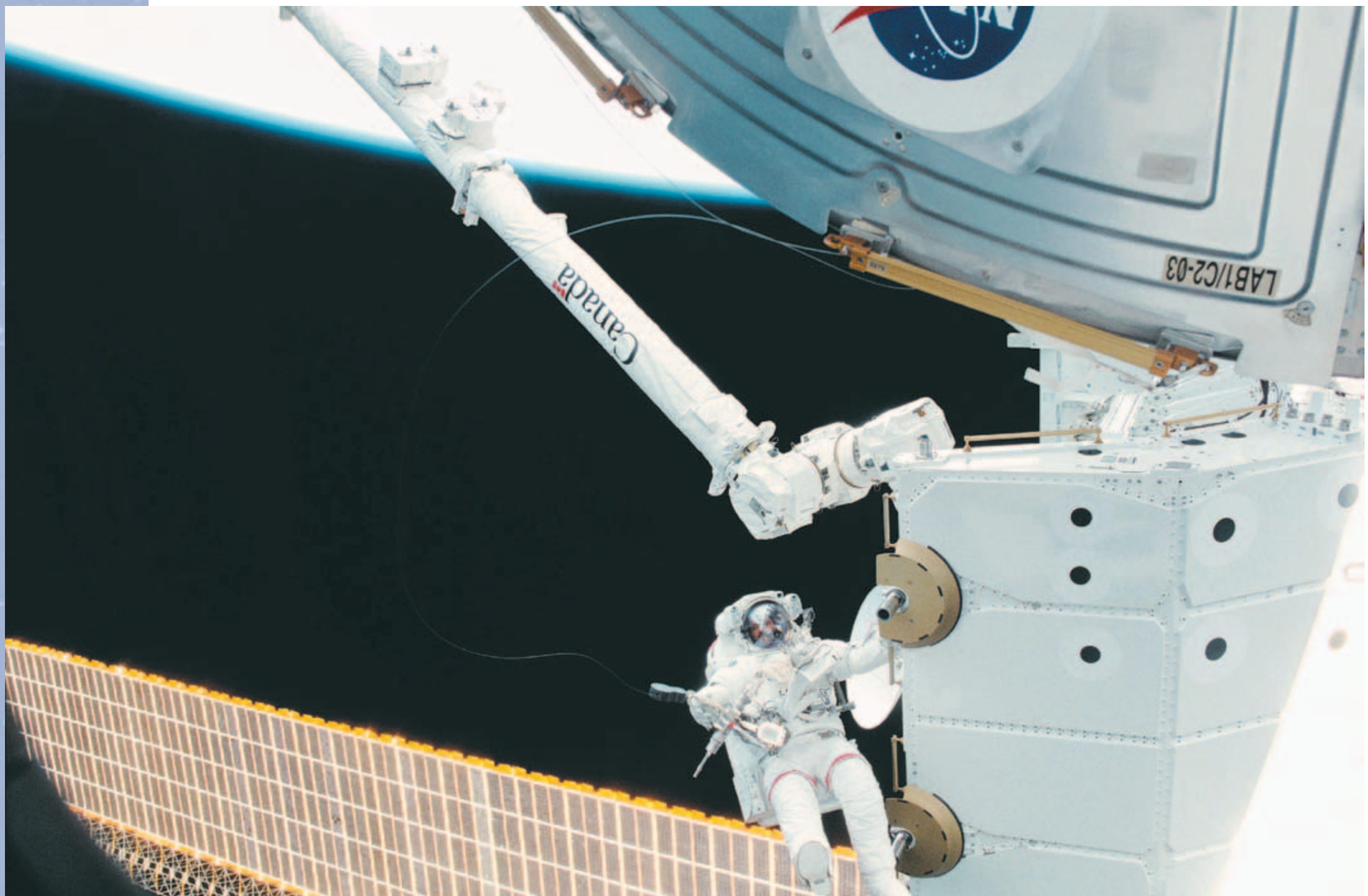
Humans versus Robots

As humans step off their home planet into the surrounding solar system and beyond, they do not go alone. Machines have preceded them. And as people go into space, machines will go along. Of all the machines we have used and imagined, none have captured our interest and feelings so strongly as the class of machines called robots.



The International Space Station's new Canadarm2 robotic arm grasps a Spacelab pallet while Canadian mission specialist Chris A. Hadfield helps maneuver it into loading position while on a space walk.

But what exactly is meant by the term "robot"? Moreover, how is it decided that it is better to use a robot for a job rather than a human? What are robots like in the early twenty-first century and what they will be like in the future? Will humans ever become more robot-like?

What are Robots?

Let's begin with a bit of speculation on why robots are so interesting to us. Humans have always tried to create "life" from inanimate objects. From literary history, there have been robot-like figures such as Pinocchio and Frankenstein, and from more recent popular culture we have *Star Trek*'s Data and the Terminator. These entities could be good or evil, and were deliberately created in our image.

Fictional robots are often capable of moving around the world and having other characteristics of humans. In their depiction, there is frequently some essence that transcends their physical trapping and they may be capable of thinking, feeling, judging, and exploring. It is easy to imagine R2D2 and C3PO, robots from George Lucas's popular movie *Star Wars* (1977), as companions—even friends. These machines of fiction give robotic researchers goals to build toward. Unfortunately, humans in 2002 do not yet have the capability of creating any of these imagined robots.

Nevertheless, we have created machines for space exploration that we do call robots. Examples include the Sojourner robot from the 1997 Mars Pathfinder mission and the robotic arms from the space shuttle and the International Space Station. It is possible to coax these machines to do marvelous tasks in space and on planetary surfaces, although in most ways these devices are much closer to a car than they are to the robots of science fiction.

Space missions are expensive and require a great deal of planning and long, careful preparation. Hence, the technologies flown on missions are often several years behind the state of the art for terrestrial applications. One of the consequences of this is that we can simply look at the technology that is available for use in Earth applications (e.g., autonomy used in vehicles in agriculture) and realize that the technologies behind these applications will be available in a decade or so in space missions.

What is a Space Robot? Given that modern space robots have a closer relationship to appliances than they do to the robotics stars of Hollywood, it is not easy to clearly define what is a robot and what is not. Generally for space applications, robots are machines that have some level of autonomy, can follow instructions, and are capable of interacting with their environment. Robots will usually have either arms or some means of mobility, like wheels. We would think of a robot as having more autonomy if by using that robot, humans can do more of what they want to do, and less of what they do not want to do.

To do a task in space we have both humans and robots as possible agents for that action. But when should we use robots and when should we use humans? There are three criteria that are considered in deciding on humans versus robotic tools:

1. What activities are humans best at? What activities are robots best at?
2. What are the costs of using humans versus using robots?
3. What activities do we want humans to be a part of in space?

The Utility of Humans and Robots

Obviously, humans and robots should be used where and when each are most useful. As technologies for robots improve the number of those tasks that robots are better at will increase.

Currently robots are better than humans at a number of things. Machines can perceive beyond the human visual spectrum, they need a smaller mass of consumables (e.g., food), they are more expendable, and they can be built to better tolerate environmental extremes (e.g., cold and radiation).

On the other hand, humans also have a great many advantages for tasks in space. Humans are the most adaptive, creative, and smartest tool for doing science and exploration that we have available. Humans would be the core of every scientific and exploration task we attempt except for the costs and the dangers. In spite of quickly advancing robotics technology, the overwhelming value of humans as tools for space exploration is not likely to change drastically in the foreseeable future. However, costs and dangers are real considerations, and are often sufficient to preclude humans from being the tool of choice unless there are other overriding reasons for the use of humans.

Humans have major advantages over machines in many areas, including mobility, manipulation skills, pattern recognition (e.g., geological evaluation of a site), robustness with respect to plan failures and system failures, self repair under broad parameters, capability to repair a multitude of other tools, and robustness in communication, to name a few. Tests indicate that a human scientist in the field is at least a couple of orders of magnitude more efficient than a **rover** in space supported by a remote human team.

rover vehicle used to move about on a surface

It is important to note that when humans are used in the exploration of space, machines tools are sent as well. So for a realistic understanding of the advantages of humans in exploration and in science in space it is useful to compare humans with robots as tools.

Relative Costs of Robotic versus Human Missions

Humans are wonderful tools, but they are also expensive tools. Generally, the more mass we launch into space the more costly a mission. Human missions require more mass than robotic missions because we must carry our food, water, and environmental support systems. Unlike machines, humans cannot be put into sleep states for weeks or months to decrease consumable use. For most operations humans want to remain in an environment warm enough for only needing shirtsleeves. Also it is usually necessary to have airlocks and space suits for astronaut egresses. Egress is the word we use for astronauts leaving a spacecraft and going outside. All of these elements add mass, and consequently, cost. Costs are also added because the safety standards for human crews are higher than for robotic devices.

In summary, for most tasks humans are preferable to robots, but they are much more expensive than robots. Another factor that affects the decision to use humans in space exploration is the societal importance of human exploration. We do not only explore space because of the scientific value of that exploration; we also explore space because human beings are curious and like to explore. We have the same motivation to explore Mars and the Moon as we have to climb Mount Everest or reach the bottom of the sea.

Human Exploration

The exploration of space is not the activity of an individual but a cooperative effort by many elements of society. It gives back to that society a sense of accomplishment, international prestige, a sharing of the excitement of exploration and new frontiers, a set of goals for future generations, advances in technologies, and the economic benefits of commercial uses of new technologies. To a lesser degree this is true of all space exploration, but it is most prominent when humans are involved. Space exploration in the early twenty-first century requires the commitment and resources of a government and the political considerations and agreements that this entails. Thus the decision to use humans is often dominated by societal issues. One motivation for society deciding to explore space with humans is simply the excitement we all share for that exploration.

Synergistic Robotic-Human Exploration

Once it is decided to use humans in a particular exploration task, the next question is how machines, including robots, are used to make tasks easier, safer, more effective, and cheaper. Each specific exploration goal leads to different answers to this question. For example, if we are robotically setting up a Mars or lunar base prior to human arrival, then the specifics of what robots and how they are used depends crucially on the details of those habitats.

The robotic augmentation of humans is a recurring theme in science fiction. For example, astronauts donning an exoskeleton suit to augment their strength, as the character Ellen Ripley did in the movie *Aliens*, is a non-invasive human augmentation that will probably be available in space missions in the not too distant future.

As we explore our solar system we will first send our robotic machines and then explore ourselves. And as we go about exploring space ourselves it will always be in a partnership with robots. The goal is to use robots to make space exploration easier, safer, more effective, and cheaper. The answer to the question of whether to send robots or humans is "both" and each at their proper time. SEE ALSO History of Humans in Space (volume 3); Living in Space (volume 3); Robotic Exploration of Space (volume 2); Robotics Technology (volume 2).

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Hypersonic Programs

Hypersonic flight is achieved at speeds at or above Mach 5, or five times the speed of sound. In the 1940s and 1950s the goal of aeronautical research was to design and build aircraft that could fly at that speed and reach altitudes at the edge of space.

Spacecraft Re-entry

When orbiting spacecraft reenter Earth's atmosphere, they are traveling at many times the speed of sound and they generate high temperatures because of friction with the air. **Ballistic** re-entry vehicles such as the **Gemini** and **Apollo** capsules have a thick heat shield that slows the spacecraft and dissipates heat. Aircraft designers have always considered this solution practical but primitive. They would prefer to build a spacecraft that could act like an aircraft as it reentered the atmosphere, flying through the atmosphere to a safe landing.

The X Planes

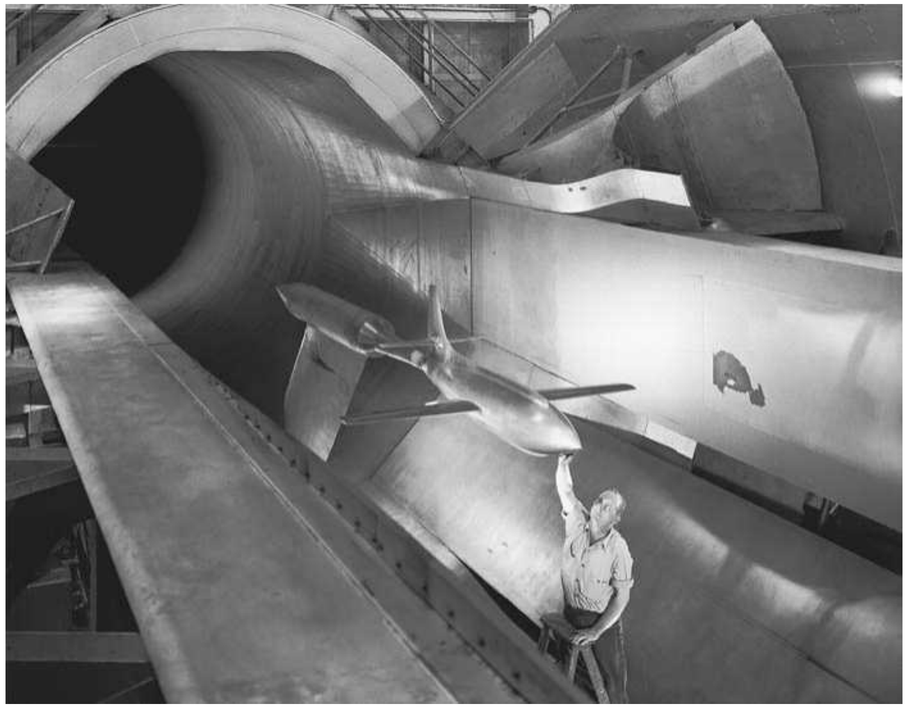
High-speed aircraft design began with **rocket**-powered craft. Many rocket-powered aircraft built in the 1940s and 1950s carried the X, or experimental, designation, beginning with the bullet-shaped Bell X-1, which on

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

rocket vehicle or device, especially designed to travel through space, propelled by one or more engines



This model of the Bell X-1 airplane was tested in the 16 FT High Speed Tunnel in March 1951 by a Langley engineer. The actual Bell X-1 was the first airplane to break the sound barrier.

October 14, 1947, became the first airplane to break the sound barrier. The rocket-powered D-558 2 set an altitude record of 25,377 meters (83,235 feet) on August 21, 1953, and a speed record on November 20, 1953, when it became the first aircraft to reach Mach 2. The Bell X-2 reached a speed of Mach 3.2, but the aircraft broke up in flight, killing its pilot. Before its last flight the X-2 set an altitude record of 38,476 meters (126,200) feet on September 7, 1956.

The X-15

Flight at altitudes of 76,220 meters (250,000 feet) and above required an aircraft that was also a spacecraft and could maneuver in a near **vacuum** when normal control surfaces were useless. This type of aircraft required tremendous advances in aeronautical technology. Because the plane had to operate in near-vacuum conditions, it also needed advanced life support systems. The North American X-15 rocket plane was built to achieve these goals.

vacuum an environment where air and all other molecules and atoms of matter have been removed

The X-15 was a joint program of the National Aeronautics and Space Administration (NASA), the U.S. Air Force, the U.S. Navy, and North American Aviation. This aircraft had an internal frame of titanium and a skin made from an alloy of chrome and nickel. The X-15 set many speed records, reaching Mach 6.7 on October 3, 1967. It also set many altitude records, reaching 354,200 feet (67 miles or 107 kilometers) on August 22, 1963. That achievement qualified the pilot for astronaut wings.

The X-15 was launched from under the wing of a converted B-52B Stratofortress. For high-speed flights the X-15 was flown as a conventional airplane, using aerodynamic controls. For high-altitude flights the plane flew at a steep angle until the fuel was exhausted and then coasted up for 2 or 3 more minutes.

Lifting Bodies

A lifting body is an aircraft that has a high lift-to-**drag** ratio. Usually, the wings are very short or nonexistent and the shape of the body of the aircraft provides lift. The impetus for the design of a lifting body came from the desire to develop a reusable launch vehicle (RLV). Such a vehicle would have to be able to operate in space and then reenter the atmosphere and operate at hypersonic, supersonic, and subsonic speeds, eventually landing on a runway as a conventional airplane does.

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

The first attempts to develop a controlled, recoverable spacecraft capable of landing at airfields led to the Air Force X-20 in the late 1950s. The X-20 was to be a piloted glider that could also carry a small **payload** and would be boosted into orbit by a Titan rocket. The X-20 would carry one pilot into orbit, complete its mission, and glide back to a runway landing. Rising costs and competition from NASA's Gemini program led to the cancellation of the X-20 in 1963.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Research and testing continued in other U.S. Air Force projects, such as the Aerothermodynamic Elastic Structural Systems Environment Tests (ASSET) and the Precision Recovery Including Maneuvering Entry (PRIME). ASSET was started in 1960 to test heat-resistant materials and investigate high-speed re-entry and glide characteristics. PRIME was started in 1966 to test unpiloted lifting bodies flown into space by Atlas rockets. The U.S. Air Force also investigated piloted lifting bodies dropped from high altitudes, proving that pilots could fly the craft to a safe landing. This research was extremely valuable in the development of the space shuttle orbiter.

The Future

The high cost of launching satellites into Earth orbit led NASA to invest in a prototype launch vehicle called the X-33. The prototype was intended to lead to a lightweight, fully reusable space plane. NASA later withdrew funding for the project, leaving it about 75 percent complete. Many of the target goals of the project had been met, including engine tests. Companies have subsequently competed for financing to design various components of RLVs under NASA's Space Launch Initiative.

There have also been joint efforts to build a hypersonic aircraft for commercial purposes. On April 18, 2001, Orbital Sciences Corporation and NASA announced plans for the development of a hypersonic test vehicle dubbed the X-43A or Hyper-X. This vehicle could be launched by a small rocket. In flight, it is expected that the plane will be powered by an engine using compressed atmospheric oxygen mixed with fuel in a "scramjet" engine. Test missions would originate from Edwards Air Force Base and fly off the coast of California. The launch vehicle and scramjet research vehicle "stack" will be air launched from NASA's B-52B carrier aircraft, the same one used for the X-15. SEE ALSO Getting to Space Cheaply (volume 1); Heat Shields (volume 3); Launch Management (volume 3); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4).

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I

Inertial Measurement Units

Inertial Measurement Units provide inertial attitude and **velocity** data to a spacecraft's guidance, navigation, and control system. On the space shuttle, IMU data are used to convert steering commands into control surface, engine gimbal, and reaction control system thruster fire commands. Flight can be accomplished with just one IMU but the shuttle has three for redundancy.

velocity speed and direction of a moving object; a vector quantity

Shuttle IMUs are located forward of the flight deck control and display panels. The inertial sensors each consist of two **gyroscopes**, each with two degrees of freedom. The gyroscopes are used to maintain the IMU's inertial orientation. Four resolvers in each IMU measure vehicle attitude. Two accelerometers in each IMU measure linear vehicle accelerations. IMUs are carefully calibrated prior to each shuttle flight, and on-orbit alignments using a star tracker are necessary to correct the effects of uncompensated gyro drift.

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

During ascent, the IMUs provide accelerometer and resolver data to the navigation software to determine attitude and display flight parameters. In orbit, the IMUs provide attitude and accelerometer data. On entry, IMU data again contribute to state vector determination—identifying the precise attitude and speed of travel of the orbiter. SEE ALSO Flight Control (volume 3); Guidance and Control Systems (volume 3); Gyroscopes (volume 3).

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International Cooperation

Cooperation between nations in carrying out space missions has been a central feature of space activities since the launch of the first satellites. In fact, the launch of the first satellite by the Soviet Union, Sputnik 1, in October

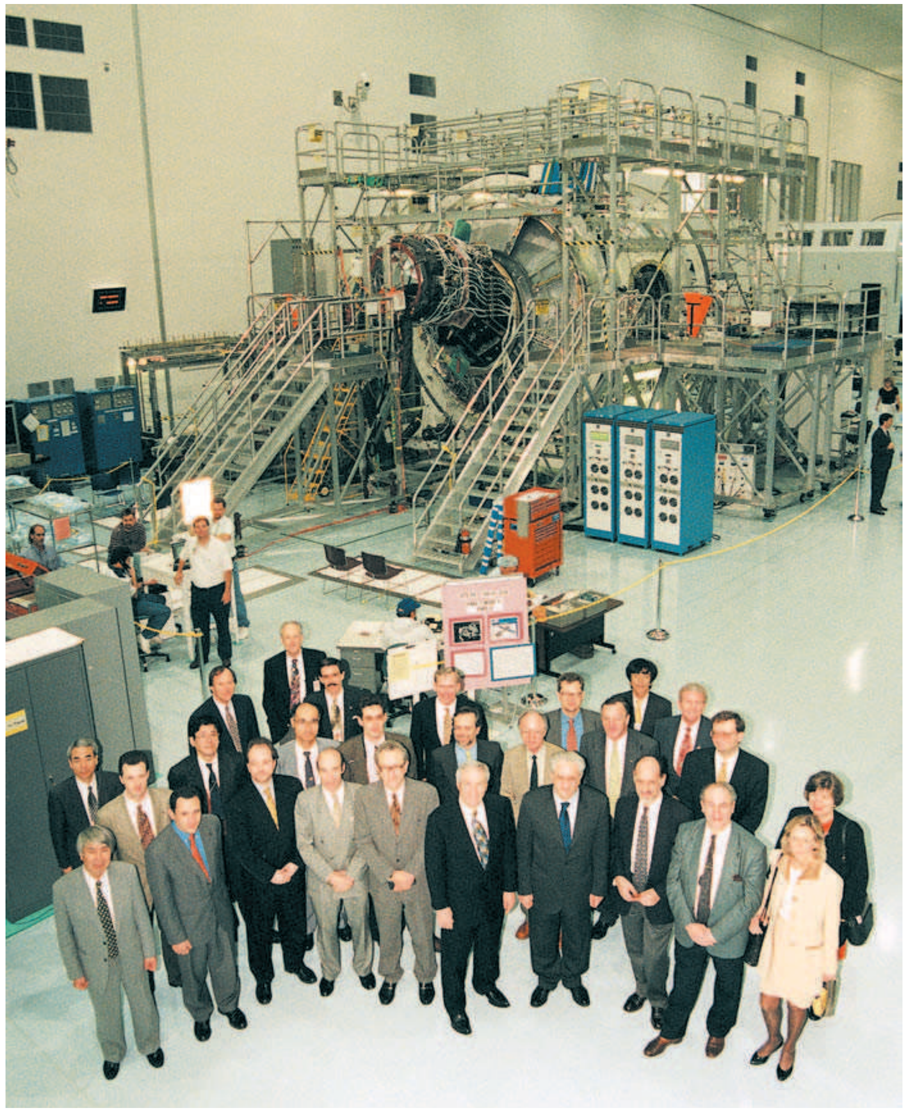
U.S. mission specialist C. Michael Foale (left) and Claude Nicollier, a European Space Agency astronaut, participate in the second of three space walks to repair the Hubble Space Telescope.

1957 and of the first U.S. satellite, Explorer 1, in January 1958 were carried out as part of a sixty-nation international program of scientific cooperation called the International Geophysical Year. In the years since, most robotic space missions carried out by any one country have included some form of cooperative participation by other countries. In particular, scientists are comfortable working on an international basis, and most space science missions involve international cooperation of some sort.

Cold War Era Competition and Cooperation

The early years of human spaceflight activities were marked by Cold War competition between the United States and the Soviet Union. Even though U.S. President John F. Kennedy suggested several times that the two countries should cooperate in sending men to the Moon, the Soviet Union never accepted his suggestion. It was only after the United States won the race to the Moon in 1969 that cooperation in human spaceflight between the two space superpowers, and between each of them and their allies, became possible.

Since then, there has been substantial cooperation in human spaceflight, with the focus being the activities in Earth orbit carried out by the United States and the Soviet Union. There is general agreement that when human exploration beyond Earth orbit resumes with trips back to the Moon, to Mars, or to some other destination, international cooperation will be essential for success. The experience of cooperation to date will provide the foundation for future journeys beyond Earth orbit.



Senior government officials from 15 of the 16 countries participating in the International Space Station (ISS) gather in the Kennedy Space Center after signing agreements regarding the operation of the ISS.

As it planned its space activities to follow the Apollo program, the United States decided to invite other countries to participate in its human spaceflight efforts. In response, several countries in Europe, working through a newly-formed European Space Agency in 1973, agreed to develop and provide to the United States a laboratory called Spacelab to be carried in the **payload bay** of the new space shuttle, and Canada the same year agreed to provide a robotic arm for use with the shuttle. In return, the United States agreed to assist these countries in developing technologies associated with human spaceflight and, perhaps more important, to fly astronauts from cooperating countries on the space shuttle once it became operational in the 1980s.

payload bay the area in the shuttle or other spacecraft designed to hold the experiment to be performed or cargo to be launched

The Soviet Union in the 1970s and 1980s concentrated on developing a series of Salyut orbiting **space stations** and, after 1986, the Mir station. It did not invite its allies to cooperate in developing these orbital outposts, but it did offer to fly guest cosmonauts for short stays on them. Also, the United States and the Soviet Union in 1972 agreed to a cooperative mission in which the U.S. Apollo spacecraft and the Soviet Soyuz spacecraft

space stations large orbital outposts equipped to support human crews and designed to remain in orbit for an extended period would rendezvous in orbit, dock to each other, and carry out joint experiments. The Apollo-Soyuz Test Project took place in July 1975.✶ The project was intended to lead to increased U.S.-Soviet cooperation in human spaceflight, but political difficulties between the two countries blocked subsequent cooperation for almost twenty years.

✶**Apollo-Soyuz featured the first international "handshake in space."**

The International Space Station

In 1984 U.S. President Ronald Reagan announced that he had approved development of a space station, and he invited U.S. allies to participate in that development. This time, both the European Space Agency and Japan agreed to contribute fully equipped laboratories to the station, and Canada agreed to provide an advanced robotic arm. Because the planned cooperation would extend over more than a decade, including the development, operation, and utilization of the space station, the cooperating governments negotiated a complex agreement that spelled out their rights and responsibilities with respect to the station and set up the legal and management framework for it. The United States was the major contributor to, and managing partner of, the space station, and its partners were often frustrated by U.S. redesigns and schedule delays over which they had little control.

Then in 1993, after the end of the Cold War and the collapse of the Soviet Union, the United States decided, for a mixture of political and technical reasons, to invite Russia to join a redesigned space station program. The station, which had been christened "Freedom" during the 1980s, was renamed the International Space Station. It was necessary to renegotiate the existing intergovernmental agreement to bring Russia into the partnership, and the station design was adjusted once again, making Russian contributions essential to its operation. This decision added more delays and costs to the program, as economic problems in Russia made it difficult for that nation to meet its commitments. In 2001, the United States deferred completion of the agreed-upon space station capable of hosting a seven-person crew because of budget and management problems, creating stresses between it and its international partners.

Achieving Goals through Cooperation

Governments choose to cooperate in human spaceflight when they believe that such cooperation is the best, and sometimes the only, way to achieve their space goals. Since different countries have differing goals in space, an agreement to cooperate in a particular space mission, or in a long-term program such as the International Space Station, is best understood as a "deal" or a "bargain" between partner countries. Each country tries to achieve as many of its objectives as possible, while recognizing that it must compromise with its partners on some issues important to them. Success in cooperation comes from providing enough benefits to each participating country so that each is satisfied with its involvement.

The Benefits and Risks of Cooperation

The benefits of cooperation include spreading the costs of space missions among several participants, bringing the technical capabilities of various partners together to achieve a common objective, and strengthening broader technical and political relations among cooperating nations. For leading space countries, cooperation is a way of demonstrating leadership and increasing prestige. For other countries, cooperation may be the only way to become involved in ambitious missions that they could not afford on their own, and it provides a way to gain experience in the organization and conduct of complex space activities. Since only the United States and Russia currently have the capability to send humans into space, cooperating with them is essential for any other country desiring to have astronauts of its own. (China has announced plans to develop a human spaceflight capability.)

There are also risks associated with international space cooperation. Cooperation means that each partner loses some freedom of action and becomes to some degree dependent on others. Cooperation increases the overall costs of a project, because it increases managerial complexity. Technical and political problems can appear if one partner does not honor its commitments. There is a possibility of unwanted **technology transfer** and a leading country can create future competitors by involving them in cooperative projects.

technology transfer the acquisition by one country or firm of the capability to develop a particular technology through its interactions with the existing technological capability of another country or firm, rather than through its own research efforts

All of these benefits and risks have appeared in the International Space Station program. It is the largest and most complex peacetime example of international technological cooperation in history. It may well be a precedent for international cooperation in future large-scale human activities in space, but its lessons underline the obstacles to, as well as the promise of, such cooperation. SEE ALSO International Space Station (volumes 1 and 3).

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International Space Station

There have long been dreams of a permanently inhabited base or station in space. In 1957 it first became possible to put human-made objects into **orbit** around Earth. But while both the United States and the Soviet Union raced to send a man to the Moon in the 1960s, the goal of a space station in orbit was secondary. It was after the United States won that "space race" in 1969 that both spacefaring countries sought new directions for their human spaceflight programs.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Previous Space Stations

Shortly before the National Aeronautics and Space Administration (NASA) launched the first Moon mission, the agency began focused design work on

The first crew of the International Space Station (left to right): Flight engineer Sergei K. Krikalev, U.S. Commander William M. (Bill) Shepherd, and Soyuz Commander Yuri P. Gidzenko.

America's first orbiting laboratory—Skylab—a converted Saturn Moon rocket stage. Only 36 meters (117 feet) long, it did not rotate to create the artificial gravity that physiologists of two decades earlier believed would be required for humans to live in space. Skylab was launched in May 1973 and occupied intermittently over the following five and a half months by three successive three-person crews. Since it was already known that astronauts could survive weightlessness, answering other questions became paramount. There were unlimited questions about how chemistry, physics, biology, and engineering principles worked without gravity, along with a unique vantage for observations of the Sun and Earth. In February 1974, after only 171 days of occupancy, this successful project was ended. NASA had been given a higher priority manned spaceflight project by President Richard M. Nixon: build a reusable spaceship—the space shuttle. Skylab was to be the last U.S. space station project for a decade.

Soon after Apollo 11 ended the Moon race in 1969, the Soviet Union turned its efforts to short-term Earth-orbiting laboratories. The Soviets named their first generation space station Salyut. In April 1971 Salyut 1 was orbited. Two to three cosmonauts, launched to the station in Soyuz spacecraft, lived for weeks in the cylindrical lab/home with a volume half that of the inside of a school bus. The Russians orbited seven successive space stations over a period of eleven years and conducted thirty-eight crewed missions onboard. They were mostly successful. These early Soviet stations were occupied intermittently for increasingly long periods of up to almost eight months. Salyut 7 was still in orbit when a new Soviet space station project began in February 1986 with the launch of the Mir core module.

Mir was the first permanently crewed station designed as an assembly, or complex, of specialized research modules. The five modules were added one at a time through April 1996. Even while beginning the assembly and

VISIONS OF SPACE STATIONS

The first description of a habitable satellite was made by Rev. Edward Everett Hale in an 1869 *Atlantic Monthly* magazine story titled "The Brick Moon." The 1920s brought more realistic descriptions from German researcher Hermann Oberth and from two Austrians, Baron Guido von Pirquet and Captain Herman Potočnik (writing as Hermann Noordung). These visionaries foresaw bases in space observing Earth, relaying communications around the world, and refueling spaceships for travel to the Moon and the planets.

In the 1940s and 1950s, German writer Willy Ley and rocket scientist Wernher von Braun popularized the space station concept. Von Braun's rotating wheel-shaped design (76 meters [250 feet] in diameter), orbiting 1,730 kilometers (1,075 miles) high, became the most widely recognized space station concept.

operation of Mir, the Soviets were planning another Mir-type station—a plan revised because of developments both at home and in the United States.

The Modern Space Station Project

In his State of the Union address before a joint session of the U.S. Congress on January 25, 1984, President Ronald Reagan directed NASA "to develop a permanently manned space station and to do it within a decade." He went on to say that "NASA will invite other countries to participate." So began the International Space Station (ISS) project and, indirectly, the coalescing of Russian and American space station projects.

NASA had pressed the White House and Congress for a permanent space station project since the successful Space Transportation System (space shuttle) flight program began in 1981. Preliminary design studies were already underway when the president made his announcement. Within weeks NASA invited other countries to join the project. Interest was already high at the European Space Agency (ESA), the intergovernmental agency for eleven European countries, with whom the United States had a decade of experience through ESA's contributions to the space shuttle program. The Canadian Space Agency and the National Space Development Agency of Japan were also interested in participating.

There was basic agreement among all space agencies as well as the Congress (now a virtual partner in its role as authorizer of NASA activities and appropriator of funds) that the station was to be modular in construction. The space shuttle was to be the major launcher of components and crew.

In early 1984, the space station concept was an architecture of three elements: a crewed complex with laboratories, a co-orbiting automated science satellite or platform, and another platform in polar orbit. The reference design for the central complex was called the "Power Tower," reflecting its resemblance to that structure. But when technical evaluation revealed a less than adequate **microgravity** environment for the laboratories, another concept called "Dual-Keel" became the baseline design in 1985. The large squared structure of trusses and beams with the occupied modules at the center of gravity gave this configuration its name. Outrigger-like trusses secured the **solar arrays**. ESA negotiated a preliminary agreement to contribute a pressurized laboratory module and the polar platform; Japan agreed to provide another laboratory and a cargo carrying module; and Canada would provide a mobile robotic system that would do work along the external structure. By the end of 1986 the space shuttle Challenger accident had enhanced the concern for crew safety, leading to such changes as reduced shuttle flight rates and fewer space walks for construction. A "lifeboat" for emergency crew return was also added to the plans. These changes forced a reduction in size.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

In 1988, the international partners signed formal cooperation documents for the space station project, which they agreed would be named "Freedom." Each partner's contribution would be paid for by that partner. In this period the cost of the U.S. portion—the largest share of the project—began to draw the attention of NASA and the U.S. Congress. The initial cost estimate in 1984, just for design, development of new technical hardware and software, manufacture, and preparation for launch, was $8 billion. Five years

The International Space Station (ISS) is shown here framed by the Earth's horizon, following its undocking from the space shuttle Atlantis. The mission of Atlantis was to prepare the space station for its first resident crew.

later the cost estimate, through "assembly complete," had grown to $30 billion. Subsequent cost-containment actions included the indefinite delaying of some structure and power generation features and the dropping of the polar platform from the station project.

As design work progressed fitfully at NASA's design centers and U.S. contractor companies tabulated further increases in estimated total cost, the activities that "Freedom" could support were under almost constant review and change. By 1993 the reductions in station capability compared to its estimated cost forced the cancellation of the "Freedom" design. Very little hardware had been built. As a new design concept was being developed, President Bill Clinton announced that the new space station project would include not only the previous international partners but Russia as well.

Even as the space station Mir continued in operation in space the Soviet government fell in the early 1990s. Soviet plans for a follow-on to Mir were evaporating. Russia joined the U.S. partnership for a new design that was named International Space Station Alpha (ISSA). The next-generation Russian space station elements would be installed as part of the Alpha station, and American astronauts would join cosmonauts onboard the Mir for seven long-duration missions in the mid-1990s. The Russians got their next-generation space station when their collapsing economy could not afford to fund the effort by itself. The United States got early long-duration spaceflight experience—up to six months at a stretch—for its astronauts and ground controllers. Russian design and operational spaceflight experience also became available for a project at least as complex as the Apollo Moon landings.

In late 1993, detailed design of ISSA, later shortened to ISS, was begun, drawing upon 75 percent of the "Freedom" design. This space station looks like a Tinkertoy assembly of one 88-meter-long (290-foot-long) beam, with four wing-like power panels at each end, and a collection of centrally mounted cylinders—the modules. If it could be assembled on the ground it would cover an area as large as two football fields. Its design is refined to provide the lowest possible gravitational disturbances—microgravity—within its four central laboratory modules, while generating power from sunlight that was greater than the energy used in ten average American homes. Initially three and eventually seven international astronauts could work onboard for up to six months before exchanging with the next crew. The volume of space where they lived and worked was about the size of three two-bedroom American homes.

The first module of the ISS was launched by Russia in November 1998. It served as the core for the two U.S. and one Russian modules that followed. Although Russian funding problems and U.S. equipment problems have caused some delays, in mid-2001 the second expedition of three was installed aboard the station, now once again named "Alpha" by the crews. Biotechnology and human biomedical research is being done in the U.S. laboratory module named "Destiny." As more shuttle flights outfit the laboratory and later the European and Japanese laboratories are docked to ISS, research will progressively increase to include science in fundamental biology and physics, fluid physics, combustion science, materials science, technology development, and the earth and space sciences.

Commercial industries of all sorts are being offered a share of the facilities for work on products and services for Earth. Completed assembly and outfitting of the ISS is planned for around 2005, with an operating life of at least ten years. Overall mission control will still be from Houston, Texas, backed up by Moscow, Russia, and with small staffs for routine operations planning and ground control functions. During the space station's operation as a hybrid science laboratory and industrial park in orbit, researchers will conduct most of their work remotely from desktop control stations in their Earth-bound labs or offices. Following experiment setup by a space station crew member, **telescience** will lead to great efficiencies, allowing the crew to focus on maintenance and hands-on-required research. The ISS has been a world-class challenge and is becoming a world-class facility for twenty-first century innovations in science, technology, and commerce. SEE ALSO International Cooperation (volume 3); International Space Station (volume 1); Ley, Willy (volume 4); Microgravity (volume 2); Mir (volume 3); Skylab (volume 3); Space Shuttle (volume 3); Space Stations of the Future (volume 4).

telescience the act of operation and monitoring of research equipment located in space by a scientist or engineer from their offices or laboratories on Earth

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KC-135 Training Aircraft

K

Gravity is such a common part of our daily lives that we are rarely conscious of it, even though it affects everything we do. Any time we drop or throw something and watch it fall to the ground, we see gravity at work. Although gravity is a universal force, there are times when it is not useful to conduct activities under its full influence. In these cases, space scientists and engineers perform their work in "microgravity"—a condition in which the effects of gravity are greatly decreased.

On Earth, brief periods of microgravity can be achieved by dropping objects from tall towers. Longer periods of microgravity, however, can be created only through the use of airplanes that fly special flight paths. The microgravity research aircraft of the National Aeronautics and Space Administration (NASA) is the KC-135, a four-engine turbojet, similar to the Boeing 707, which has been modified to meet NASA's needs to train astronauts and conduct microgravity research. The KC-135 is part of the space agency's Reduced Gravity Program, which was started in 1959 to expose people and equipment to microgravity. The program is operated from the Lyndon B. Johnson Space Center in Houston where scheduling, test coordination, and in-flight direction of test programs takes place.

Parabolic Maneuvers

To simulate microgravity conditions, the KC-135 is flown through a series of precise parabolic maneuvers in which the plane ascends steeply, levels off, and then begins a dive. Typically, the KC-135 soars over the Gulf of Mexico and levels off at about 8,000 meters (26,250 feet). Then the aircraft climbs rapidly until it is at an approximate 45-degree angle to the horizon. Half a minute later, the pilot pushes the KC-135 "over the top" until the plane points down about 30 degrees. Finally, each parabola is terminated with a 1.8-gravity (1.8-G) pullout as the plane levels off again. These gut-wrenching maneuvers have earned the KC-135 its famous nickname: "The Vomit Comet." Many first-time flyers feel queasy as they experience motion sickness.

The parabolic arc flown by the KC-135 is the key to simulating microgravity conditions. As the KC-135 is tracing the parabola, the plane's acceleration matches Earth's acceleration of gravity, making everything inside

The KC-135A is used by NASA in their Reduced Gravity Program to simulate weightlessness.

weightless for up to twenty-five seconds. But these parabolic maneuvers can be modified to simulate different gravity fields and provide any level of microgravity. For example, negative Gs (− 0.1 G) can be achieved for approximately fifteen seconds, and a flight profile can be flown to achieve "zero G" for about twenty-five seconds. The pilot of the KC-135 can also follow an arc that produces one-sixth G—the gravitation force on the lunar surface—for about forty seconds. "Martian-G" (i.e., one-third G) can also be simulated for about thirty seconds when the KC-135 flies a specific type of **parabolic trajectory**. These parabolas can be flown in succession (i.e., roller-coaster fashion) or with short breaks between maneuvers to reconfigure test equipment. As many as forty arcs can be flown on a typical flight so that scientists and technicians can conduct several activities or repeat short runs of a single activity many times. A typical mission lasts two to three hours and consists of thirty to forty parabolas.

parabolic trajectory path followed by an object with velocity equal to escape velocity

Specific Uses of the KC-135

Many years ago NASA recognized that short periods of microgravity could be used to conduct basic research, train astronauts, test hardware and experiments destined for space, and evaluate medical protocols that may be used in space. With the coming of age of the space shuttle and the construction of the International Space Station, the KC-135's ability to simulate microgravity conditions remains essential for crew training, experiments, and the development and verification of space hardware. Astronaut candidates are given exposure to the microgravity of spaceflight

Astronaut Mary Ellen Weber tests a device for stabilizing herself during a short period of weightlessness while training onboard a KC-135 aircraft.

aboard the KC-135. In addition, the KC-135 provides a unique laboratory for research in which scientists can observe and explore physical events, phenomena, and processes that are normally masked by the effects of Earth's gravity. Russian space officials use a similar type of aircraft to simulate microgravity conditions for training and research.

Student experiments that require microgravity conditions have also been flown aboard the KC-135 as part of NASA's Reduced Gravity Student Flight Opportunities Program. The program offers American college and high school students a unique opportunity to fly with their microgravity experiments aboard the KC-135 aircraft and provides the students a behind-the-scenes look at science and engineering programs and the Johnson Space Center.

To support all of these research and training activities, the KC-135 has a full complement of crew members (pilot, copilot, flight engineer, and two reduced gravity test directors), plus room for technicians, engineers, scientists, and all the necessary equipment and **infrastructure**. The test area of the KC-135's cargo bay where microgravity activities are carried out is approximately 20 meters (66 feet) long, 3 meters (9.8 feet) wide, and 2 meters (6.6 feet) high. Most of the test equipment is bolted to the floor using 50-centimeter (19.5-inch) tie-down grid attachment points. Electrical power and liquid or gaseous nitrogen are available for experiments or other uses. The aircraft is also equipped with photographic lights to support still and motion picture photography and video.

Since the inception of the Reduced Gravity Program, KC-135 parabolic microgravity missions have been flown in support of the **Mercury**, **Gemini**, **Apollo**, Skylab, space shuttle, and International Space Station programs as well as for general microgravity research. The KC-135 has even played a role in a Hollywood movie. It was used to fly the actors and crew of the

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

Mercury the first American piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

1995 movie Apollo 13 to film scenes about the ill-fated trip to the Moon. However, in the years ahead, the KC-135 will remain an important tool to investigate real-life human and hardware reactions to a microgravity environment. SEE ALSO Career Astronauts (volume 1); G Forces (volume 3); Human Factors (volume 3); Medicine (volume 3); Microgravity (volume 2); Zero Gravity (volume 3).

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Kennedy, John F.

U.S. President
1917–1963

John F. Kennedy is often touted as a champion of space exploration and for good reason. It was he who challenged the United States to put the first man on the Moon. His motives were probably political, not visionary.

The world situation for the young president was tense. The Cold War with the Soviet Union was heating up. Kennedy believed that countries were

During his historic message to Congress on May 25, 1961, President John F. Kennedy stated that the United States would move forward with a program to land a man on the Moon by 1970.

aligning themselves with the most powerful nation. To be that nation, the president felt the United States needed to show its superiority in a particular arena. As a senator he had voted to kill the space program. As president he had told the National Aeronautics and Space Administration (NASA) that he would not approve new funding for the Apollo program. But Kennedy was so shaken when the Soviet Union launched Yuri Gagarin as the first human in space, in April 1961, that he consulted with Wernher von Braun, the premier rocket expert at the time, for a goal at which the United States could beat the Soviet Union. With the United States having only fifteen minutes of suborbital flight experience and having yet to design a rocket that could leave Earth orbit, he challenged the nation "before the decade is out, to put a man on the moon and return him safely to Earth." America rose to the challenge, and Apollo 11 landed on the Moon on July 20, 1969. SEE ALSO Apollo (Volume 3); Moon (Volume 2); NASA (Volume 3); von Braun, Wernher (Volume 3).

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Korolev, Sergei

Russian Engineer and Designer
1907–1966

Sergei Pavlovich Korolev was the chief designer of launch vehicles during the early years of the Soviet Union's space program and the driving force behind the development of the R-7 ("Semyorka") **rocket**, which launched Sputnik 1, the first artificial satellite, and the first man and woman into orbit. Korolev was born in 1907 and as a youth was greatly influenced by the writings of Russian space pioneer Konstantin Tsiolkovsky. In 1931 Korolev helped organize the Moscow-based Group for the Study of Reactive Propulsion, which in 1933 launched its first successful liquid-fueled rocket.

rocket vehicle (or device) especially designed to travel through space, propelled by one or more engines

When World War II ended in 1945, Korolev headed the development of an "all Soviet" long-range missile, based on the German V-2. After the death of Joseph Stalin in 1953, Korolev headed a design team that developed an intercontinental missile—the R-7—which was fueled with liquid oxygen and kerosene. Later he won the support of Communist leader Nikita Khrushchev for a strong rocket program. Korolev directed the Soviet human lunar program during the 1960s, but he died in 1966 from massive hemorrhage after surgeons discovered colon cancer. Only after his death did Soviet officials acknowledge Korolev's accomplishments. SEE ALSO Cosmonauts (Volume 3); Tsiolkovsky, Konstantin (Volume 3).

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L

Launch Management

A sleeping cylindrical giant points upward from a large concrete slab. Next to it stands the launch tower, pumping fuel into the cylinder and ferrying technicians up and down the length of its body. The voice of the launch controller intones: "T minus one second . . . ignition." The giant roars up into the sky, impaled on a pillar of fire and smoke.

Flowery metaphors aside, this is an ordinary, everyday rocket launch. However, the steps leading up to that moment are anything but ordinary. Understanding these steps requires a basic knowledge of how rockets are built.

To escape Earth's gravity, rockets utilize a technique called staging. A staged rocket consists of two or more cylindrical rocket bodies stacked one on top of another. Each stage has its own propellant, tanks, engines, and instrumentation. The first stage does the heavy lifting of getting the vehicle off the ground. When its fuel runs out, the empty stage is **jettisoned** and falls back to Earth, after which the next stage takes over. Since dead weight is dropped continuously, staging reduces the total amount of propellant needed to put people or satellites into orbit.

jettisoned ejected, thrown overboard, or gotten rid of

Standing Up versus Lying Down

The process of attaching the stages of a rocket to one another is known as integration, and it can be done in one of two ways—vertically and horizontally. Most American launch vehicles, including the space shuttle, are assembled vertically—standing up.

The **payload** and the upper stage are first put together, or mated, in an integration and test facility. Then the payload is sealed within a protective compartment known as the **payload fairing** (the nose cone) and transported to the launch pad, where the stages are placed on top of one another by cranes.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

payload fairing structure surrounding a payload designed to reduce drag

The alternative method, favored by Russia and other countries, is horizontal integration. With this approach the rocket is built lying flat and then is transported to the pad and hoisted upright. Horizontally integrated rockets such as the Ukrainian Zenit-2 can be rolled out, erected, and launched in a matter of hours. By contrast, the large, vertically assembled American rocket the Titan IV can tie up a pad for several months, and even the space shuttle can wait on the pad up to four weeks before blastoff.

Counting Down

The countdown begins from a few hours to a few days before launch (T-0). That time is taken up by extensive tests and fueling procedures. Rockets that use solid propellants, such as the space shuttle's solid rocket boosters, arrive with the propellant already stored inside them in a puttylike form. Liquid propellants such as liquid oxygen/liquid hydrogen (LOX/LH_2) must be pumped onboard at the launch site.

An hour or two before launch the guidance software that controls the vehicle's ascent is loaded. This is delayed until the "last minute" so that accurate weather data can be incorporated.

Space shuttle Columbia lifts off from NASA's Kennedy Space Center.

As liftoff approaches, various batteries within the vehicle are switched on. Since most rocket flights last only eight or nine minutes, long-lived batteries are unnecessary. However, if the countdown must be stopped after the batteries have been switched on, they may run out prematurely, requiring the launch to be scrubbed while the batteries are replaced.

If everything goes smoothly, when T-0 arrives, the rocket ignites and the mission begins. This moment, representing the culmination of countless hours of work by the ground crew (in the case of the space shuttle, 11,000 people at Cape Canaveral), is a time for celebration and relief.

Recycled Space

With the exception of the space shuttle, all launch vehicles today are one-use only. This makes getting into space very expensive. The key to reducing these costs is the development of reusable launch vehicles (RLVs), which will operate like aircraft: After each flight they will undergo inspection, refueling, and reloading and then launch again within hours. By comparison, a 747 airplane can spend 21 hours of each day flying, with only minimal maintenance on the ground. When such efficiency is achieved in space launches, the cost of getting into space will drop precipitously.

In March 2001 the National Aeronautics and Space Agency (NASA) canceled the X-33 and X-34 experimental vehicle programs, two of the major pillars in the agency's efforts to develop an RLV to replace the space shuttle. NASA and prime contractor Lockheed Martin spent nearly $1.3 billion on the X-33, which was intended to pioneer single-stage-to-orbit launch technology. Escalating costs and engineering difficulties led to the program's cancellation.

NASA is still striving to develop a successor to the space shuttle through the $4.5 billion Space Launch Initiative. Under this program, NASA is scheduled to begin development of a new RLV in 2006. SEE ALSO LAUNCH INDUSTRY (VOLUME 1); LAUNCH SITES (VOLUME 3); LAUNCH VEHICLES, REUSABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4); SPACEPORTS (VOLUME 1).

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Launch Sites

For centuries, ships have set sail from ports that bordered the sea. Today, launch sites around the world serve as the point of departure for rockets about to be launched into space. The United States possesses a number of launch sites, located primarily on the East and West Coasts. Perhaps the most widely recognized is the National Aeronautics and Space Administration's (NASA) Kennedy Space Center (KSC), which is situated on a strip of land off the coast of Florida. The major launch sites at KSC are Launch Complex 39's Pad A and Pad B, which were originally built to support Apollo missions, but have been modified for the space shuttle. Pads 39A and 39B are virtually identical and roughly octagonal in shape.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The Kennedy Space Center is dotted with a number of supporting launch facilities. Between missions the shuttle orbiter is refurbished in the Orbiter Processing Facility (OPF). Here previous mission **payloads** are removed and the vehicle is fully inspected, tested, and readied for its next mission. The orbiter is mated with its External Tank and twin Solid Rocket Boosters in the giant cube-shaped Vehicle Assembly Building (VAB) located east of the OPF. Adjacent to the VAB is the Launch Control Center (LCC), a four-story building that acts as the "brain" of Launch Complex

39. The LCC houses four "firing rooms," in addition to telemetry and tracking equipment, plus computers that oversee the checkout and launch process.

The Kennedy Space Center has been America's exclusive launch site for human spaceflights since 1968. Prior to that, Mercury and Gemini missions were launched from Cape Canaveral just south of KSC. Today, this strip of land serves as the launch site of **expendable launch vehicles** (ELVs) from the Cape Canaveral Air Station. Many famous launch pads are located on Cape Canaveral, including Launch Complex 36A and 36B used to launch military and commercial Atlas vehicles. Just south of these facilities is Launch Complex 17A and 17B, which support Delta II and Delta III launch vehicles. The 45th Space Wing of the U.S. Air Force operates the Eastern Range from Cape Canaveral. Spaceport Florida, the first commercial space launch facility in the United States, also operates from Cape Canaveral.

Thousands of kilometers to the north, off the Eastern Shore of Virginia lies NASA's Wallops Flight Facility. Established in 1945 under NASA's predecessor, the National Advisory Committee for Aeronautics, Wallops is one

The space shuttle Discovery sits on a launch pad at NASA's Kennedy Space Center in Florida. The center has a number of supporting launch facilities, including the Vehicle Assembly Building and Launch Control Center.

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused of the oldest launch sites in the world and supports scientific research and orbital and sub-orbital payloads for NASA. Wallops Flight Facility focuses on providing fast, low cost, and highly flexible support for aerospace technology and science projects.

On the other side of the continent, the U.S. Air Force's thirtieth Space Wing maintains launch sites at Vandenberg Air Force Base on California's Central Coast. The Wing launches a variety of expendable vehicles including the Delta II, Pegasus, Taurus, Atlas, Titan II and Titan IV. All U.S. satellites destined for near polar orbit are launched from Vandenberg. Co-located on the base is Spaceport Systems International's Commercial Spaceport, which provides commercial payload processing and launch alternatives to polar or **ballistic** space launch programs.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

Another commercial spaceport had been built by the Alaska Aerospace Development Corporation at Narrow Cape on Kodiak Island, about 400 kilometers south of Anchorage. The Kodiak Launch Complex contains all-weather processing adaptable to all current small launch vehicles, and is the only commercial launch range in the United States not co-located with a federal facility.

Major Launch Sites Outside of the United States

Europe. Outside of the United States, the Guiana Space Center, operated by the European consortium Arianespace, is strategically located on the French Guiana coastline to support commercial launches. The spaceport was deliberately built close to the equator at 5.3° North latitude to reduce the energy required for orbit plane change maneuvers for missions to **geostationary orbit**. The spaceport's ELA-2 Launch Complex supports the Ariane 4 vehicle while the ELA-3 Launch Complex was built specifically to serve the new Ariane 5 heavy-lift vehicle. It is designed to handle a launch rate of up to ten Ariane 5 missions per year.

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Russia. Russia launches all its human space missions as well as all geostationary, lunar, and planetary missions from the Baikonur Cosmodrome. In reality, the Baikonur launch site is located more than 320 kilometers away from a town of that name. Instead, the Baikonur Cosmodrome is situated north of the village of Tyuratam on the Syr Darya River (45.9° North attitude and 63.3° East longitude). The Baikonur name is a relic of Cold War deception. Despite the potential confusion, the Baikonur Cosmodrome is the site where Sputnik 1, Earth's first artificial satellite, was launched. Today, it is the only Russian site capable of launching the Proton launch vehicle, and was used for several International Space Station missions. The Plesetsk Cosmodrome, Russia's northernmost launch complex, is used to launch satellites into high inclination, polar, and highly **elliptical** orbits.

elliptical having an oval shape

Japan. The Tanegashima Space Center is Japan's largest launch facility. Located on Tanegashima Island, 115 kilometers south of Kyushu, this 8.6 million square meter complex plays a central role in pre-launch countdown and post-launch tracking operations. On-site facilities include the Osaki Range that supports J-I and H-IIA launch vehicles, tracking and communications stations, and several **radar** stations and optical observation facilities. There are also related developmental facilities for firing of liquid- and solid-fuel rocket engines.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

China. The Chinese have several launch facilities—Jiuquan, Taiyuan, and Xichang—though the Xichang Satellite Launch Center, located in southern China, supports all geostationary missions and is the site from which many U.S.-manufactured satellites are launched. Two separate launch pads support flight operations, and a command and control center is located 7 kilometers from the launch site. The nominal launching **azimuth** is 97°, with downrange safety constraints limiting launch azimuths to 94° to 104°.

azimuth horizontal angular distance from true north measured clockwise from true north (e.g., if North = 0 degrees; East = 90 degrees; South = 180 degrees; West = 270 degrees)

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

One of the most unusual launch sites is the floating Sea Launch facility managed by Boeing. Two unique ships form the marine **infrastructure** of the Sea Launch system. The first is a custom-built Assembly and Command Ship (ACS), and the second is the Launch Platform (LP), a semi-submersible vessel that is one of the world's largest oceangoing launch platforms. Homeport for Sea Launch is in Long Beach, California. SEE ALSO External Tank (volume 3); Launch Management (volume 3); Modules (volume 3); Rocket Engines (volume 1); Rockets (volume 3); Solid Rocket Boosters (volume 3); Space Shuttle (volume 3); Vehicle Assembly Building (volume 3).

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Leonov, Alexei

Russian Cosmonaut
1934–

Alexei Leonov was a former Soviet cosmonaut who was the first human to walk in space. Leonov was born in Listvyanka, Siberia on May 30, 1934. After graduating from pilot school in Ukraine in 1957, he served as a Soviet

Alexei Leonov works onboard the Soyuz 19 spacecraft during link-up with Apollo 18 in Earth orbit, 1975. The Apollo-Soyuz docking was the first of spacecraft built by different nations and foreshadowed future American/Russian cooperation in space.

Air Force pilot before being selected as one of the Soviet Union's first 20 cosmonauts in 1960.

Leonov's first spaceflight was in March 1965 on Voskhod 2. During that flight, Leonov performed the first space walk, leaving the spacecraft through an inflatable airlock for several minutes. He was almost unable to reenter the spacecraft after his suit stiffened in the vacuum of space; only after releasing some air was he able to fit through the airlock.

Leonov was scheduled to command Soyuz 11 in 1971, but a backup crew flew instead when another crewmember became sick just before launch. That turn of events proved fortunate when the Soyuz 11 crew died when their capsule depressurized during re-entry. Leonov finally flew in space again in July 1975 as commander of Soyuz 19, which docked with an Apollo spacecraft for the first joint American-Soviet space mission. Leonov served as chief cosmonaut from 1976 until 1982, then as deputy director of the Gagarin Cosmonaut Training Center until his retirement in 1991. SEE ALSO COSMONAUTS (VOLUME 3); GAGARIN, YURI (VOLUME 3); HISTORY OF HUMANS IN SPACE (VOLUME 3).

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Life Support

Human space exploration is a critical aspect of space sciences. Although robotic probes are invaluable for preliminary studies or high-risk environments, humans are able to solve problems, improvise, and make discoveries

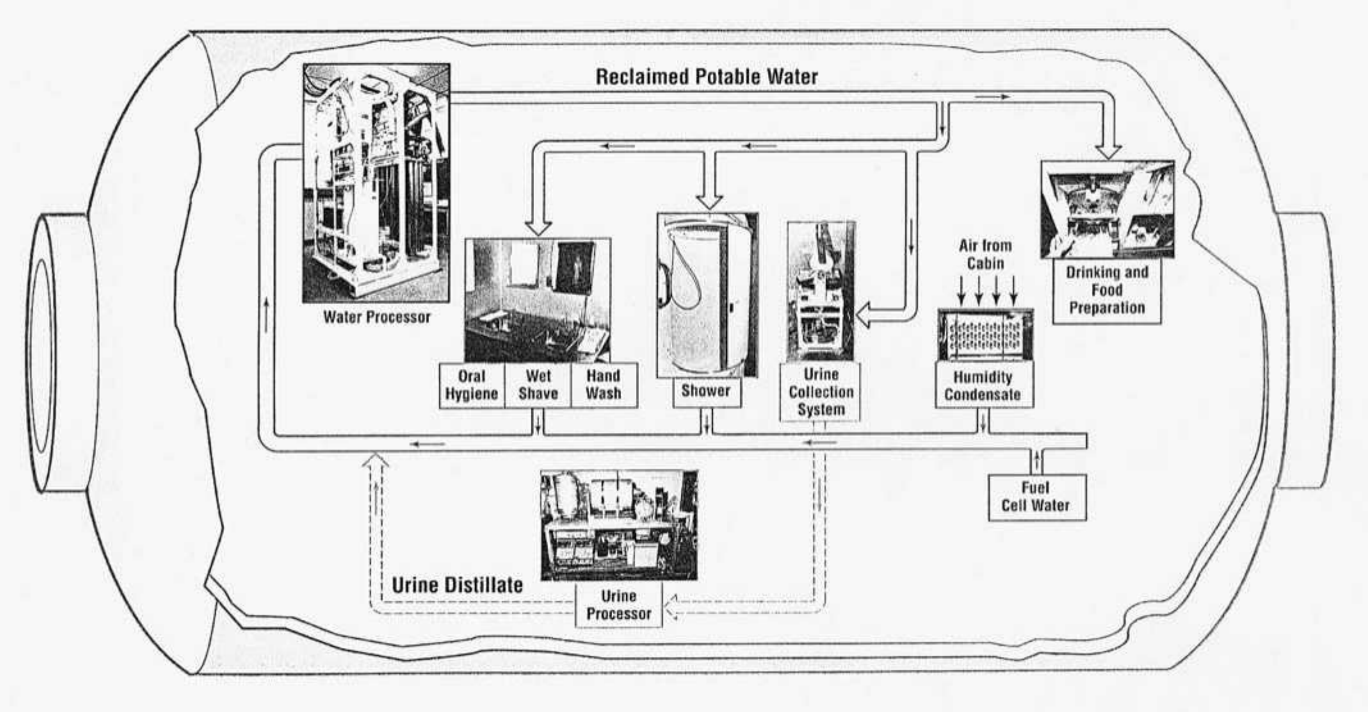

Diagram showing the flow of water recovery and management in the International Space Station (ISS).

that are not programmed into a probe's software. Keeping astronauts safe and healthy while in space is a major concern. Non-astronauts take for granted many of the life support concerns that astronauts must consciously address to ensure their mission's success. Variables include gas requirements, temperature, gravity, radiation, and pressure. Waste products must be carefully monitored, and disposal or recycling must be planned. When astronauts leave Earth, many plans, procedures, and backup systems are in place for their comfort and survival.

Temperature

During a space mission, astronauts and their spacecraft are exposed to temperature extremes on both ends of the scale. On the Moon, for example, when the Sun is up, the surface temperature can go as high as 243°F (117°C) but at night it can drop to −272°F (−169°C). This was a major concern for the Apollo Moon missions.

The **vacuum** of space is extremely cold and deadly to unprotected human life. However, the heat felt during liftoff and re-entry through the atmosphere is intensely hot. Engineers must design space suits that keep astronauts warm when they embark on space walks in the extreme cold of space. They must also design heat shielding for the space shuttle that will withstand the high temperatures of re-entry into Earth's atmosphere. For example, after the shuttle has entered orbit, the cargo bay doors open to help release much of the pent-up heat created during liftoff and ascent. Conversely, the shuttle must be pointed at a appropriate angle and rotation to ensure that the heat of re-entry is distributed properly against specially reinforced, heat-resistant panels. During re-entry, the space shuttle will encounter incredibly hot temperatures—up to 3,000°F. This requires the shuttle to be equipped for the temperature extremes.

vacuum an environment where air and all other molecules and atoms of matter have been removed

Gravity and Microgravity

During liftoff, the effects of gravity on the human body are intense and cause physical discomfort. Astronauts are tested in simulators to ensure they can survive the gravitational effects of space shuttle liftoff, which are up to three times that of Earth gravity.

Once in space, astronauts must adapt to microgravity, a nearly weightless environment. Human bodies are accustomed to the amount of gravity experienced on Earth, where muscles and bones are always competing with gravity. But in space, astronauts lose bone and muscle mass. Their hearts do not have to beat as hard or as fast to make blood pump through the body. Despite a rigorous exercise schedule while in space, nearly all astronauts exhibit muscle and bone deterioration after spaceflights of significant duration.

Other Survival Concerns

jettison to eject, throw overboard, or get rid of

Humans bodies take in food, water, and oxygen necessary for life, and then produce wastes as liquids, solids, and carbon dioxide. Space missions must ensure an adequate supply of life-sustaining resources for the journey, as well as a safe way of disposing of waste products. Recycling is important in space, and both technological and biological equipment are used. Many different ways of waste product disposal have been used and or studied by NASA. These methods include space **jettison**, plant fertilizers, and technology that filters and cleans the waste to allow useful materials to be reused.

Extra vehicular activity (EVA) suits, protect astronauts in the vacuum of space. These suits protect against extreme cold, radiation, and help recycle carbon dioxide into oxygen. However, just as the space shuttle has its limitations, these suits do as well. Their life support systems can be overwhelmed, requiring that they be used for only short periods of time, such as space walks. During space walks, MMUs (Manned Maneuvering Units) have been used as a means of moving small distances. The MMUs are similar to jetpacks for the astronauts. They allow small bursts of propulsion thrusters to be fired from the pack, allowing astronauts to change their direction and momentum.

One commonly forgotten life support concern is the energy required for all of the spacecraft's equipment. The space shuttle must have failsafes to ensure that there will be enough energy for the onboard computer systems, just as there must be sufficient fuel. These energy sources are as important as any other because without them, the mission would not be feasible. Extensive research is underway to try and use new, cheaper fuels in future human space exploration missions. SEE ALSO Living in Space (volume 3); Manned Maneuvering Unit (volume 3); Space Walks (volume 3).

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Lifting Bodies *See Hypersonic Programs (Volume 3).*

Living in Space

Outer space is a harsh and unforgiving environment. To get there, astronauts must ride atop complicated **rockets** that rely on controlled explosions to attain the terrific speeds required to achieve orbit. Out there, spacecraft and spacesuits must protect their occupants from wild temperature swings, a near perfect **vacuum**, and in some cases poisonous atmospheres and corrosive dusts. People must adjust to "weightlessness" and they may be exposed to potentially harmful doses of radiation. In addition, spacefarers must adjust to the psychological and social conditions of flight.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

vacuum an environment where air and all other molecules and atoms of matter have been removed

Acceleration

The first step in leaving Earth—achieving **orbital velocity**—requires high acceleration. In the 1830s, some people feared that the human body could not withstand the greater than 40-kilometer-per-hour (25-mile-per-hour) speed that might be achieved by railroad trains. Today we know that people are capable of accelerating to very high speeds as long as they are protected from the wind and other dangers. If necessary, occupants can wear inflatable suits that apply pressure to the body and in this way help the heart circulate blood. During acceleration to orbit, riders face forward in form-fitting chairs that distribute the body's weight over as much of the surface of the chair as possible. This prevents the force of acceleration from being concentrated on one small part of the body. Acceleration was a much bigger problem in the 1960s when astronauts went into space atop modified military rockets. In those days, acceleration (and deceleration) sometimes approached eleven times the force of gravity. The maximum acceleration of the space shuttle is approximately three times the force of gravity.

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

Microgravity

In orbit, people live under conditions of microgravity, which is commonly referred to as "weightlessness." Floating in the interior of the spacecraft, effortless somersaults and pushing large objects with one hand are proof positive of arrival in space. Microgravity also has some less desirable aspects. No longer do people have a firm sense of up and down. Fluids shift within the head, and the otoliths (tiny mechanisms within the inner ear that provide humans with a sense of orientation and balance) no longer send a familiar pattern of signals to the brain. The information coming from the eyes and the balance mechanisms no longer match, and the result is space adaptation syndrome (SAS). Symptoms of this syndrome resemble those of car or boat sickness. Not everyone who enters space experiences SAS, and it

Everyday living onboard the space shuttle Discovery, as mission specialist Pedro Duque opens a can of food in the weightless environment of space. His anchored feet provide stability while in this inverted position.

can be treated with medicine. Even untreated, SAS tends to disappear after two or three days.

In microgravity, human muscles, including the heart, do not have to work as hard as they do on Earth. Consequently, spacefarers experience muscular deconditioning. This weakening is less of a problem in space than upon return to Earth when it becomes necessary, once again, to operate under conditions of normal gravity. On occasion, spacefarers returning from lengthy missions have had to be carried out of their spacecraft. Many astronauts report that after they return from space they feel as if they weigh a ton and that it requires tremendous exertion to do even simple things, such as breathe and walk from place to place.

Years of careful research have shown how the process of deconditioning can be slowed. The most important ingredient is regular and strenuous exercise, perhaps using a treadmill or stationary bicycle. Additionally, dietary supplements and careful regulation of fluid intake helps counteract deconditioning and ease the transition back to Earth.

Radiation

High levels of radiation come from deep within the Galaxy and from flare-ups on the surface of the Sun. The invisible Van Allen belts that circle Earth in a region known as the **magnetosphere** trap much of this radiation and serve as an umbrella that protects people in **low Earth orbit** or below. Earth's atmosphere offers additional protection. Such shields are not available for people in transit or on the Moon, and the thin atmosphere of Mars affords but the slightest protection. Massive amounts of radiation produce debilitating sickness and even rapid death. Lower amounts may not produce immediate illness, but they do affect long-term health by increasing risks of infertility or birth defects, cataracts, and cancer.

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Almost any kind of barrier provides some protection against radiation. The problem is that very substantial barriers—such as a concrete vault lined with sheets of lead—are too heavy and expensive to lift into space. It will be possible to bury habitats under the lunar and Martian regolith (soil), but protecting people in transit remains a central concern. The primary remedy is limiting individual exposure to radiation—for example, restricting the total amount of time in orbit—and finding efficient, lightweight shields to provide a "storm shelter" where spacefarers can retreat during peak periods of solar activity.

Personal and Social Adjustment

Early studies of adventurers in polar regions such as Antarctica suggested that isolation from family and friends coupled with close confinement with other members of the crew could affect safety, performance, and quality of life. The importance of psychological factors was brought home in Bryan Burrough's 1998 book *Dragonfly: NASA and the Crisis Aboard Mir.* This work gives vivid examples of loneliness, cultural misunderstandings, and interpersonal tensions, not only among crew members but also between the crew and flight controllers. Psychological factors will become even more important as larger and more diverse crews (including, perhaps, construction workers, accountants, chefs, and nurses) remain away from Earth for longer and longer periods of time. Selecting astronauts on the basis of their psychological and interpersonal as well as technical skills helps minimize such problems. Training in human relations is one part of astronaut training programs, and designers seek ways to make their spacecraft more comfortable and user-friendly. Psychological support groups that offer advice, encouragement, and entertainment by radio have been a big help.

Be Prepared

In the earliest days of space exploration scientists were not completely sure that people in orbit could breathe properly, swallow water, and digest food. Decades of careful biomedical research have enabled people to venture into space without suffering lasting debilitating effects. So far, there have been many challenges but no "show stoppers." With continued research we should be able to overcome the biomedical challenges associated with a permanent return of humans to the Moon and the establishment of the first human camp on Mars. SEE ALSO Habitats (volume 3); Human Factors (volume 3); Living on Other Worlds (volume 4); Long-Duration Spaceflight (volume 3); Microgravity (volume 2).

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Long-Duration Spaceflight

Imagine this scenario: You have been chosen as one of seven astronauts on the first human mission to Mars. You are four months into the three-year, round-trip mission. You share a small spacecraft with six people of different cultures who you do not know very well; one of them does not like you, and there is no place to escape from this person. The spacecraft is noisy and the lighting is poor. You have not been sleeping well because your internal clock has been thrown off by the lack of a normal day/night cycle. The last time you spoke to your loved ones on Earth was a month ago. Though you cannot feel it, your bones are becoming weaker due to calcium loss. Your heart is shrinking too. You have a toothache, but there is no dentist onboard—one of your crewmates will have to drill and fill the tooth. There is no way to turn this spacecraft around and head back to Earth; you must endure these conditions for another thirty-two months.

Inviting? Maybe not, but this is a very real description of the challenges an astronaut would face on a long-duration spaceflight. Before accepting such an assignment, you may want to know about all the dangers you could encounter.

Dangers: The Big Three

"Space travel is severely debilitating to humans in many ways," stated a team of fourteen doctors and psychologists in a report titled *Safe Passage: Astronaut Care for Exploration Missions* issued in 2001 by the National Academy of Sciences Institute of Medicine. After reviewing the medical data available from U.S. and Russian piloted space missions, the panel noted three main areas of concern:

bone mineral density the mass of minerals, mostly calcium, in a given volume of bone

1. Loss of **bone mineral density**. Astronauts have lost an average of 1 percent of bone mineral density—mostly calcium loss—for every month in space, making their bones brittle and more susceptible to fracture. Medical scientists do not know why this happens. The prescribed treadmill and bicycle exercise regimens have had very little effect in preventing bone mineral loss. Questions remain: Does the loss stabilize at some value, say 50 percent, or does it keep getting worse? How well do broken bones heal in space? If bone mineral density loss cannot be prevented, the report stated, "interplanetary missions will be impossible."

In 1996 Shannon Lucid set the U.S. record for spaceflight endurance by staying aboard the Mir space station for 188 days. While onboard the station, she logged almost 400 hours on the treadmill (above) and stationary bike to reduce the muscle atrophy caused by the microgravity environment of space.

2. Radiation dangers. Earth's magnetic field and atmosphere protect us from most of the charged particles coming from the **solar wind**, and from other forms of high energy **cosmic radiation**. But on interplanetary missions, astronauts will experience this damaging radiation full force. Electrons, protons, neutrons, **atomic nuclei**, **X rays**, and **gamma rays** will strike the spacecraft in a steady stream, and there is currently no way to stop them all. What is more, when a particle such as an electron slams into a metal barrier, it releases its energy in the form of X rays; a spacecraft hull that stops the electrons would still have to deal with the secondary X rays produced in the collision. Astronauts subjected to heavy doses of radiation may develop radiation poisoning and cancer.
3. Behavioral issues. For a space mission to be successful, all members of the crew must cooperate to reach common goals. Social compatibility and psychological health are therefore prime concerns in long-duration spaceflights. What if a dispute breaks out between two astronauts that leads to physical violence? Or what happens if an astronaut becomes claustrophobic in the cramped living quarters? Perhaps a crewmember will become severely depressed due to the isolation of outer space and separation from loved ones. While psychologists on

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

atomic nuclei the protons and neutrons making up the core of an atom

X rays high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

Earth might be able to help, any social or psychological problems that could threaten the success of the mission must ultimately be resolved by the crewmembers.

Other Dangers

atrophy to wither, shrink, or waste away

Muscles deteriorate in microgravity conditions; significant muscle **atrophy** has been seen in humans after only five days in space. The most important muscle—the heart—is no exception. Two-thirds of astronauts returning from long missions have experienced dizziness, lightheadedness, and disorientation when standing up. Recent studies have shown that this is due to shrinking and stiffening of the heart. Since the heart does not have to work as hard to pump blood throughout the body in microgravity conditions, it becomes weaker, and shrinks. Back on Earth, it is unable to pump enough blood up to the head, resulting in dizziness. Fortunately, this appears to be a temporary change that reverses itself in time after a return to Earth's gravity.

Problems with the nervous system show up in the form of motion sickness, loss of coordination, and altered sleep patterns. Without the daily signals of sunrise and sunset to tell astronauts when to wake up and when to fall asleep, they tend to sleep for shorter periods and get less deep sleep, making them tired and less clearheaded during their work shifts.

Medical emergencies could cause big trouble. While some, like the toothache described in the opening scenario, may be relatively minor, other more serious conditions could prove to be deadly. An astronaut may have a heart attack, or a diseased appendix might require surgery before it bursts. Without a doctor or a surgeon onboard, these illnesses could be fatal.

Possible Solutions

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

As scientists collect more medical data from astronauts aboard the International Space Station and conduct experiments to determine the causes of bone mineral density loss, muscle deterioration, and heart shrinkage, they will likely discover new exercise, nutrition, and pharmaceutical solutions to these problems. Alternatively, designing a spacecraft that rotates to create artificial gravity could eliminate problems caused by microgravity entirely. But such spinning spacecraft are much more costly to design, build, and operate. For the radiation problems, engineers may develop new materials that would provide proper **shielding**. Behavioral problems might be avoided by studying the interactions of small groups of people in cramped living spaces, and deliberately choosing astronauts who will be likely to remain compatible in stressful situations. Drugs to treat depression, anxiety, and other psychological conditions will no doubt be included in the spacecraft's medicine chest.

So there are many challenges to be met before long-duration spaceflight is safe for humans. Is there a "point of no return"—a period of time in microgravity conditions after which it is impossible for the human body to readapt to Earth's gravity? We do not know, and the astronauts on the first flight to Mars may not know either. Like all pioneers before them, they must accept the fact that they are taking major risks, that they do not have solutions to all possible problems, and that their lives are at risk in space. SEE ALSO Career Astronauts (volume 1); Human Factors (volume 3);

HUMAN MISSIONS TO MARS (VOLUME 3); LIVING IN SPACE (VOLUME 3); MARS MISSIONS (VOLUME 4); MEDICINE (VOLUME 3); MIR (VOLUME 3).

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Lunar Rovers

In forty-five years of spaceflight and exploration, there have only been six rovers: three Apollo mission lunar rovers, two Russian Lunokhods, and one Sojourner rover on Mars. Under current conditions, the need has been for small robotic vehicles rather than a vehicle to transport humans.

Original Use and Purpose

The primary purpose of the Apollo lunar rovers was to transport the astronauts, saving their energy and oxygen supplies for collecting rock samples to bring back to Earth. These rovers were built by the Boeing Company and NASA's Marshall Space Flight Center. Rovers were sent on Apollo 15, 16, and 17. Each one weighed about 204 kilograms (450 pounds) and could carry about 454 kilograms (1,000 pounds). The frames were made of aluminum alloy tubing, and the **chassis** was hinged in the middle so that the rover could be folded up and fit in the lunar module. There were two foldable aluminum seats with nylon webbing. Adjustable footrests, Velcro seat belts, and an armrest between the seats were important features. Communications were aided by a large metal dish antenna mounted on the back. The suspension consisted of a double horizontal wishbone torsion bar.

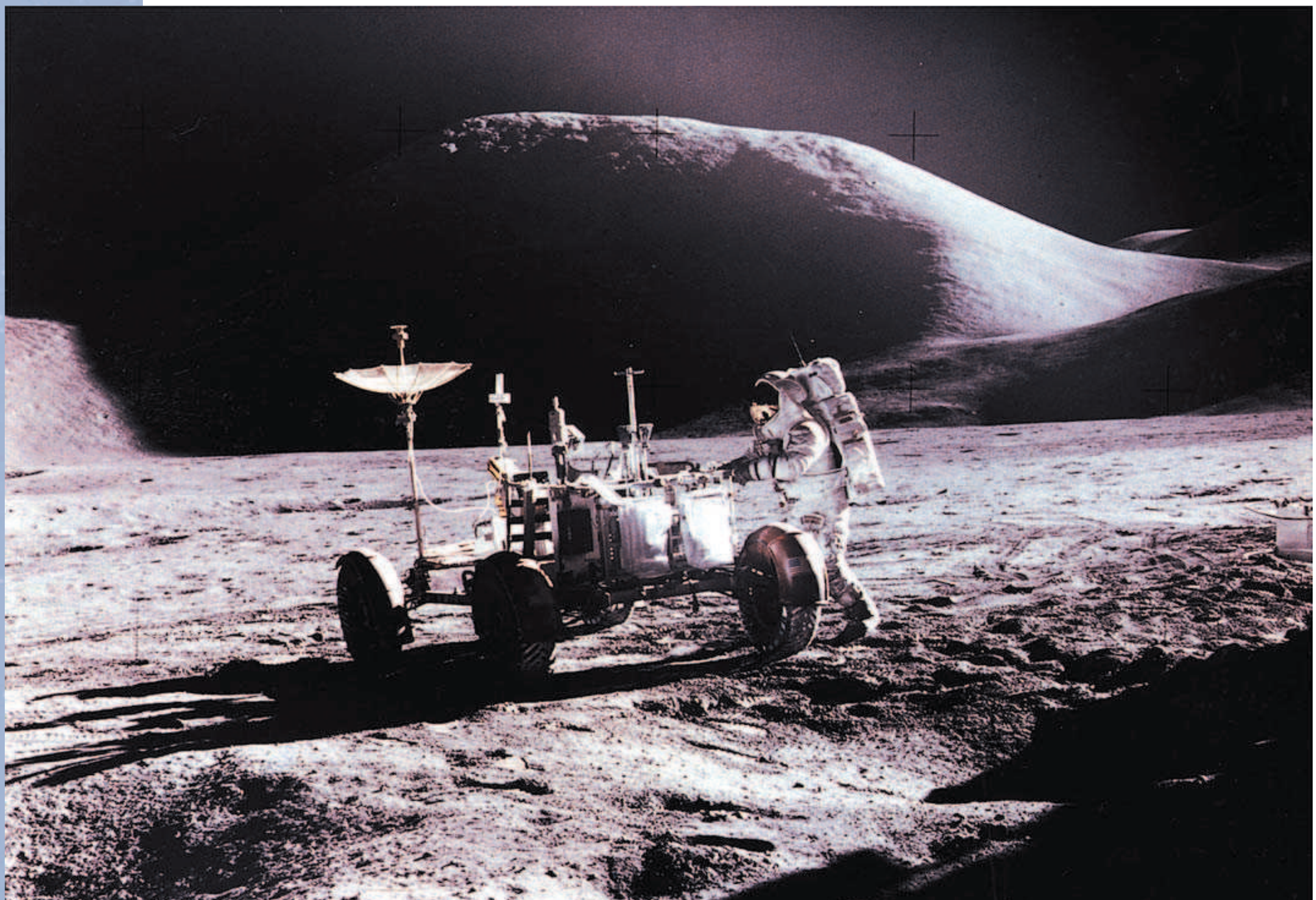
chassis frame on which a vehicle is constructed

The wheels were a woven mesh about 23 centimeters (9 inches) wide that was made of zinc-coated steel strands with aluminum rims and disks. The chevron-shaped treads were made of titanium. An important feature was the dust guard for each wheel. The Moon's fine dusty **regolith** covered everything. The rover kicked up the regolith and would not have been operable without the dust guards. At one point a spare guard had to be fashioned out of a notebook cover because the original had been damaged. Each wheel had its own 0.25-horsepower motor.

regolith upper few meters of the Moon's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

Power was supplied by a 36-volt silver zinc potassium hydroxide battery that could not be recharged but would run for 121 amp hours. A 36-volt outlet for communications or a television camera was mounted up front.

The original cost estimate was $19 million for each unit, but the final cost was $38 million. Four were built for use on the Moon, one of which was used for parts when the last mission was dropped. Several prototypes were made as well.



Astronaut James B. Irwin works near the Lunar Roving Vehicle (LRV) during Apollo 15 lunar surface extravehicular activity (EVA-1) at the Hadley-Apennine landing site, July 31, 1971.

Each rover had a 48-kilometer (30-mile) range and could theoretically go about 13 kilometers (8 miles) per hour. For the three missions the total mileage traveled was around 95 kilometers (60 miles). All three rovers remain on the Moon and have only a minimal number of plastic parts that might deteriorate.

There are two Lunokhod rovers from the Soviet Union on the Moon. The Lunokhod 2 had a mass of 838 kilograms (1,848 pounds) and was about 1.5 meters (5 feet) long and 1.5 meters (5 feet) wide. It had eight wheels, each with its own suspension, motor, and brake. Because it carried its four cameras, it could go 1 or 2 kilometers per hour (0.6 to 1.2 miles per hour), receiving directions for movement from controllers on Earth.

Power was supplied by solar panels. The rover was designed to work during the two-week long lunar day, periodically charging its batteries. At night it would shut down, retaining warmth from a radioactive heat source. The rover was equipped with many scientific instruments. Lunokhod 2 operated for 4 months and covered around 35 kilometers (22 miles) of lunar terrain.

For several years there was a lunar rover initiative to promote new designs for lunar rovers sponsored by Carnegie Mellon University and LunaCorp. Radio Shack has bought sponsorship rights to the Icebreaker rover, which is earmarked to explore a crater at the polar region of the Moon that is thought to harbor ice in an area where sunlight never reaches. Another design being tested is the Nomad, a 544-kilogram (1,200 pounds) rover.

Future Uses of Rovers

Rovers will be important to any future lunar colonies because they will increase the amount of ground that can be explored safely and efficiently. Locating water as well as other mineral resources will require the extensive use of new-generation rovers equipped with high-technology electronics. The race to land a human on the Moon may be over, but the race to discover and tap its resources is just beginning. Plans call for the use of a variety of rovers in plans involving the exploration of Mars over the next decade. Rovers will collect rock and soil samples and search for subsurface water in their landing site area. SEE ALSO Apollo (volume 3); Apollo Lunar Landing Sites (volume 3); Mars Missions (volume 4); Moon (volume 2); Robotic Exploration of Space (volume 2); Robotics Technology (volume 2).

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Manned Maneuvering Unit

The image of space-suited astronaut Bruce McCandless flying free high above Earth is one of the most famous in spaceflight history, yet the device that made it possible, the manned maneuvering unit (MMU), had a surprisingly short career. The MMU flew for only ten hours, twenty-two minutes during three space shuttle flights in 1984.

The MMU measured 1.25 meters (49 inches) tall, 0.83 meters (33 inches) wide, and 1.2 meters (47 inches) from front to back with hand controller arms fully extended. Without nitrogen propellant, it weighed 142 kilograms (312 pounds). The MMU attached to the shuttle space suit's backpack by two spring-equipped latches.

The MMU was a product of maneuvering device development spanning nearly thirty years, and it became a stepping-stone to the Simplified Aid For EVA Rescue (SAFER) unit carried today during International Space Station (ISS) space walks. The first U.S. astronaut maneuvering aid was the Hand-Held Maneuvering Unit carried by spacewalkers outside Gemini capsules (1965–1966). The MMU's immediate precursor was the Automatically Stabilized Maneuvering Unit, a maneuvering backpack successfully tested in 1973–1974 inside Skylab, the first U.S. **space station**.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

The National Aeronautics and Space Administration (NASA) added the MMU to the space shuttle program in 1974 to allow an astronaut to fly under the shuttle orbiter prior to Earth atmosphere re-entry to inspect its crucial heat shield tiles for damage. Development was slowed, however, by

Astronaut Bruce McCandless tests his nitrogen-powered Manned Maneuvering Unit. This jetpack enabled McCandless to "free-fly" 320 feet from space shuttle Challenger, the farthest untethered space walk at the time, on February 11, 1984.

management disinterest and lack of money. In 1979, however, space shuttle Columbia lost tiles during a test flight atop its 747 ferry aircraft, so NASA launched a crash program to prepare the MMU for flight. Engineers soon solved the shuttle's tile problems, however, and the first shuttle mission (STS-1, 1981) flew without an MMU.

NASA then decided to use the MMU for satellite servicing. Astronauts Bruce McCandless and Robert Stewart tested the MMU on mission STS-41-B (February 1984). On STS-41-C (April 1984), astronauts failed to capture the *Solar Max* satellite using the MMU; they succeeded, however, by using the shuttle's Remote Manipulator System (RMS) robot arm. Astronauts using the MMU and RMS worked together to capture the Palapa and Westar VI satellites during STS-51-A (November 1984). These flights showed that the RMS was easier to use than the MMU.

The January 1986 Challenger disaster led to a sweeping safety examination of NASA human spaceflight systems, and the MMU was found wanting. In 1988 NASA put the two flight MMUs into long-term storage until a purpose could be found for them that justified the cost of upgrades for increased safety. As of 2002, no such purpose has been found.

The experience gained through MMU development has, however, been put to vital use. NASA applied it to the Simplified Aid For EVA Rescue (SAFER) device now worn under the shuttle space suit backpack. SAFER acts as a "life jacket" permitting astronauts who drift away from the International Space Station to maneuver back to safety. SAFER development began in 1992, and Mark Lee and Carl Meade first tested the device in orbit on mission STS-64 (September 1994). SAFER was first worn outside a space station—Russia's Mir—during STS-76 (March 1996), the third shuttle-Mir flight, and was first tested outside the International Space Station during STS-88 (November 1998). SEE ALSO CHALLENGER (VOLUME 3); SPACE SHUTTLE (VOLUME 3); SPACE SUITS (VOLUME 3); SPACE WALKS (VOLUME 3).

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Medicine

Traditionally, space medicine has tackled medical problems associated with the space environment. Increasingly, however, space medicine also encompasses research conducted aboard space stations and vehicles. Medical research conducted in **microgravity** is making significant contributions to the understanding of the molecular structure of living things—a key to the development of new disease-fighting drugs. The scope of biological molecules includes proteins, polysaccharides and other carbohydrates, lipids and nucleic acids of biological origin, and those expressed in plant, animal, fungal, or bacteria systems. The precise structure of proteins and some other biologic molecules can be determined by diffracting **X rays** off crystalline forms of these molecules to create a visual image of the molecular structure. Determining the structure of these **macromolecules**—which allow living

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

A researcher examines images of insulin crystals grown on a space shuttle.

X rays high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

macromolecules large molecules such as proteins or DNA containing thousands or millions of individual atoms

organisms to function—is essential to the design of new, more effective drugs against infectious diseases and other afflictions, such as AIDS, heart disease, cancer, diabetes, sickle-cell anemia, hepatitis, and rheumatoid arthritis.

Medical Advances from Space Research

Space-based crystal growth facilitates the study of how macromolecules work in the human body, which has important implications for medicine. For example, through protein crystal growth research, scientists have made an important step toward developing a treatment for respiratory syncytial virus—a life-threatening virus that causes pneumonia and severe upper respiratory infection in infants and young children. Investigators have determined the structure of a potentially important antibody to the virus, allowing scientists to understand key interactions between the antibody and the virus, thus, facilitating development of treatments. Factor D protein crystals have also been grown in space, leading to development of a drug that may aid patients recovering from heart surgery by inhibiting the body's inflammatory responses. Experiments in protein crystallization research have also yielded detailed structural data on proteins associated with Chagas' disease, a deadly illness that afflicts more than 20 million people in Latin America and parts of the United States.

Medical research in space has likewise yielded precise images of insulin proteins—mapped from space-grown crystals—which can aid the development of new insulin treatments for diabetes. Such treatments would greatly improve the quality of life of insulin-dependent diabetics by reducing the number of injections they require. In addition, a space-based study of the HIV protease-inhibitor complex has resulted in improved resolution of the protein's structure, which has important implications for designing new drugs for AIDS therapies. Microgravity research has also provided insight into an enzyme called neuraminidase, which is a target for the treatment and prevention of the flu. Meanwhile, influenza protein crystals grown aboard several space shuttle flights have had a significant impact on the progress for a flu medicine. As a result, several potent inhibitors of viral influenza (types A and B) have been developed. Medical research in space has also provided insight into fundamental physiologic processes in the human body. A protein crystal growth study conducted during a space shuttle flight shed new light on antithrombin—a protein that controls coagulation of blood.

Research on the International Space Station

Equipped with a dedicated research laboratory, the International Space Station (ISS) will support longer-duration experiments in a more research-friendly, acceleration-free, dedicated laboratory than the space shuttle can allow. Onboard ISS, astronauts and cosmonauts will use the Microgravity Science Glovebox to support investigations and demonstrations in all of the microgravity research disciplines. When it is sealed, the Glovebox serves as a single level of containment by providing a physical barrier. A planned protein crystal growth facility will be used to expose a pure protein solution to a substrate, which draws the liquid out of the protein solution, leaving crystallized proteins behind.

Plans for the ISS also call for a "bioreactor" onboard that will be used in experiments to grow cells and tissues in a controlled environment. On

Blood is drawn from astronaut John Glenn as part of the Protein Turnover Experiment (PTO), which examined muscle atrophy during exposure to microgravity.

Earth, bioreactors have to rotate to allow cell growth in three dimensions, very similar to the way cells grow naturally within an organism. However, this works only up to a certain sample size because the larger the sample gets, the faster the bioreactor has to spin to keep the cells suspended. In the microgravity environment of the International Space Station, the cells will remain suspended on their own because there is virtually no gravity to cause sedimentation. As a result, samples can be grown larger and be kept alive for longer periods.

With these cells and tissues, new medicines in the fight against AIDS, cancer, and diabetes can be safely tested, without harming animal or human test subjects, and long-term exposure to microgravity and its effects on human bones, muscles, cartilage, and immunity can be studied effectively. Bioreactor research will also be valuable in the study of potential cartilage and liver tissue transplantation. SEE ALSO CAREERS IN SPACE MEDICINE (VOLUME 1); CRYSTAL GROWTH (VOLUME 3); INTERNATIONAL SPACE STATION (VOLUMES 1 AND 3); MADE IN SPACE (VOLUME 1).

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Mercury Program

In ancient Rome, Mercury was the mythical messenger of the gods. His winged helmet and sandals represented his ability to run extremely fast. Ancient astronomers immortalized him by giving the name Mercury to the planet that circled the Sun in the shortest amount of time. In 1958 speed was very much on the minds of the managers of the National Aeronautics and Space Administration (NASA). Speed was critical to meeting the goal of the Mercury program: to launch an astronaut into orbit and safely return him to Earth. ✶ To achieve that goal NASA would have to accelerate a vehicle containing an astronaut, life support equipment, and other systems to more than 29,000 kilometers (18,000 miles) per hour. Speed was also critical in another sense. NASA was expected to achieve the goal of piloted orbital flight before the Soviet Union did so to help the United States gain the lead in the space race. The Soviets had unexpectedly seized the lead by launching the first artificial satellite—Sputnik—in 1957.

✶It would not be until 1978 that the first American women were selected for astronaut training.

Success and safety were at least as important as speed. To avoid failure because of mechanical problems, NASA carried out an extensive system design and test program. To avoid failure due to human problems, NASA conducted an extensive astronaut selection and training program. As the program began, scientists knew little about how the human mind and body would react to the stress of spaceflight and the environment of space. Would an astronaut's heart stop beating from weightlessness? How would the human body be affected by the radiation in space, which was unfiltered by Earth's atmosphere? Could astronauts become so disoriented that they would be unable to accomplish their tasks while weightless?

There was so much doubt concerning humans' abilities under the conditions the astronauts would encounter that initial proposals called for astronauts to be merely passengers, the subjects of experiments rather than contributors to flight operations. Such astronauts would not have to be qualified pilots. This approach, which was dubbed "Man in a Can," was ultimately replaced by one that gave astronauts a role in flight operations, an approach that led to the decision to use highly skilled military test pilots as astronauts.

Selecting the First Astronauts

A system of record screening using preliminary criteria reduced the number of military test pilots considered from more than 500 to 110. These pilots were arbitrarily divided into three groups, two of which were brought to Washington, D.C., and briefed on the Mercury program. There were so many volunteers from the first two groups that NASA decided not to call the third to Washington. After written tests, interviews covering technical knowledge and psychological makeup, medical history reviews, and extensive medical testing, the number of potential astronauts who were qualified and interested was reduced to 31. These candidates completed a series of elaborate and frequently exotic tests to determine their physical and psychological limits under some of the extreme conditions they might encounter. Humorous examples of the testing program are depicted in the movie *The Right Stuff* (1983) based on Tom Wolfe's book about the space program.

With 18 finalists a NASA panel selected the first Americans to fly into space. Unable to agree upon only six astronauts as planned, they selected

Astronaut Virgil "Gus" Grissom hangs from a Marine helicopter safety harness after being rescued from his Liberty Bell 7 spacecraft.

seven: Scott Carpenter, Gordon Cooper, John Glenn, Gus Grissom, Walter Schirra, Alan Shepard, and Donald Slayton—the "Mercury Seven." Their choice was announced on April 9, 1959, and the seven astronauts became instant heroes.

As concepts were developed into systems, systems were validated through testing, and astronauts were prepared by means of training and rehearsals, the Mercury program began to take shape. There first would be a series of suborbital flights using Redstone **rockets** (an intermediate-range rocket developed for military use) to carry the Mercury capsule and its occupant (dummy, primate, or person) on a brief up-and-down **ballistic** flight through space. Later, orbital flights would be made using the Atlas, a military booster with intercontinental range and more power. The first piloted flight was planned for March 1961 but was delayed until May because of technical problems. Those problems were to have an unexpected and unwanted consequence. On April 12, 1961, the Soviet Union launched cosmonaut Yuri Gagarin into a one-orbit flight around Earth. The Soviet Union thus added "first human in space" to its record of accomplishments and extended its lead in the space race against the United States.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

Astronaut and future senator John Glenn is outfitted in his Mercury space suit during preflight training at Cape Canaveral.

The Mercury Flights

The first piloted suborbital Mercury flight, achieved by the astronaut Alan Shepard in the Mercury capsule named Freedom 7, did not occur until May 5, 1961. In July, Gus Grissom piloted a suborbital flight, but August brought a second Soviet flight in which the cosmonaut Gherman Titov completed seventeen orbits. The space race was in high gear, and the United States seemed to be falling farther behind. Then, on February 20, 1962, an Atlas booster propelled the Friendship 7 Mercury capsule and astronaut John Glenn to a three-orbit flight. An American had finally made it to orbit.

The American launches were conducted more publicly than the Soviet missions. The preparation, launch, flight, re-entry, and landing were followed, often with fingers crossed and breath held, by millions in America and by people around the world. Although Glenn's flight was far shorter than Titov's, it clearly put the United States back into the space race. Three months later Scott Carpenter would fly another three-orbit mission. Then came two simultaneous, long-duration Soviet missions, including one of sixty-four orbits that lasted nearly 4 days. On October 3, 1962, Wally Schirra flew a six-orbit mission in the Sigma 7. Then, on May 15, 1963, Gordon Cooper and the Faith 7 were launched into space for a twenty-two orbit mission, the last flight in the Mercury program.

The Results

The Mercury flights lifted two rhesus monkeys, two chimpanzees, and six men into space. Of the six men, four were placed in Earth orbit, with the longest and last flight, Faith 7, exceeding 34 hours. The Mercury program was a tremendous success. Although the Soviets still led in the space race, the Mercury program reduced the gap. More importantly, it fired the public's imagination and gave scientists and engineers the knowledge and experience critical for Gemini, Apollo, and the first lunar landing in 1969. SEE ALSO Animals (volume 3); Apollo (volume 3); Capsules (volume 3); Career Astronauts (volume 1); Gargarin, Yuri (volume 3); Gemini (volume 3); Glenn, John (volume 3); History of Humans in Space (volume 3); Kennedy, John F. (volume 3); Primates, Non-Human (volume 3); NASA (volume 3); Shepard, Alan (volume 3); Space Suits (volume 3).

Timothy R. Webster

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Mir

The word *mir* means "peace," but to millions of Russians it is associated with a symbol of national pride. The space station Mir claimed a number of distinctions that are unmatched, even in the early twenty-first century, by the spacecraft of other nations. This station, once a national symbol of the Soviet Union, is gone, replaced by the joint effort of numerous countries to create the new International Space Station.

The History of Mir

The first component of Mir, its core module, was launched on February 20, 1986. It would take ten years for Mir's construction to be completed, a time frame that does not include the continual supply missions to the station. Mir's main component had six ports for the attachment of other modules. These ports were placed in key locations, allowing the station's configuration to be changed.

Soyuz spacecraft, similar to U.S. Apollo spacecraft, were used for transporting cargo to and from the station. Cargo included people, equipment, food, and even trash. During its life a total of forty-six missions were made by the United States and Russia to Mir, including the missions to bring more modules to the spacecraft.

The five additional modules were the Kvant-1, Kvant-2, Kristall, Spektr, and Priroda. Kvant-1 contained astrophysics research equipment. Measuring 5.7 meters (19 feet) long and 4.3 meters (14 feet) wide, it studied **neutron stars**, **quasars** radar, X-ray emissions, and active galaxies. Kvant-2 was a multipurpose module that housed the air lock as well as scientific equipment. It enabled biotechnology research, as well as photography. Kvant-2 was over 12.2 meters (40 feet long) and 4.3 meters (14 feet) wide. Kristall housed a zero-g greenhouse and produced high-technology equipment, including **semiconductors**, in the **microgravity** environment, and processed biological material. Spektr, which was delivered in June 1995, was used for surface studies of Earth and atmospheric research. The last module, Priroda, was launched in spring, 1996, and employed **radar** systems, **spectrometers** for ozone research, and **infrared** detectors.

By the end of construction, Mir weighed 135 tons, offered 283 cubic meters (9,900 cubic feet) of space, and measured 1.8 meters (6 feet) by 26 meters (85 feet). This meant that with the exception of the Moon, Mir was the heaviest object in Earth's orbit. Over its lifetime, its maintenance cost continued to sky-rocket, and Mir ultimately cost $4.2 billion to construct and maintain. The station was not designed or constructed to last for the 15 years it spent orbiting Earth. It far surpassed the records set by Skylab or the space shuttles for time in space.✶

Problems Plague Mir

With the fall of the Soviet Union in 1991, Mir became more expensive than the former superpower could afford. Over the next 10 years Mir deteriorated with age and become more difficult to fix. It suffered from problems with its insulation and glitches during docking and undocking procedures with Soyuz supply craft.

neutron star the dense core of matter composed almost entirely of neutrons that remains after a supernova explosion has ended the life of a massive star

quasars luminous objects that appear starlike but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

semiconductors a group of elements with properties intermediate between the metals and nonmetals

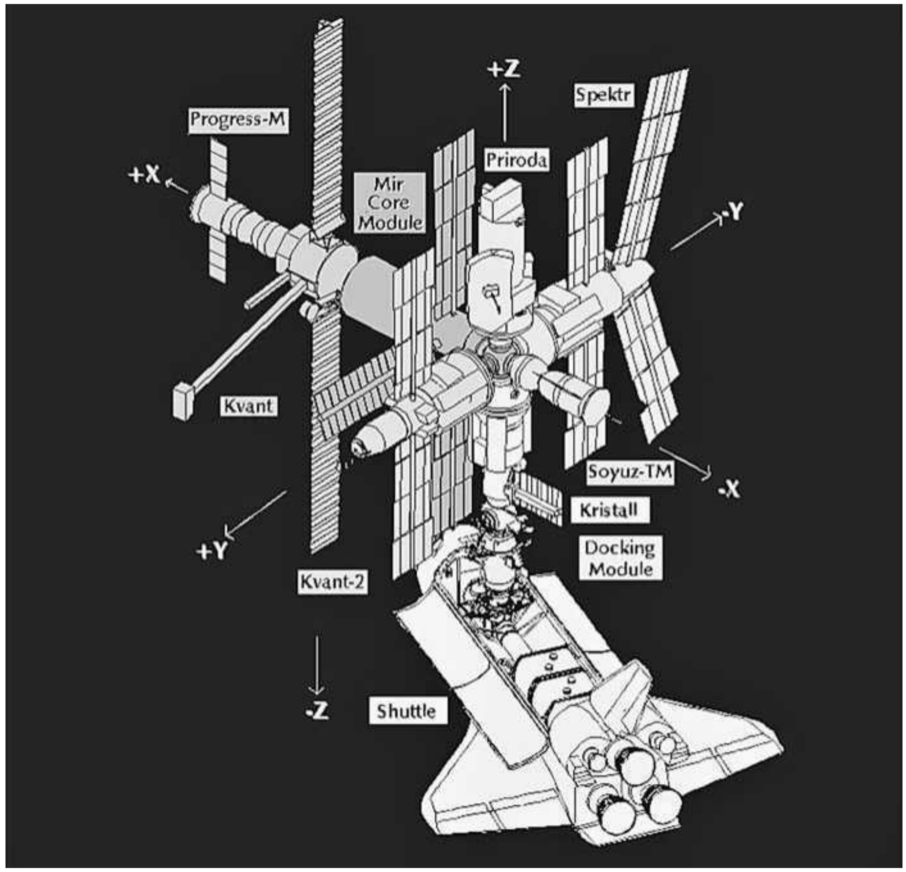
microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

spectrometer an instrument with a scale for measuring the wavelength of light

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

✶**Mir housed cosmonaut Valery Polyakov, who has the distinction of living in space for the longest period of time in the twentieth century: 438 days.**



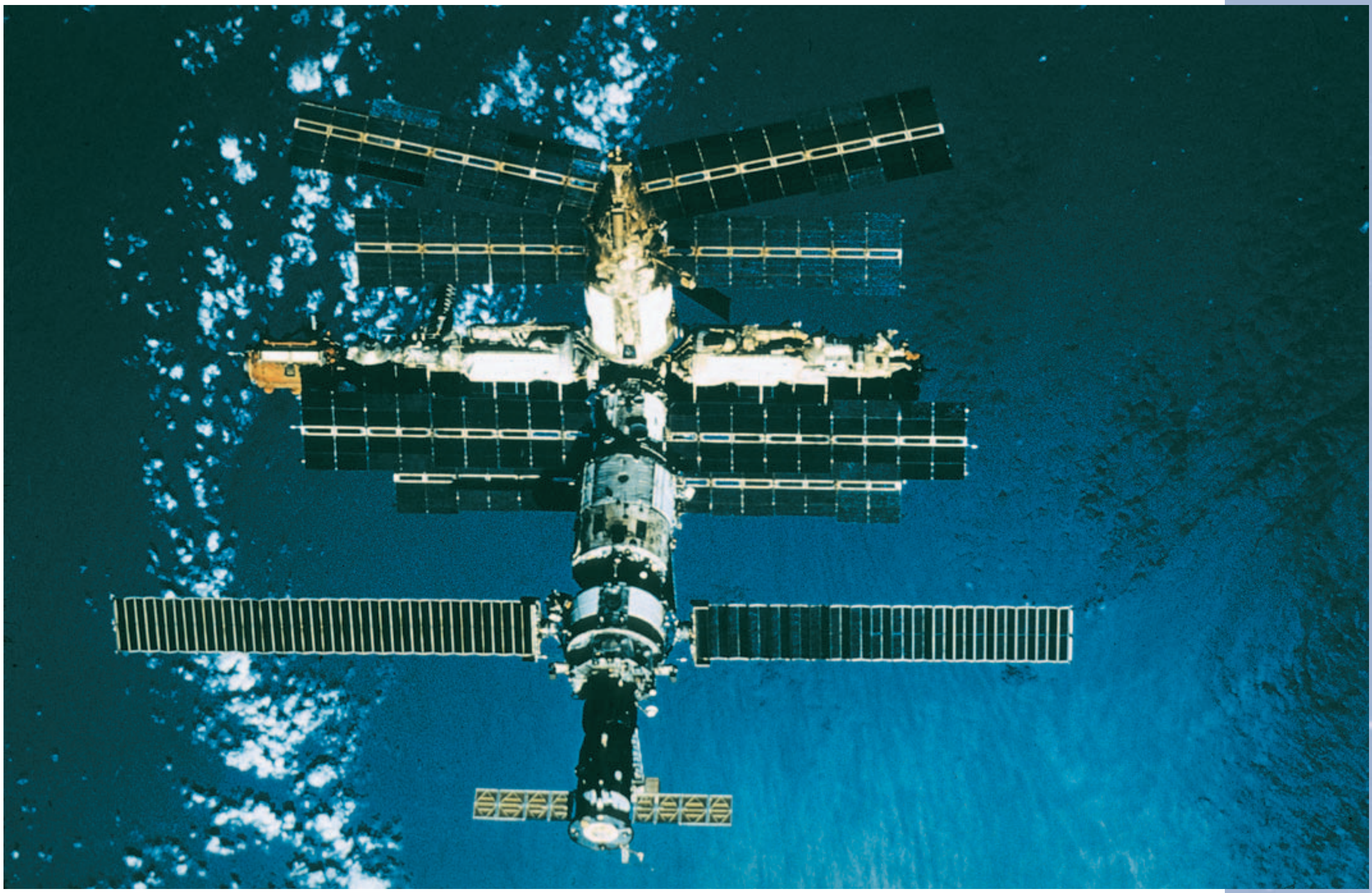
Illustrated view of the Russian space station Mir, with space shuttle, Progress, and Soyuz vehicles attached.

On January 14, 1994, cosmonauts ignored weight limitations on the Soyuz craft and caused a collision with the station. On February 23, 1997, a fire ignited onboard. Luckily, no one was harmed and the fire was extinguished. Less than six months later, on June 25, 1997, Soyuz craft again collided with the station. This time the craft punctured Mir's skin, and air began to escape. Luckily, both cosmonauts and the American astronaut onboard were quick enough to take corrective action, sealing off the breached segment so that there was enough oxygen left for their survival.

As the cost of keeping Mir operable and the risk factor to the astronauts continued to increase, it became apparent that Mir's days were numbered. Attempts were made by both nonprofit and for-profit groups to save the station. As the International Space Station (ISS) began to require the funding on which Mir was dependent, offers came in from different groups to try to save the station. One group of entrepreneurs tried to turn Mir into a destination for wealthy tourists. Wealthy financial analyst Dennis Tito, founder of the investment firm Wilshire Associates, had agreed to pay a rumored $20 million for the experience, but the deal fell through and Russia kept postponing what seemed to be inevitable.✶

✶**In May, 2001, Dennis Tito became Earth's first space tourist, spending ten days on the International Space Station.**

Mir was damaged, aged, and outdated, but it was not worthless. However, Russia ultimately decided to end the 15-year saga of the Mir space station. By that time Mir's orbit was degrading by almost a mile a day.



Russia's Mir space complex as seen from the U.S. space shuttle Atlantis prior to docking.

The End of Mir

On March 23, 2001, the story of Mir came to an end. After much planning, the Russian space agency decided to send Mir through Earth's atmosphere, breaking it apart into small pieces before its final splashdown in the South Pacific. The area had been used previously to destroy more than eighty other Russian craft.

Everything went according to plan, and Mir broke up into several large pieces and thousands of small ones. The larger pieces made a splashdown in the ocean, with no injuries resulting from the debris. SEE ALSO Government Space Programs (volume 2); International Space Station (volume 1 and 3); Long-Duration Spaceflight (volume 3); Space Stations, History of (volume 3); Space Stations of the Future (volume 4).

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Mission Control

Mission Control is crucial to the success of any space mission. This command center, located in Houston, Texas, helps astronauts complete their missions. Mission control was created in the 1960s to perform nearly all functions for the **Mercury**, **Gemini**, and **Apollo** missions. As time went on, Mission Control began to have less control as spacecraft became more complex and allowed astronauts to have better control.

Mercury the first American piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

Today Mission Control is responsible for being the "eyes and ears" for astronauts on Earth. Mission controllers use a variety of computers to monitor everything from weather conditions on Earth to spacecraft communications. Mission Control is filled with computers with abbreviated titles written on top of them. Each computer monitors a different aspect of the mission. The room that houses Mission Control, however, is only the command center. For each person sitting at a console, there are many engineers and National Aeronautics and Space Administration (NASA) employees working in other areas to provide accurate up-to-the-minute information for Mission Control.

The 15 to 20 people who work in Mission Control follow a chain of command. The flight director has the final authority to make life-or-death decisions. Called "Flight," he or she is in command of everyone else.

"Capcom" is the name given to the individual who communicates directly with the astronauts. That name refers back to the time when the Mercury **capsules** were in use (capsule communicator).

The flight dynamics officer (FIDO) is in charge of ascents, deorbits, and space shuttle performance, and the guidance officer makes sure that the navigation software functions properly. The guidance officer only watches navigation software; the data processing systems engineer is in charge of the five computers on the shuttle.

Engineers for propulsion and boosters watch to make sure that all engines are firing properly from the moment liftoff occurs, while the shuttle is in space, and until the touchdown. Every area has its own controller, from the payload officer who monitors the shuttle's **payload**, to the payload deployment officer who watches over the shuttle's robotic arm, to the EVA engineer who monitors the **extravehicular activity** suits.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

extravehicular activity a space walk conducted outside a spacecraft cabin, with the crew member protected from the environment by a pressurized space suit

The health and safety of the astronauts are a paramount concern for NASA, requiring a flight surgeon who watches the vital signs of all astronauts and provides medical advice if necessary. The emergency environmental and consumables (EECOM) systems engineer watches over the temperature and pressure inside the spacecraft. The electrical generation and integrated lighting systems engineer ensures that there is sufficient electricity for the astronauts to complete their mission.

The mission controller most often seen by the media is the public affairs officer. This job entails not only explaining mission details to the media and the general public but also providing a commentary to outsiders who are not trained by NASA.

The International Space Station (ISS) has its own control room, separate from the space shuttle's mission control. Although it is smaller than its counterpart, most data on either the shuttle or the ISS can be displayed in

Flight controllers at NASA's Kennedy Space Center monitor the countdown of shuttle flight STS-102 Discovery. Any pre-launch irregularities noted during a countdown can cause a launch to be aborted.

either facility. SEE ALSO Capcom (volume 3); Communications for Human Spaceflight (volume 3); Computers, Use of (volume 3); Flight Control (volume 3); Launch Management (volume 3); Launch Sites (volume 3); Navigation (volume 3); Space Centers (volume 3); Tracking of Spacecraft (volume 3); Tracking Stations (volume 3).

Craig Samuels

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Mission Specialists

"Mission specialist" is one of two categories of astronauts in the U.S. space program. Mission specialist astronauts team up with astronaut pilots to form a space shuttle or station crew, and together they operate the spacecraft and carry out the mission's flight plan.

Job Description

The National Aeronautics and Space Administration (NASA) created the term "mission specialist" in 1978 when it hired the first group of space shuttle

Mission specialist Edward T. Lu is photographed here on September 11, 2000, during his six-hour space walk outside the International Space Station.

astronauts. The agency recognized that in addition to the two pilot astronauts in the front seats of the space shuttle (the commander and the pilot), the spacecraft would require additional crew members to conduct orbital operations. One mission specialist would aid the pilots as the flight engineer. Other mission specialists would operate the shuttle's Canadian-built robot arm and leave the shuttle cabin in protective space suits to carry out extravehicular activity (EVA), commonly known as space walks. They would also have the primary responsibility for operating scientific experiments aboard the shuttle, either in the cabin or in a bus-size laboratory called Spacelab carried in the shuttle's cargo bay.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

remote sensing the act of observing from orbit what may be seen or sensed below Earth

Because of these specialized responsibilities, NASA dropped the requirement that mission specialist candidates be aviators or test pilots. Instead, the administration sought persons with a strong scientific, engineering, or medical background. Successful candidates have at least a master's degree in the sciences or engineering, and many of them have earned a doctorate or medical degree. While undergoing their first year of training, all mission specialists become qualified air crew members in NASA's fleet of T-38 jet trainers. Once assigned to a flight, mission specialists receive the detailed training necessary to accomplish the mission's objectives: **space station** construction, **microgravity** research, satellite repair, robot arm or EVA operations, **remote sensing** of Earth or the universe, and other types of scientific experimentation.

Experienced mission specialists can expect to fly on the space shuttle every two to four years. Between flight assignments they support other shuttle or station crews in training and in orbit and participate in the assembly or testing of spaceflight hardware. On flights with complex scientific **payloads** a mission specialist may serve as the payload commander, advising the shuttle commander on the health and status of the experiment and overseeing its operations. Mission specialists are also eligible for a long-duration expedition (four to five months in length) aboard the International Space Station (ISS), where they can serve as flight engineers or commanders.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Required Skills

The most demanding skills required of mission specialists are those involved in robot arm operations or in conducting an EVA. To perform either task a mission specialist may train for hundreds of hours, using simulators that recreate the spaceflight environment. Arm operators learn to "fly" the arm on computer displays and then on a full-scale high-fidelity arm simulator. EVA astronauts train for weightlessness in a huge swimming pool that makes their space suits neutrally buoyant, giving them an accurate feel for the movements needed to work in **freefall**. Another important skill for mission specialists is teamwork; crewmembers must work closely together on critical tasks to minimize mistakes and ensure accuracy. With the wide range of skills required for future expeditions to the Moon, asteroids, or Mars, mission specialists will be an important part of the future astronaut corps. SEE ALSO ASTRONAUTS, TYPES OF (VOLUME 3); CAREER ASTRONAUTS (VOLUME 1); PAYLOAD SPECIALISTS (VOLUME 3); PAYLOADS (VOLUME 3); SPACE SHUTTLE (VOLUME 3); SPACE WALKS (VOLUME 3); T-38 TRAINERS (VOLUME 3); WOMEN IN SPACE (VOLUME 3).

freefall the motion of a body acted on by no forces other than gravity, usually in orbit around Earth or another celestial body

Thomas D. Jones

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Modules

A module is a self-contained unit of a launch vehicle that serves as a building block for the overall structure. It is commonly referred to by its primary function—for example the "command module" used in the Apollo lunar missions. More recently, the term has been used to describe a distinct pressurized, crewed section of an orbiting spacecraft, suitable for conducting science, applications, and technology activities. An example of this would be the Spacelab module in the Space Transportation System.

Early Use of Modules

Modular construction was used in many early piloted spacecraft to minimize the size and weight of the re-entry vehicle and to ease assembly of the

The Apollo 11 Lunar Module is seen in landing configuration as viewed from lunar orbit, July 20, 1969.

spacecraft. Modules can be constructed and tested independently of other sections and then integrated into the rest of the spacecraft at a later stage. Completion of the International Space Station (ISS) depends on this technique of modular construction, as no single rocket could lift the entire station into orbit.

The first human in space was also the first to ride aboard a modular spacecraft. Yuri Gagarin's Vostok 1 was composed of two modules, the spherical descent module and the cone-shaped service module. The service module contained various consumables for life support (such as food, water, and oxygen), the attitude control system, batteries, telemetry systems, and a retrorocket at its base. The 5,100 kilogram (11,243 pound) service module was **jettisoned** before the 5,300 kg (11,684 pound) descent module returned to Earth.

jettisoned ejected, thrown overboard, or gotten rid of

Later Spacecraft

The Soviets modified the Vostok spacecraft for use in their Voskhod and Soyuz programs. Voskhod craft retained the two-module organization. The more advanced Soyuz spacecraft added an orbital module where the cosmonauts ate and slept, but it and the instrument module (which contained the thrusters and power supply) were jettisoned before the descent vehicle returned.

For the Gemini program, NASA modified its Mercury capsule to hold two astronauts and added an adapter module to its base. The adapter module's increased capacity to carry oxygen and other supplies permitted astronauts to stay in orbit for up to two weeks. (Mercury astronauts could only stay aloft for a day at most.) The adapter module also had an attitude control system that gave the astronauts full control over their spacecraft, allowing them to practice docking techniques for Apollo missions.

Apollo spacecraft comprised three modules, one of which was a separate spacecraft. The command module (CM) served as the crew's quarters and flight control section. The Service Module (SM), which held the rocket motors and supplies, remained attached to the CM until re-entry. Together, they were called the Command-and-Service Module, or CSM. The Lunar Module, or LM, transported two crew members to the lunar surface and back to the waiting CSM.

The International Space Station

The International Space Station requires far more specialized modular construction than any previous spacecraft. Approximately forty-three rocket and space shuttle launches will be necessary to ferry the components into orbit. Sections will include a habitation module, a docking module, laboratory modules, four modules containing the eight solar power arrays, and the Multipurpose Logistics Module, a reusable section that will deliver and return any cargo requiring a pressurized environment via the space shuttle. SEE ALSO CAPSULES (VOLUME 3); INTERNATIONAL SPACE STATION (VOLUMES 1 AND 3); MERCURY PROGRAM (VOLUME 3).

Chad Boutin

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Monkeys *See Primates, Non-Human (Volume 3).*

NASA

The National Aeronautics and Space Act of 1958 created the National Aeronautics and Space Administration (NASA) to "provide for research into problems of flight within and outside the Earth's atmosphere, and for other purposes." At the time of NASA's creation, it was not possible to predict what the organization would later accomplish. Although not without its critics, NASA has been one of the most respected organizations in the world for more than forty years. The impetus for the Space Act was the Cold War. The act was passed by Congress one year after the Soviet Union launched the first satellite, Sputnik, into space. From these beginnings, NASA has continued to educate and amaze the public with a nearly continuous stream of "out of this world" achievements.

NASA's accomplishments in its more than forty years of existence are led by the **Apollo** missions that landed humans on the Moon, the exploration

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

On July 24, 1969, flight controllers at NASA's Mission Control Center in Houston waved flags and cheered in celebration of the splashdown and success of the Apollo 11 lunar landing mission.

remote sensing the act of observing from orbit what may be seen or sensed below Earth

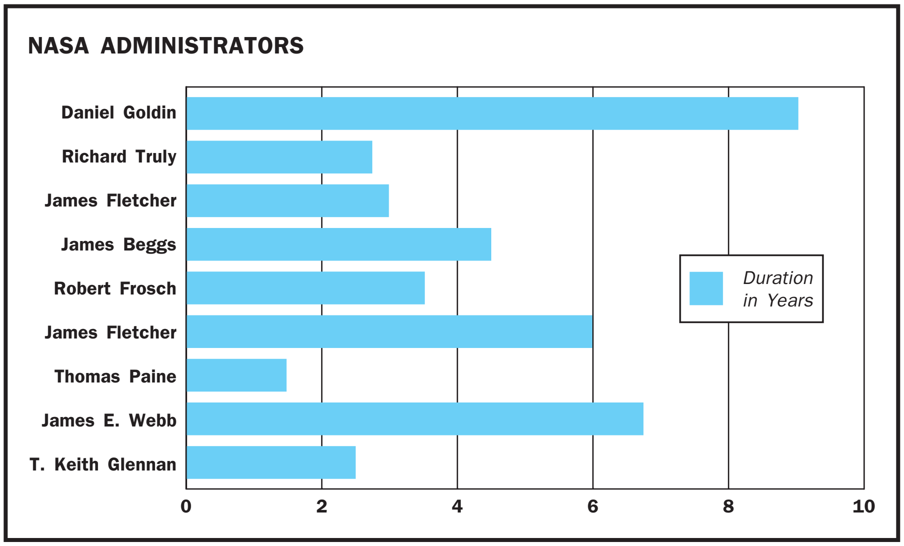
of all but one of the planets in the solar system, the development of **remote sensing** and communications satellites, and dramatic advances in aeronautical research. NASA technology has been adapted for many non-aerospace uses by the private sector, and NASA remains a leading force in scientific research. Perhaps most importantly, NASA has served as a beacon for public understanding of science and technology as well as aerospace innovation.

Current Missions

NASA is undertaking ambitious programs such as the International Space Station to provide a permanently inhabited outpost for humankind. NASA's space science program is planning to send an armada of spacecraft to Mars to prepare for future human missions to that planet. The space agency is a "solution" organization, solving problems as mandated by the Space Act and the nation's leadership.

The National Aeronautics and Space Act declares that "it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind." NASA is organized into five Enterprises and four Crosscutting Processes that are responsible for carrying out the nine objectives of the Space Act:

1. The expansion of human knowledge of phenomena in the atmosphere and space;
2. The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles;
3. The development and operation of vehicles capable of carrying instruments, equipment, supplies and living organisms through space;
4. The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;
5. The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;
6. The making available to agencies directly concerned with national defenses of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of information as to discoveries which have value or significance to that agency;
7. Cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results thereof;



★ **In 2002 NASA appointed Sean O'Keefe as the agency's tenth administrator.**

8. The most effective utilization of the scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort; and

9. The preservation of the United States' preeminent position in aeronautics and space through research and technology development related to associated manufacturing process.

The Agency, the Plan, and the Personnel

NASA's twenty-five-year goals and objectives are codified in the NASA Strategic Plan, most recently published in September 2000. The agency's current organizational structure is outlined in its Strategic Management Handbook. Both are available on NASA's web site: www.nasa.gov.

The space agency has been led by a total of ten administrators (nine individuals, one of whom served two separate terms) since its inception. These individuals have had the opportunity to carry out the mandate of the Space Act while being responsive to the political will of the nation, the true owners of the government's civil space activities.

Public interest in NASA's success has fluctuated. Many people assume that the decade of the 1960s were the agency's high-water mark not only for large budgets but also for public support. While this is true in the budgetary sense (see NASA Briefing chart), public opinion polls show a greater level of support twenty-five years after the Moon landings than existed at that time.

The space agency was born in the Cold War environment. Increased spending on NASA throughout the early 1960s was rationalized as an investment in beating the Russians in the space race. Thus, when the Cold War ended in the early 1990s, NASA required a new rationale for its exploration programs. The agency found that rationale partly through cooperation with the former Soviet Union. NASA seized the opportunity to partner with the Russians, and as a result cosmonauts and astronauts are living and working permanently on the International Space Station today.

NASA BRIEFING

Mission
- To understand and protect our home planet
- To explore the Universe and search for life
- To inspire the next generation of explorers as only NASA can

Budget
- 2001 Budget: $14.2 billion*
- 1985 Budget: $11 billion*
- 1967 Budget: $21 billion*

Staff
- 2001 Staff: 18,000
- 1985 Staff: 21,000
- 1967 Staff: 36,000

*2001 dollars

In 1997 a poll revealed that joint missions involving Americans and Russians was the space program most favored by adult Americans. The public has continued to support government spending for the civilian space program. The America's Space Poll shows consistently favorable support for NASA and space activities. No federal agency has higher favorable impression ratings among the public.

This public support has led to essentially stable budgets for NASA for over two decades. Early fluctuations in the budget reflected the Cold War–fueled Apollo program and its aftermath. Since a post-Apollo low in 1975, NASA funding has climbed from $10 billion to $15 billion.

NASA has succeeded in carrying out the bold objectives of the National Aeronautics and Space Act beyond expectations. When the national leadership has set a goal and articulated a rationale, NASA has produced results. From Apollo to voyages to the outer planets and beyond the solar system, NASA has given the public the Moon and the stars. SEE ALSO Apollo (volume 3); Apollo-Soyuz (volume 3); Challenger (volume 3); Gemini (volume 3); History of Humans in Space (volume 3); Humans versus Robots (volume 3); International Space Station (volumes 1 and 3); Mercury Program (volume 3); Skylab (volume 3); Space Centers (volume 3); Space Shuttle (volume 3).

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America's Space Poll™. Space Foundation, April 2000. <http://www.spaceconnection.org/poll/>.

Navigation

In order for a spacecraft to close in on a destination such as the International Space Station or to enable the space shuttle to retrieve the Hubble Space Telescope, scientists must do most of the groundwork prior to the launch phase. Scientists need to know the workings of the solar system well enough to predict a spacecraft's destination, when to launch, and how fast it must travel to meet the target in space.

Gravity also must be taken into account. Gravity exerted by large bodies like planets and the Sun will alter the trajectory of a spacecraft. Diffi-

Three 34-meter (110 foot) wide antennae in California's Mohave Desert help provide radio communications for NASA's interplanetary spacecraft, radio astronomy, and radar observations of the solar system.

culties arise when a spacecraft is allowed to deviate too far off the intended course. If the error is realized late in the flight, the target may have moved a long distance from where the ship was originally supposed to meet it. The mistake often cannot be remedied because spacecraft do not carry enough fuel to make large course corrections. The launch vehicle pushes the spacecraft onto a heading that pushes it in the direction of a final destination. Sometimes mission planners use the gravity of a planet by swinging by that object to change the path of a spacecraft.

Spacecraft Position

Spacecraft navigation is comprised of two aspects: knowledge and prediction of spacecraft position and velocity; and firing the rocket motors to alter the spacecraft's velocity.

To determine a spacecraft's position in space, NASA generally uses a downlink, or radio signal from the spacecraft to a radio dish in the Deep Space Network (DSN) of ground receivers. The distance between Earth and the spacecraft is measured by sending a radio signal up from Earth with a time code on it. The spacecraft then sends back the signal. Because all radio waves travel at the speed of light, scientists can determine how long it took for the signal to travel and calculate the exact distance it traveled.

A more precise way of measuring distance uses two radio telescopes. Spacecraft send a signal back to Earth. Three times a day, this signal can be received by two different DSN radio telescopes at once. Researchers are able to compare how far the spacecraft is from each signal. Mission trackers can then calculate the distance to a known object in space whose location never changes, like a pulsar (pulsing star). From the three locations (two telescopes and a pulsar), scientists can use a technique called triangulation to get the ship's location.

By using a different process called Optical Navigation, some spacecraft can use imaging instruments to take pictures of a target planet or other body against a known background of stars. These pictures provide precise data needed for correcting any discrepancy in a spacecraft's path as it approaches its destination.

The exact location of the spacecraft must be determined before any course correction is made. The spacecraft will first fire small rockets to change the direction it is pointing. After that, the main thruster will give the spacecraft a push in the new direction.

During rendezvous and proximity operations, taking the space shuttle as an example, the onboard navigation system maintains the state vectors of both the orbiter and target vehicle. During close operations where separation is less than 15 miles, these two state vectors must be very accurate in order to maintain an accurate relative state vector. Rendezvous **radar** measurements are used for a separation of about 15 miles to 100 feet to provide the necessary relative state vector accuracy. When two vehicles are separated by less than 100 feet, the flight crew relies primarily on visual monitoring through overhead windows and closed-circuit television. SEE ALSO Gyroscopes (volume 3); Mission Control (volume 3); Navigation from Space (volume 1); Tracking of Spacecraft (volume 3).

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Lisa Klink

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Oxygen Atmosphere in Spacecraft

O

Astronauts sealed in a spacecraft or **space station** need a continuous supply of oxygen. When they inhale, the oxygen in the air is absorbed by the blood and used by the body. When they exhale, nitrogen, water vapor, and carbon dioxide (CO_2) are expelled. During a flight, oxygen must be added to the air, while water vapor, CO_2, and other impurities must be removed.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

Earth's atmosphere at sea level consists of 21 percent oxygen, 78 percent nitrogen, and 1 percent CO_2, water vapor, argon, methane, and traces of other gases, at a pressure of 14.7 pounds per square inch (psi). Pure oxygen is highly corrosive and reacts with most substances, sometimes violently, as in a fire or an explosion. Nitrogen in Earth's atmosphere dilutes the oxygen so that such violent reactions do not usually occur spontaneously.

In January 1967 three astronauts died while testing and practicing procedures on the launch pad in the Apollo 1 capsule, which had been supplied with a pure oxygen atmosphere at 16 psi pressure. A fire started, spread extremely rapidly, burned out in less than a minute, and the astronauts did not have time to escape. Later Apollo flights used a mixture of 60 percent oxygen and 40 percent nitrogen at 16 psi on the launch pad, then switched to pure oxygen at only 5 psi in space. This proved to be much safer.

The Skylab space station also had a pure oxygen atmosphere at 5 psi. Russian Salyut and Mir space stations all maintained atmospheres similar in

Astronauts float in the oxygenated, weightless environment of Spacehab. To maintain a breathable environment in space, oxygen must be added to the air, while impurities must be removed.

composition and pressure to Earth's atmosphere, as do the space shuttle and the International Space Station.

On Earth, gravity keeps the air moving continuously as warm air rises and cool air sinks. In a weightless spaceship blowers must force the cabin air to circulate. As it is drawn through the ducts of the circulation system the air is cleansed of impurities. A bed of charcoal removes noxious gases and odors. Filters with very small holes trap floating particles down to the size of bacteria. Moisture condenses onto cold plates similar to refrigerator coils, and the water is collected in a tank.

Excessive CO_2 can be deadly and must be removed. The simplest way is to blow the air through a canister of lithium hydroxide, which absorbs CO_2. However, the canisters must be replaced when they become saturated with CO_2. This is not practical for long voyages because many heavy canisters would have to be carried along. The International Space Station uses better absorbing materials that can be recycled while in orbit. To drive out the CO_2 some of these materials are heated while others are just exposed to the **vacuum** of space.

vacuum an environment where air and all other molecules and atoms of matter have been removed

The space shuttle carries tanks of liquid oxygen to replenish the air. For the Mir space station, Russia developed an electrolysis system called Elektron, which split the water molecules (H_2O) into hydrogen and oxygen. The oxygen was used in the cabin and the hydrogen was vented outside to space. This type of system will be used throughout the International Space Station. In this case, Elektron's water supply will come from the space shuttle and from recycling moisture in the air, urine, and wash water. In the future, the CO_2 removed from the air could be chemically combined with the hydrogen from Elektron to produce methane and water. The methane would be vented overboard and the water would be reused in Elektron to produce more oxygen—an exceptional recycling system.

As a backup, lithium perchlorate generators can be used to produce oxygen when they are ignited. They must be used with care. In February 1997 one of them burned out of control for fourteen minutes on Mir with a blowtorch-like flame at about 480°C (900°F). Mir was damaged, but no one was injured. SEE ALSO APOLLO (VOLUME 3); CLOSED ECOSYSTEMS (VOLUME 3); EMERGENCIES (VOLUME 3); LIVING IN SPACE (VOLUME 3).

Thomas Damon

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Payload Specialists

P

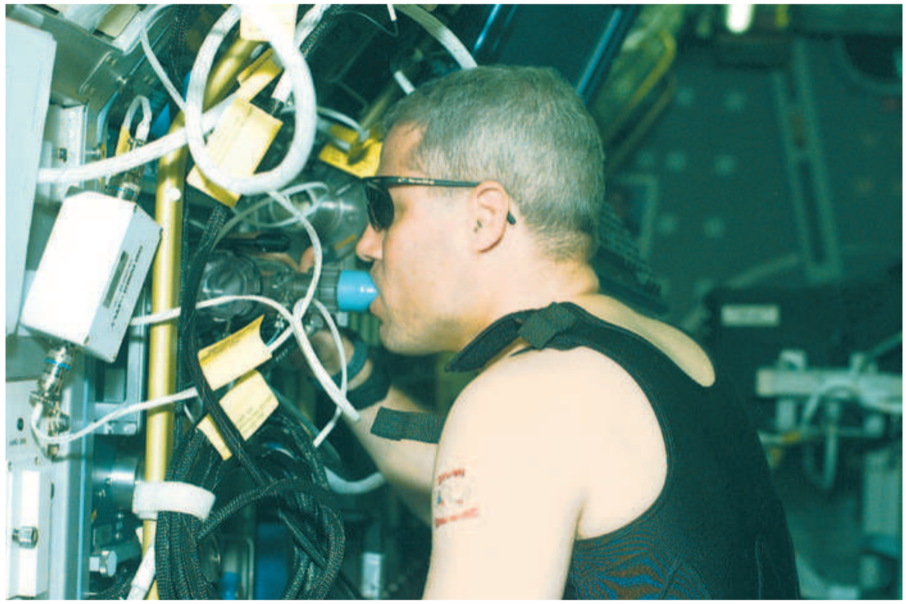
Payload specialists are persons who have been designated by the National Aeronautics and Space Administration (NASA) or its commercial or international partners to serve as crewmembers in association with a specific **payload** and/or to accomplish a specific mission objective. Payload specialists include persons other than NASA astronauts who have specialized onboard duties; they may be added to the crew manifest if there are unique requirements or activities and more than the minimum crew size is needed. Individuals selected for crew assignment under the Space Flight Participant Program or similar programs also are referred to as payload specialists.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The payload specialist category represents an evolution in astronaut specialization. The first astronauts were required to have jet aircraft flight experience and engineering training. They conducted all operational and scientific activities aboard the spacecraft. Later, the emphasis shifted away from flight experience and toward superior academic qualifications. Some astronaut applicants were invited on the basis of their educational background alone. These were scientist astronaut candidates, so called because applicants were required to have a doctorate or equivalent experience in the natural sciences, medicine, or engineering.

During the era of the space shuttle, astronauts were further classified as space shuttle commanders and pilots responsible for controlling and operating the vehicle; mission specialists, who work with the commander and the pilot and are responsible for coordinating selective shuttle operations; and payload specialists with specialized onboard duties. Today the crew of each launched spacecraft is composed of astronauts or cosmonauts drawn from these categories.

Crew assignments for commander, pilot, and one or more mission specialists are drawn from among the cadre of NASA astronauts, whereas payload specialists are taken from among the selected and trained personnel designated by NASA or the commercial or international partner involved in the specific spaceflight mission. When payload specialists are required, they are nominated by NASA, the foreign sponsor, or the designated payload sponsor. In the latter two cases, these individuals may be cosmonauts or astronauts designated by other nations, individuals selected by a company or consortium flying a commercial payload aboard the spacecraft, or persons selected through some other formal selection process. In the case of



Payload specialist Jay C. Buckey, Jr. performs a lung function test during a sleep/respiratory study in the Neurolab of the space shuttle Columbia.

NASA or NASA-related payloads, the nominations are based on the recommendations of the appropriate Investigator Working Group.

Although payload specialists are not strictly part of NASA's astronaut candidate program, they must have the appropriate education and training for the payload or experiment. Payload specialists have had a wide range of backgrounds, ranging from scientists and researchers to technicians and even a U.S. senator and congressional representative. Nevertheless, all payload specialist applicants must meet certain physical requirements and must pass NASA space physical examinations with varying standards that depend on classification. SEE ALSO Astronauts, Types of (volume 3); Career Astronauts (volume 1); Mission Specialists (volume 3); Payloads (volume 3); Payloads and Payload Processing (volume 1).

John F. Kross

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Payloads

Ninety-nine percent of the mass of a rocket poised on the pad for launch is accounted for by the rocket itself. This mass consists mostly of propellant, but it also includes tanks, valves, communications and navigation instrumentation, stage separation mechanisms, and a **fairing**. The remaining 1 percent consists of the rocket's payload. Protected by the fairing from the supersonic airflow of rapid ascent, the payload reaches orbit altitude and **velocity** within one or two minutes of the launch initiation.

fairing a structure designed to provide low aerodynamic drag for an aircraft or spacecraft in flight

velocity speed and direction of a moving object; a vector quantity

Many spacecraft are equipped to modify the orbit that the rocket carries them to. They might have propulsion onboard to raise their orbit or to trim it, or to escape Earth orbit altogether and head out to the planets or beyond the solar system. This onboard propulsion system—chemical, electric or even solar sail—is part of the launch vehicle payload, but in the design of the propulsion system, the rest of the spacecraft is its payload.

A spacecraft itself is an integrated suite of parts. The components that provide necessary services in orbit are known collectively as the spacecraft bus. They include the telemetry system (radios); the structure, including attachment to the launch vehicle; solar panels and batteries; enough computing power to accomplish onboard "housekeeping" tasks; the guidance system needed to navigate in space and control the spacecraft's attitude, and sometimes services such as data storage. The spacecraft bus is intended to provide all the services and resources that the science instruments, communications equipment, imaging or other **remote sensing** system, and any other onboard devices specific to the mission, require. These instruments are referred to by the spacecraft bus developer as the payload.

remote sensing the act of observing from orbit what may be seen or sensed below Earth

Humans as Payloads

The first spacecraft carried computers, cameras, and sometimes animals as their payloads. Gradually, humans began to take over many observation, experimentation, and control functions aboard spacecraft. Human payloads are also known as astronauts. The human payload imposes many special requirements on a spacecraft's design. Whereas all spacecraft must be highly reliable because they are out of human reach for servicing, the additional burden of ensuring flight safety for the crew is particularly demanding in regard to the design. A typical astronaut weighs 75 kilograms (165 pounds) or more, a mass exceeded by support material for the astronaut, including a breathable atmosphere, food, water, waste disposal, seating and viewing accommodations, an exercise facility, instrumentation, medications and first aid, and clothing and other personal items. On brief missions, such as the space shuttle, each human payload accounts for 300 kilograms (660 pounds) of additional mass to be carried into orbit.

Although the human ingenuity and dexterity of an astronaut are not yet replicable by machines, the majority of space payloads are electronic and electro-optical. Synthetic optics with very high resolving and light-gathering power perform imaging of Earth and astronomical objects across a broad range of **wavelengths**. Microwave, **infrared**, visible, **ultraviolet**, **X-ray**, and gamma ray sensors are flown routinely on small and large spacecraft. Many satellites are communications relay stations, and the payload consists mainly of high-powered transponders. The transponders receive signals from ground stations, for instance, digital television transmissions, and rebroadcast them to large areas where they can be received by consumers directly. Alternatively, the downlinks are carried through a smaller number of large dish antennas and distributed terrestrially. Some telephone and computer data are also relayed via satellite. The Global Positioning System (GPS) carries highly accurate rubidium clocks into orbit. These clocks are synchronized with a number of atomic standards on Earth to provide the highly precise time reference needed to locate objects precisely on or near Earth's surface.

wavelength the distance from crest to crest on a wave at an instant in time

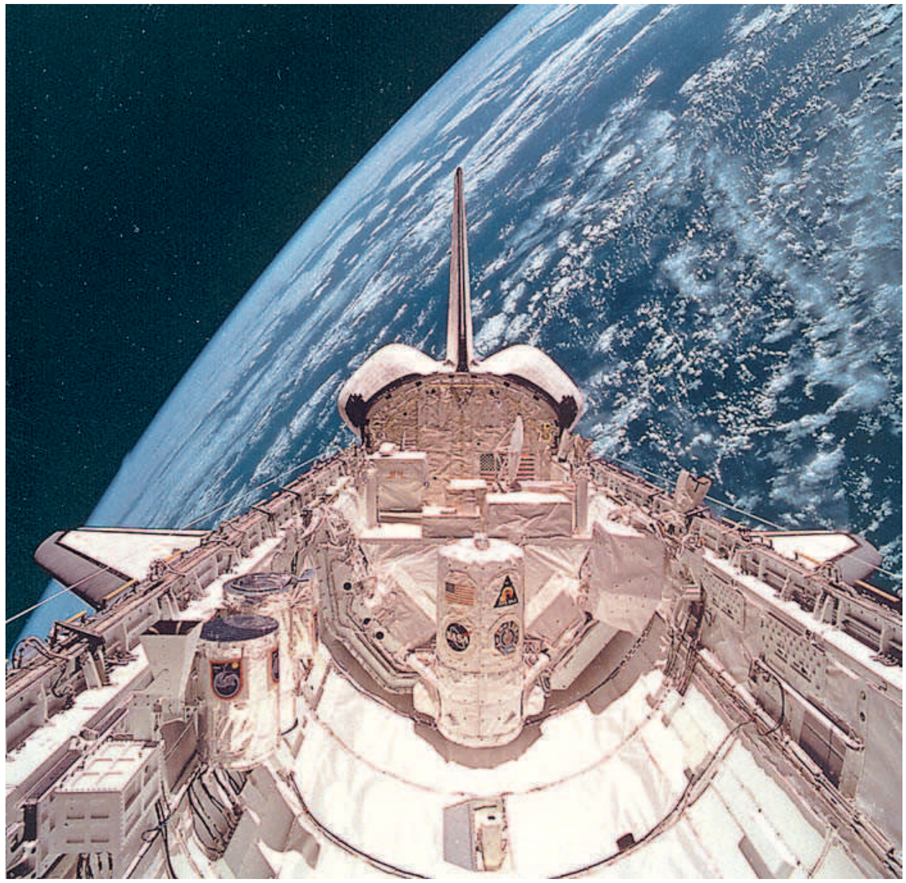
infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

X ray form of high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

The Use of Robotics and Small Satellites

In addition to human, electro-optical, radio, and precise timing payloads, some satellites now carry robotic payloads. The best known of these payloads are



The cargo payload bay of the space shuttle Atlantis is open to space.

rovers vehicles used to move about on a surface

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

the small **rovers** that were released by a spacecraft that landed on Mars. As the science of robotics advances, the search for resources and signs of life on distant planets and moons will be carried out increasingly by rovers and other robots. Unlike a human, a robot does not need to return to Earth. Launching enough mass to the surface of another planet to support human crew members and then launching back off the surface to return to Earth requires launch vehicles larger than any that exist in the early-twenty-first century. However, a one-way trip for even a small swarm of rovers is within current capabilities, and a planetary exploration mission can be carried out more economically by a rover than can a weeklong human sojourn in **low Earth orbit**. Robots can withstand greater environmental extremes than humans and can "sense" the atmosphere around them.

Some satellite payloads are themselves very small satellites. These tiny spacecraft can be used to look back at the host spacecraft. Visible and infrared imagery, plus other radio diagnostics onboard the subsatellite, can be used to watch the major spacecraft in its deployment from the rocket and operation to help diagnose problems and restore operations. The space shuttle has demonstrated a small robotic spacecraft that is a precursor to the inspection craft that will be used in place of astronaut extravehicular activity (EVA) to monitor the condition of the exterior of the space station. SEE ALSO Crystal Growth (volume 3); Getaway Specials (volume 3); Payload Specialists (volume 3); Space Shuttle (volume 3).

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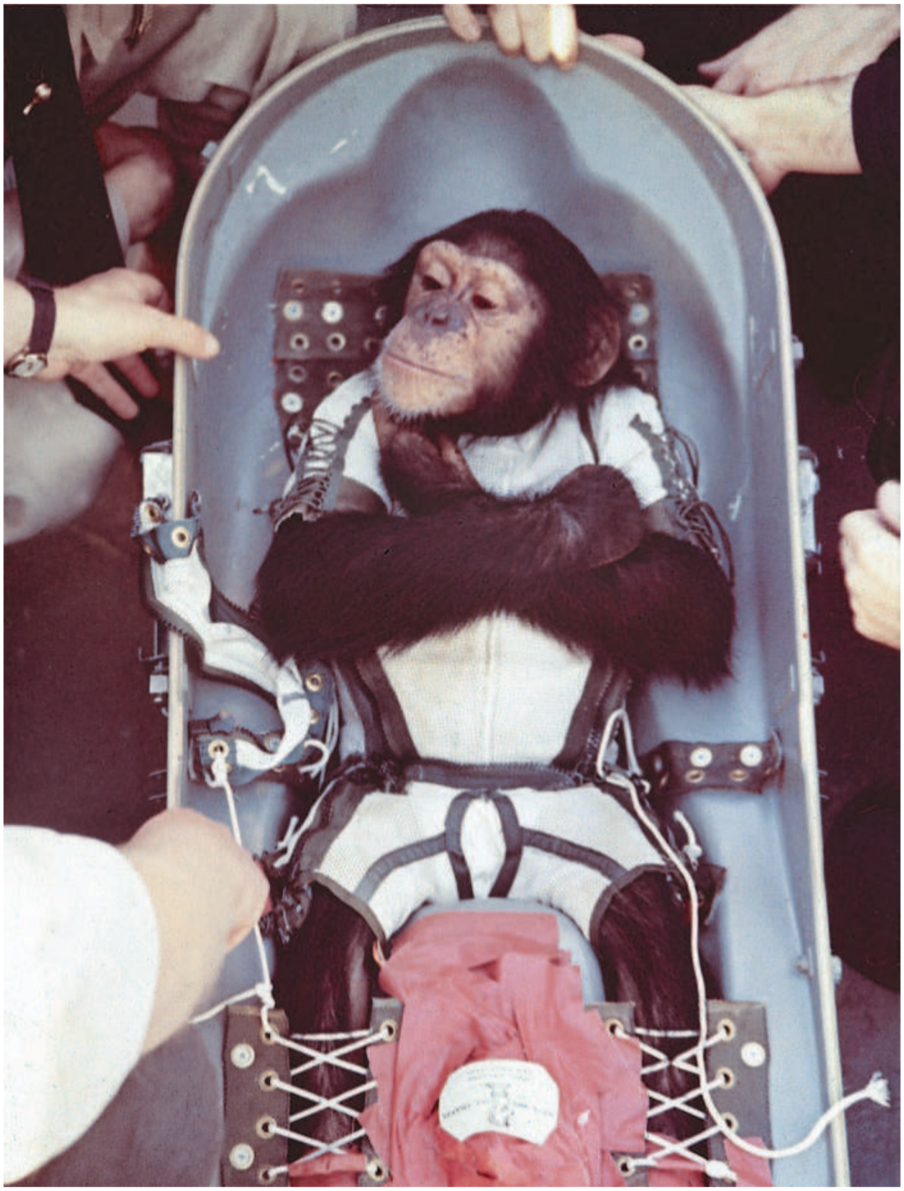
Primates, Non-Human

Surprisingly few non-human primates have been used in the more than forty-five years of space exploration. Some of these missions were essential for humans to travel into the near reaches of space. A total of twenty-nine non-human primates have flown in space; of these, twelve flew on Soviet or Russ-



Pre-launch preparations are made to the seating configuration of Ham the monkey, as he sits in the nose cone of the Mercury-Redstone 3 rocket. The rocket took him on a 1,500 mile journey in February 1961.

ian flights and seventeen on U.S. missions. Many of these were suborbital missions during which basic physiology and the risks associated with launch and **microgravity** were assessed.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

Early missions involved significant risks because of unknowns in engineering the life-support systems, the monitoring systems, and the design of the capsule itself. Some animals were lost due to failures in parachute recovery systems. The non-human primate was selected because of its size, ability to sit upright, ease of monitoring, and physiological similarity to humans. Early experiments, prior to 1958 when the National Aeronautics and Space Administration (NASA) was founded, were conducted by the military.

Before astronauts flew in Mercury **capsules**, Ham and Enos, the only chimpanzees to fly, tested the systems for humans. Non-human primates provided significant information on physiology, safety, and risks. Animal well-being is essential in scientific research. NASA uses non-human primates when the animal's safety can be assured and the scientific question can be answered only in this animal model. SEE ALSO Animals (volume 3); Capsules (volume 3); Microgravity (volume 2).

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R

Reaction Control Systems

The space shuttle has a forward reaction control system (RCS) located in the nose of the vehicle and an aft RCS located in the right and left pods at the rear of the shuttle. These reaction control engines can be used for 100 missions and can sustain 20,000 starts and 12,800 seconds of cumulative firing. The engines can be fired in a steady-state thrusting mode of 1 to 150 seconds, or in pulse mode with a minimum impulse thrusting time of 0.08 seconds. The space shuttle RCS is fueled by monomethyl **hydrazine** with a nitrogen tetroxide **oxidizer**.

hydrazine a dangerous and corrosive compound of nitrogen and hydrogen commonly used in high-powered rockets and jet engines

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

velocity speed and direction of a moving object; a vector quantity

The RCS provides the thrust for attitude maneuvers—pitch, yaw, and roll—and for small **velocity** changes along the orbiter axis. After the main engines cut off about 8 minutes after launch, the reaction control system is used to move the orbiter away from the external fuel tank when the tank separates from the shuttle. Before the space shuttle returns to Earth, the RCS thrusters are used to put the orbiter in appropriate attitude to reenter the Earth's atmosphere (this is called the entry interface attitude). Remaining fuel in the forward RCS is then dumped.

If the Orbital Maneuvering System engines fail, the aft RCS thrusters can be used to complete the shuttle's deorbit maneuver. From an entry interface at 400,000 feet (121,920 meters), the after RCS thrusters control roll, pitch, and yaw. The orbiter's ailerons become effective at a dynamic pressure of 10 pounds per square foot and the aft RCS roll jets are deactivated at that point.

Reaction Control Systems are also employed on satellites and on the upper stages of unmanned rockets. They fulfill a similar role to that described earlier for the space shuttle, assisting in delivering **payloads** to the required orbit and achieving the appropriate attitude. Aerojet is one of the major companies providing RCS systems commercially for space applications. SEE ALSO GUIDANCE AND CONTROL SYSTEMS (VOLUME 3); INERTIAL MEASUREMENT UNITS (VOLUME 3).

Pat Dasch

Internet Resources

Kennedy Space Center. <http://www.ksc.nasa.gov/shuttle/>.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Re-entry Vehicles

A re-entry vehicle is the part of a spacecraft that is designed to return through Earth's atmosphere. It is built to survive intense heating during high-velocity flight through the atmosphere and to protect the crew and/or instruments until it brings them safely to Earth. Although the technology has changed over time, re-entry vehicles since the early **Mercury** program have used the same basic design concept: a blunt shape protected by a heat shield.

Mercury the first American-piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963

Early Re-entry Vehicles

Early re-entry vehicle design benefited primarily from **ballistic** missile research. Designers initially thought that a re-entry vehicle should have a sleek aerodynamic shape, but launch and wind tunnel tests demonstrated that no known material with that shape could withstand the heat of re-entry. National Aeronautics and Space Administration (NASA) engineer Harvey Allen decided that a blunt-shaped vehicle should be used. The increased air resistance of that type of vehicle would, like the bow of a ship in the water, produce a "shock wave" that would absorb much of the vehicle's **kinetic energy** that was transformed into heat as it entered the atmosphere. Blunt re-entry vehicles were used successfully as intercontinental ballistic missile (ICBM) warheads and later as piloted and unpiloted spacecraft.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

kinetic energy the energy an object has due to its motion

The blunt-body concept furnished only part of the solution to the heating problem; a form of heat shield was also necessary. Extensive testing in arc jet heated wind tunnels showed that the most effective thermal protection method for single re-entry vehicles was **ablation**. An ablative heat shield is made of a resinous composite material that slowly vaporizes during descent, allowing the heat to dissipate along with the ashes. Ablative heat shields were used on all early NASA missions.

ablation removal of the outer layers of an object by erosion, melting, or vaporization

Lifting Body Research

Although NASA used ballistic **capsules** for its earliest re-entry vehicles, another vehicle type had been proposed—the lifting body—a shape that combined the blunt-body concept with the aerodynamics of a glider. Designers continued to do research on the shape of the lifting body. Between 1963 and 1975 NASA built and tested eight different lifting body designs. These

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

The X-38 is a prototype Crew Return Vehicle (CRV) designed to be an emergency rescue ship for the International Space Station.

craft varied tremendously. The M2-F1, for example, was an unpowered plywood glider, whereas the X-24 was a rocket-powered metal aircraft capable of supersonic flight. Data on aerodynamic performance during re-entry obtained from lifting bodies was crucial in the design of the space shuttle orbiter and the X-38.

Modern Re-entry Vehicles

The successful launch of the space shuttle in 1981 provided a significant demonstration of several new technologies, one of which was its thermal protection system. Because the shuttle was designed for repeated reentry, an ablative heat shield was not an option. The thermal blankets and the silica and reinforced carbon-carbon tiles that make up the shuttle's heat shield were tested extensively on the ground before the shuttle's first launch.

The X-38 resembles the lifting bodies of the 1960s and 1970s more than it does the shuttle. The X-38 could provide an emergency lifeboat for the crew of the International Space Station. Its heat shield will employ the same kind of tiles and blankets used on the shuttle, but they will be easier to attach and maintain because of the advanced composite materials that form the X-38's hull. SEE ALSO HEAT SHIELDS (VOLUME 3); HYPERSONIC PROGRAMS (VOLUME 3); LAUNCH VEHICLES, REUSABLE (VOLUME 1).

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"The X-38: Low-Cost, High-Tech Space Rescue. NASA Human Spaceflight. <http://www.spaceflight.nasa.gov/spacenews/factsheets/pdfs/fs_x-38.pdf>.

Rendezvous

Rendezvous is the procedure by which space vehicles in differing flight paths and orbits can be placed into the same orbital space, with **relative zero velocity**, at a preselected location and time. Various types of rendezvous maneuvers have been developed, but all depend on orbital mechanics. Fundamentally, a satellite in orbit moves in an **elliptical** path created by the gravitational force of a celestial body such as a planet. The speed of the satellite is inversely proportional to the square root of the radius of the orbit (or more strictly the **semimajor axis** of the orbit). This means that larger orbits have slower speeds than smaller orbits. For example, a satellite orbiting 8,000 kilometers (4,960 miles) from the center of Earth (about 1,500 kilometers [930 miles] above the surface) moves twice as fast as a satellite in an orbit with a radius of 32,000 kilometers (19,840 miles; about 25,500 kilometers [15,810 miles] above the surface.)

relative zero velocity two objects having the same speed and direction of movement, usually so that spacecraft can rendezvous

elliptical having an oval shape

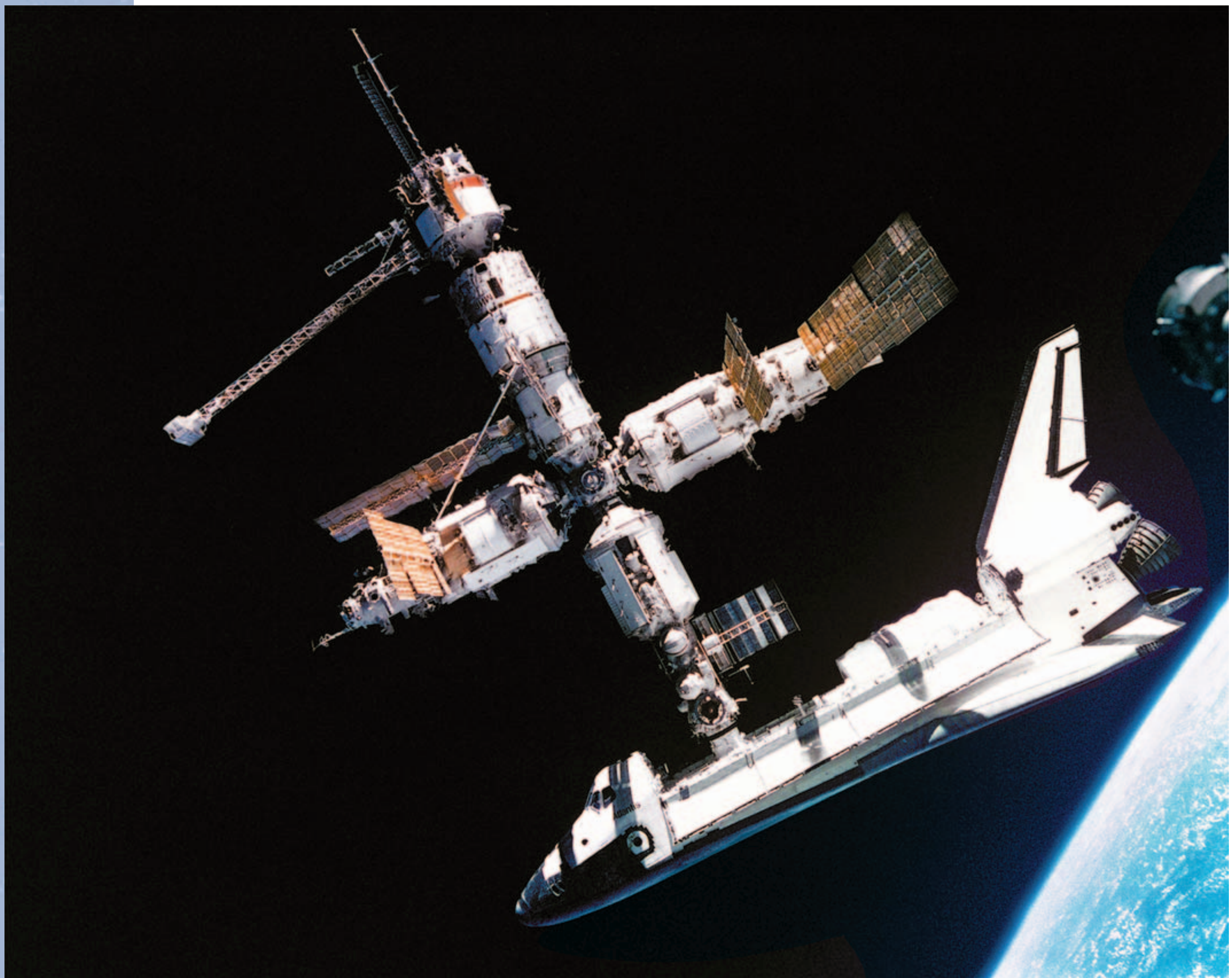
semimajor axis one half of the major axis of an ellipse, equal to the average distance of a planet from the Sun

The fact that lower orbits are faster than higher orbits has important implications for rendezvous maneuvers. Imagine two satellites in the same orbit but separated by some distance. In order for the trailing satellite to rendezvous with the leading satellite, it must fire its engines toward the leading satellite. This drops the trailing satellite into a lower and faster orbit, so that it catches up to the leading satellite. Once the trailing satellite has nearly caught up, it fires its engines away from the leading satellite to achieve the same orbit again. Of course, rendezvousing is more complicated if the two satellites are not in the same orbital plane; that is, if they do not orbit at the same angle to the equator. In such cases, one satellite must fire its engines at an angle to its line of flight to match the orbital plane of the satellite it is chasing. Plane changes are the most fuel-expensive orbit adjustments that can be made.

The Launch Window

Typically, a satellite on the ground must be launched within a certain period of time—called a "launch window"—in order to be correctly positioned to rendezvous with another satellite. The launch window is the time or set of times that a launch can occur and still meet mission objectives and stay within safety guidelines. Essentially, the launch window is defined by the position of an orbiting satellite relative to the launch site of the satellite set to rendezvous with it. To help understand this relationship, visualize an imaginary line on the ground that traces the orbital motion of a satellite—its so-called ground track. The ground track of all low-altitude, easterly launched satellites looks like a **sine wave**. The wave, however, is in a different place on the map on each successive trace, mainly because Earth rotates. There is also some rotation of the orbital plane about Earth's spin axis that causes the ground track to move because Earth is not a perfect sphere.

sine wave a wave whose amplitude smoothly varies with time; a wave form that can be mathematically described by a sine function



The space shuttle Atlantis docked to Russia's Mir space station. The techniques allowing space vehicles to rendezvous and dock were based on theories developed by scientists, engineers, and astronauts working together.

Eventually, however, the ground track of an orbiting satellite will trace a path directly over the launch site. This is the moment when a spacecraft on the ground must be launched in order to rendezvous with the satellite in orbit. Of course, some passes are better than others. The closer the ground track comes to the launch site the more efficient the launch will be. If launch occurs a couple of minutes early or late or if the satellite does not go directly over the launch site, it is still possible to achieve a rendezvous, but this requires changing the orbital plane and using a significant amount of fuel. That is why the space shuttle has only a five-minute launch window to rendezvous with the International Space Station. The shuttle has only a limited supply of fuel to use in aligning the plane.

Pioneering Orbital Rendezvous

It was recognized very early that rendezvous and docking between space vehicles were essential for a trip to the Moon. Gemini flights provided the first experience in the tricky business of rendezvousing two craft in space with the minimum expenditure of fuel. The first rendezvous between two piloted spacecraft occurred in December 1965 when Gemini 6 lifted off and approached Gemini 7, which was already in orbit. Later, during the Apollo program, the Lunar Module lifted off from the lunar surface and rendezvoused with an orbiting Command Module. Orbital rendezvous techniques were based on theories developed by scientists, engineers, and astronauts working together. Edwin "Buzz" Aldrin, Apollo 11 Lunar Module pilot, did his doctoral thesis on guidance for piloted orbital rendezvous. Aldrin's procedures were tested and refined during the Apollo flights. SEE ALSO GUIDANCE AND CONTROL SYSTEMS (VOLUME 3); NAVIGATION (VOLUME 3); ORBITS (VOLUME 2).

John F. Kross

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Ride, Sally

American Astronaut and Physicist
1951–

Sally Ride was the first American woman in space.

The first American woman in space was Sally Ride, who served as a mission specialist on the space shuttle Challenger in 1983 during mission STS-7. Ride majored in physics at Stanford University in California and earned a bachelor of science degree in 1973, a master of science degree in 1975, and a doctorate in 1978 in that field, as well as a bachelor of arts degree in English in 1973.

Ride was selected as an astronaut candidate in January 1978 and, after completing a one-year training program, became eligible for assignment as a mission specialist on space shuttle flights in August 1979. Her first flight was STS-7, when she not only gained the distinction of becoming the first American female astronaut, but was also responsible for operating the robotic arm during the deployment of several satellites. Ride flew again in 1984, aboard STS 41-G. In June 1985 she was assigned to serve as a mission specialist on STS 61-M, but she terminated her training in January 1986 to serve as a member of the Presidential Commission on the Space Shuttle Challenger Accident.

Ride left the National Aeronautics and Space Administration in 1989 to join the faculty of the University of California at San Diego as a physics professor and become the director of the California Space Institute. SEE ALSO History of Humans in Space (volume 3); Mission Specialists (volume 3); Satellites, Types of (volume 1); Space Shuttle (volume 3); Sullivan, Kathryn (volume 3); Tereshkova, Valentina (volume 3); Women in Space (volume 3).

Nadine G. Barlow

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Rockets

Rockets are machines propelled by one or more engines especially designed to travel through space. Rocket propulsion results from ejecting fuel backward with as much momentum as possible. One example is a firecracker that misfires and fizzles across the sidewalk. Currently, most rockets use a solid or liquid propellant that relies on a chemical reaction between fuel and **oxidizer** for thrust. Although chemical rockets can develop great thrust, they are not capable of lengthy operation. To overcome this drawback, research has been conducted on rockets that use different types of chemicals, or reactants. One type of nonchemical rocket is powered by **ion propulsion**. These rockets turn fuel into plasma and eject the ions to create thrust. Nuclear rockets that use a nuclear reactor to heat and eject fuel are still at the experimental stage. Scientists have also outlined schemes for fusion pulse rockets, solar sail rockets, and photon rockets.

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

ion propulsion a propulsion system that uses charged particles accelerated by electric fields to provide thrust

From "Fire Arrows" to Modern Rocketry

The Chinese were probably the first to use rockets. In 1232 C.E. they defeated a Mongol invasion using a strange weapon called "fire arrows." Filled with an explosive combination of saltpeter and black powder, these were the primitive ancestors of rockets. Later, this new weapon was carried as far as the Near East and Europe. By the sixteenth century, Europeans had taken the lead in exploiting the potential of rockets in warfare.

Rapid progress in military rocketry was made in the nineteenth century. Over 25,000 rockets developed by British artillery officer William Congrieve were launched against Copenhagen, Denmark, in 1807. The same type of rocket was immortalized as "the rocket's red glare" in "The Star-Spangled Banner." Beyond their martial applications, recognition of the potential of rockets in spaceflight began to emerge in the late nineteenth and early twentieth centuries through individuals who were to have a profound impact on the coming space age.

In Russia, the writings of Konstantin Tsiolkovsky greatly influenced many rocket pioneers. Robert H. Goddard, the father of rocketry in America, discovered, as Tsiolkovsky had, that the combination of liquid oxygen and liquid hydrogen would make an ideal rocket propellant. In March 1926,

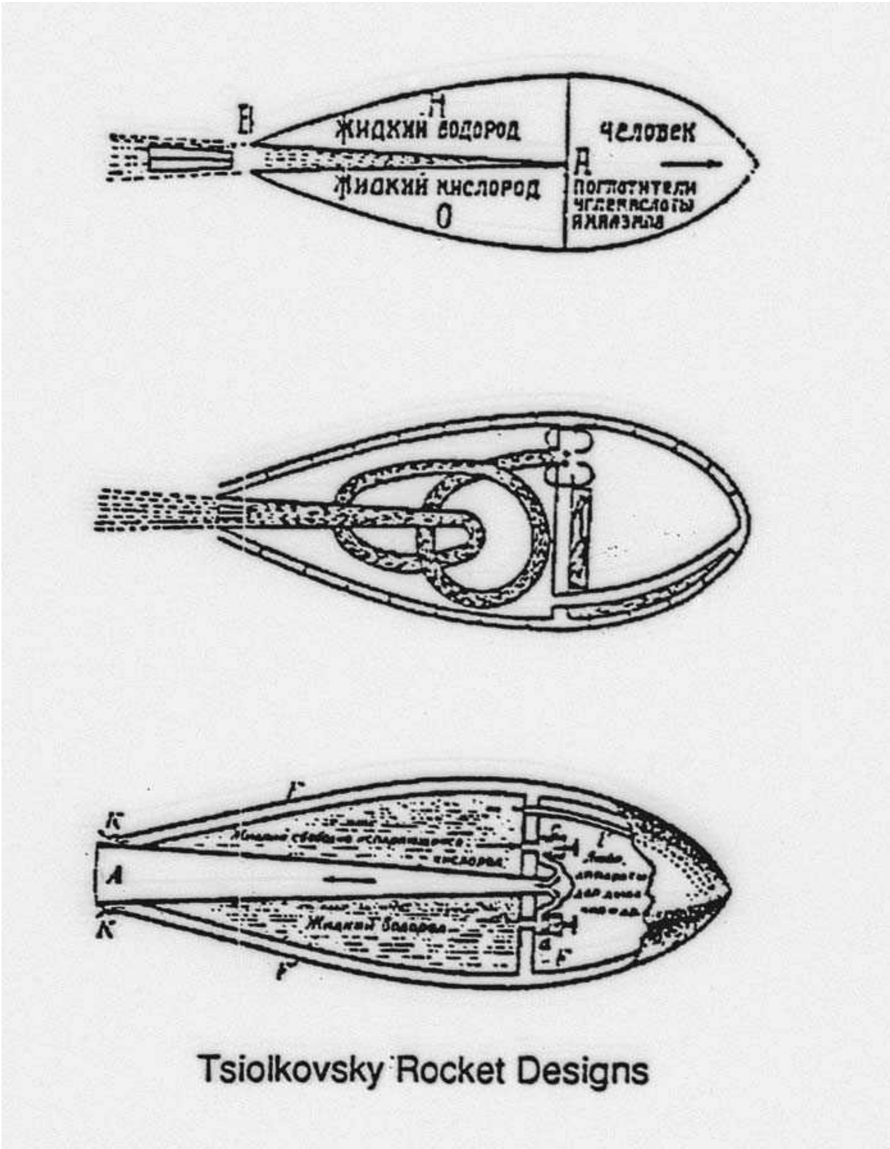

Illustration of three different early rocket designs created by Russian scientist and theorist Konstantin Tsiolkovsky. In the 1920s, Tsiolkovsky solved the mathematical problems that would allow staged rockets to break free of the Earth's atmosphere and continue into space.

a 4-meter-tall (13-foot-tall) projectile, the world's first liquid-propellant rocket, was launched from the Goddard family farm in Massachusetts. Later, Goddard set up a facility in New Mexico, where, in 1935, he launched a sophisticated rocket stabilized by **gyroscopes** and cooled by frigid propellant—features common to all modern chemical rockets.

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

As Goddard labored in the desert, rocket trailblazer Hermann Oberth proposed to the German Army the development of liquid-fueled, long-range rockets. During World War II (1939–1945), Oberth worked together with Wernher von Braun to develop the V-2 rocket for the Germans. On October 3, 1942, a V-2 was launched from Peenemunde on the Baltic coast and reached the edge of space—an altitude of 85 kilometers (53 miles)—becoming the first rocket to do so. After the war, captured V-2s were brought to the United States and Soviet Union and became the basis for postwar rocket research in both countries. The first major development in postwar rocket technology was the concept of multiple stages in which the rocket's

This Ariane 4 rocket placed an observation satellite into orbit that provided high-resolution images of Earth's surface.

first stage reaches its peak altitude and the second stage is "launched" from the first stage closer to space. This concept is used today on all major launch vehicles, with three- and four-stage rockets not uncommon.

The Origin of Today's Rockets

In the 1950s, von Braun and his "Rocket Team," many of whom had immigrated to the United States, continued their work on multistage rockets near Huntsville, Alabama. There they developed the Jupiter rocket, which evolved into the Redstone launch vehicle, which sent the first two U.S. astronauts into space. Meanwhile, in the Soviet Union, a team headed by Sergei Korolev developed the R-7 ("Semyorka") rocket, which launched the first artificial satellite, Sputnik 1, in October 1957, and the first man and woman into orbit.

Throughout the late 1950s and early 1960s, the United States developed a series of intercontinental ballistic missiles—Atlas, Thor, and Titan—that would play key roles in both piloted and unpiloted space missions. The Atlas was used to launch **Mercury** astronauts and satellites into orbit. The Thor gradually evolved into the highly versatile Delta series of rockets, which have launched a large number of National Aeronautics and Space Administration (NASA) planetary missions since the late 1960s. In its various subtypes, the Titan continues to serve both NASA and the U.S. Air Force as a heavy launcher for planetary probes and **reconnaissance** satellites.

Mercury the first American-piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963

reconnaissance a survey or preliminary exploration of a region of interest

While these vehicles are descendents of military rockets, the Saturn series of launch vehicles, the most powerful ever built by the United States, was developed expressly for the Apollo Moon program. The smaller Saturn 1B was used for the first crewed Apollo mission in 1968 and later lifted all three crews to the Skylab space station. The Saturn V, standing 117 meters (384 feet) tall, powered all Apollo missions to the Moon from 1968 to 1972. The Soviets also developed a series of advanced rockets, such as the Soyuz and Proton, but their "Moon rocket," the N-1, never successfully flew.

The space shuttle marked a radical departure from previous "expendable" rockets. The winged shuttle orbiter, flanked by two solid-propellant boosters, was designed to be reused dozens of times. While many rockets, such as the shuttle, are owned and operated by government, the commercial launch industry had grown enormously since the 1970s and become more international. Today, the International Launch Services company provides launch services on the American Atlas II, III, and V and the Russian Proton vehicles to customers worldwide. Meanwhile, the Boeing Company launches the Delta II, III, and IV and is a partner in Sea Launch, which launches Zenit rockets. Arianespace, a European consortium, is also a major player in the commercial launch industry, producing Ariane 4 and 5 rockets.

The history of rocketry is a long one, and rockets will continue to play important roles in commerce, science, and defense. SEE ALSO External Tank (volume 3); Goddard, Robert Hutchings (volume 1); Korolev, Sergei (volume 3); Launch Management (volume 3); Launch Sites (volume 3); Oberth, Hermann (volume 1); Tsiolkovsky, Konstantin (volume 3); von Braun, Wernher (volume 3).

John F. Kross

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Sänger, Eugene

Austrian Aerospace Engineer
1905–1964

An Austrian aerospace engineer, Eugene Sänger developed the first design for a spaceplane, a distant forerunner of the space shuttle. Born in 1905, Sänger began studying the concept of winged rockets while a graduate student at the Viennese Polytechnic Institute in the late 1920s. In 1933 those studies led to Silverbird, a design for a rocketplane capable of flying 30 kilometers (18.64 miles) high at Mach 10.

Sänger, along with his mathematician wife, Irene Bredt, refined Silverbird through the 1930s, eventually coming up with a design that could be launched from a rocket-powered sled and carry 3,600 kilograms into orbit. Silverbird would return to Earth by "skip gliding," performing a series of skips off Earth's upper atmosphere to lose velocity before gliding to a runway landing. During World War II, Sänger turned the Silverbird concept into Amerika Bomber, a rocketplane that could be launched from Germany, drop 300 kilograms (661 pounds) of bombs over New York City, and skip glide around the world back to Germany.

While neither Silverbird nor Amerika Bomber were ever built, they influenced the design of postwar experimental vehicles, like the X-20 Dyna-Soar, which in turn led to the development of the space shuttle. Sänger continued his study of rocketplane designs in France and West Germany until his death in 1964. SEE ALSO Hypersonic Programs (Volume 3); Space Shuttle (Volume 3).

Jeff Foust

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Sanitary Facilities

The first American to travel into space, Alan Shepard, had been lying on his back in the Mercury capsule he had named Friendship 7 for over 4 hours.

A mock-up of a space station bathroom. Due to the absence of gravity, a space station toilet must use gentle suction to remove waste.

Technical problems had delayed the launch, and Shepard was beginning to experience uncomfortable pressure in his bladder. National Aeronautics and Space Administration (NASA) engineers had not anticipated that Shepard would spend such a long time in the space suit, and so the suit had no provision for dealing with bodily waste. In desperation, Shepard requested permission from the engineers to urinate in the space suit. The engineers and doctors conferred briefly and decided it was safe to do so. Friendship 7 lifted off on May 5, 1961.

Since that first historic flight the bathroom facilities on spacecraft have improved substantially. On the next flight Gus Grissom wore a large diaper that had been quickly devised by NASA engineers and medical consultants. This arrangement subsequently evolved into a large plastic bag contraption designed to accept and contain solid waste as well as liquids. The bag attached directly to the astronaut's buttocks with sticky tape and did not always work as it was supposed to.

For extended space walks and surface excursions, space suits are still equipped with diapers or waste bags. However, for longer missions when the suit is not worn, better and more convenient sanitary facilities are required. All modern spacecraft designed for extended stays in space include personal hygiene and toilet facilities.

Studies have shown that bacteria and fungi can multiply rapidly in a spacecraft cabin. This was an issue on the Mir space station and other spacecraft. To avoid this problem, food preparation, dining, toilet, and sleeping areas are cleaned and disinfected regularly. Disposable clothing is worn for 2 or 3 days and then discarded. The clothing is then sealed in airtight plastic bags and stored in lockers. After meals, empty food containers are sealed in airtight plastic bags that are also stored. All this trash eventually is returned to Earth.

Current Facilities

Although it may be possible to skip a shower or shampoo for a flight of a day or two, astronauts are usually required to spend several days or even weeks in space. During that time they must wash their hair, brush their teeth, shave, and go to the bathroom. When astronauts brush their teeth, they may have to swallow the toothpaste or spit into a washcloth. Shaving, whether the astronaut uses a conventional or an electric shaver, is done much as it is on Earth. Astronauts use a thick shaving cream that can be wiped off without rinsing. Their electric shavers use a slight flow of air to capture the shaved hairs.

There is no shower on the space shuttle, and so astronauts use a damp sponge or washcloth and soaps that do not need to be rinsed off. For privacy, they draw a curtain across a portion of the galley. The bathroom is equipped with a washbasin that dispenses warm water, a soap dispenser, a mirror, and a reading light. Clips on the wall hold towels, washcloths, and other personal items. Since water and soap suds stick to the skin in a weightless environment, little water is needed to wash. There is even a window so that the astronauts can get a view of space.

Each space shuttle has a toilet, officially designated the Waste Collection System, that can be used by both men and women. It was designed to be as much as possible like those on Earth. However, in the weightless conditions of space, flowing air substitutes for gravity to move waste through the system. The shuttle toilet is in its own room in the crew compartment. Every attempt was made to make the toilet resemble and function like a conventional toilet on Earth. Of course, in the freefall conditions of orbit, astronauts must strap themselves into place, using a bar across the thighs or hook and loop straps. The commode seat is made of a pliable material that provides a good air seal to the buttocks. Solid waste is collected in a bag. When the astronaut is done, a valve is opened, exposing the solid waste to the **vacuum** of space. This instantly freeze-dries the

vacuum an environment where air and all other molecules and atoms of matter have been removed

waste, which is then collected, stored, and returned to Earth for chemical and biological analysis.

The shuttle urinal can be used by female and male astronauts. It consists of a flexible tube that can be attached to a funnel. Each astronaut is provided with a personalized and fitted funnel. The urinal also works by substituting air flow for gravity. The urine is collected and stored in a waste tank, and the air is filtered, sanitized, and recycled. The tank is emptied periodically by venting to space.

The Future

When the Environmental Control and Life Support System (ECLSS) is delivered to the space station (scheduled for October 2005), the waste collection system on the space station will be much more complex and sophisticated than the system used on the shuttle. Because the International Space Station (ISS) is designed for long-term stays, all water will be collected and recycled, including water vapor in exhaled air and the water in the urine from humans and laboratory animals. In the urine recycling system large solids and trash are removed with a filter similar to a coffee filter. The liquid then passes through a multilayer filtration system that removes organic and inorganic materials. Finally, the water passes through the "catalytic oxidation reactor," which removes volatile organic compounds and kills bacteria, viruses, and other microbes.

The ELCSS will allow astronauts to take real showers for the first time. The module contains a watertight compartment with a handheld spray nozzle. After the shower, astronauts will use another hose to vacuum up any excess water before leaving the compartment. Although better than a damp washcloth, it will not be a luxurious hot shower. It will use about 4 liters of water, compared to 50 liters for a shower on Earth. SEE ALSO HUMAN FACTORS (VOLUME 3); LIVING IN SPACE (VOLUME 3).

Elliot Richmond

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Schmitt, Harrison

American Astronaut and Senator
1935–

Astronaut Harrison Schmitt was photographed in December, 1971, in front of the lunar globe he helped develop.

Born in Santa Rita, New Mexico, on July 3, 1935, Harrison H. "Jack" Schmitt received a bachelor of science degree from the California Institute of Technology in 1957 and a doctorate in geology from Harvard University in 1964.

In June 1965, when the National Aeronautics and Space Administration (NASA) selected Schmitt for its first group of scientist-astronauts, he was involved in mapping the Moon with the U.S. Geological Survey's Astrogeology Center at Flagstaff, Arizona. Schmitt provided Apollo flight crews with detailed instructions in lunar navigation, geology, and feature recognition while training for his Moon mission. Additionally, he helped achieve the inclusion of scientific activities into Apollo missions and helped analyze the lunar soil samples returned by the astronauts.

On December 10, 1972, Apollo 17 Mission Commander Eugene Cernan and Schmitt landed the moonship Challenger in a mountain-ringed valley named Taurus-Littrow. "It's a good geologist's paradise if I've ever seen one!" Schmitt said as he followed Cernan to the surface.

Schmitt resigned from NASA in 1975 to run for the U.S. Senate in New Mexico. In the last two years of his term he was chairman of the Subcommittee on Science, Technology and Space. He teaches at the University of Wisconsin and is a business and technical consultant. SEE ALSO Apollo (volume 3); Apollo Lunar Landing Sites (volume 3); History of Humans in Space (volume 3); Lunar Rovers (volume 3); Why Human Exploration? (volume 3).

Frank R. Mignone

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Shepard, Alan

American Astronaut
1923–1998

Alan Bartlett Shepard Jr. was America's first human in space and the fifth of only twelve men to walk on the Moon. His combination of professionalism and impish sense of humor vaulted him to the status of space hero, and he became a symbol of perseverance to the world.

A graduate of the U.S. Naval Academy, test pilot, and flight instructor, Shepard was selected as one of the original seven Mercury astronauts. At the age of thirty-seven, he was launched atop a Redstone rocket, May 5, 1961. The tiny Mercury capsule soared to an altitude of 116 miles (187 kilometers). The 15-minute sub-orbital flight demonstrated that a human could survive and function in the weightlessness of space. The success of Shepard's mission inspired U.S. President John F. Kennedy's challenge to the nation to land men on the Moon by the end of the decade.

Alan Shepard was the United States' first astronaut in space.

After an ear problem grounded Shepard for many years, he finally returned to space as commander of Apollo 14 in 1971 aboard the giant Saturn V Moon rocket, 111-meters (363-feet) high compared to his 83-foot (25-meter) Redstone, bringing back 43 kilograms (94 pounds) of Moon rocks. Shepard left behind two golf balls hit with a cleverly devised golf club. Alan Shepard died July 22, 1998 from leukemia. SEE ALSO ASTRONAUTS, TYPES OF (VOLUME 3); CAPSULES (VOLUME 3); MERCURY PROGRAM (VOLUME 3).

Meridel Ellis

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Sickness *See Medicine (Volume 3).*

Simulation

Space explorers venture into the unknown. But the support crews of the space explorers do their best to send their imagination, analysis, and scientific knowledge ahead. Simulation has always been an integral part not only of astronaut training but also of testing engineering designs of hardware and software and all the procedures developed for the mission. The hard work of a dedicated simulation and training support team prepares the astronaut crews to successfully deal with emergencies, while mostly avoiding surprises in the mission execution.

Using virtual reality hardware, mission specialist C. Michael Foale trains for extravehicular duty for the STS-103 shuttle mission, which included plans to service the Hubble Space Telescope.

Specific Applications of Simulation

Simulation allows the astronauts to become comfortable with the unfamiliar. The astronauts practice on simulators such as a mock-up of the space shuttle's crew compartment. Pilots practice shuttle approaches and landings with the modified Grumman Gulfstream G-2 corporate jet (otherwise known as the Shuttle Training Aircraft), which mimics the different **drag** and center of rotation of the shuttle. Mission specialists maneuver cargo in the **payload bay** or practice satellite retrieval on a simulated manipulator arm.

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

payload bay the area in the shuttle or other spacecraft designed to hold the experiment to be performed or cargo to be launched

Demanding crew training regimes at the National Aeronautics and Space Administration's (NASA) Johnson Space Center in Houston, Texas, include single-system trainers that simulate specific functions such as propulsion, guidance, navigation, and communications. All of the single-system training comes together in the shuttle mission simulator (SMS) and the shuttle engineering simulator (SES). The SES simulates rendezvous, station keeping, and docking using a domed display for a realistic full-scale perspective of the shuttle cockpit view. The SMS includes a motion-based simulator for ascent and entry training, and a fixed-based simulator for orbit simulations. The SMS simulators imitate the sounds, scenes, and motion of a full shuttle mission—from liftoff to touchdown—to give the astronauts the feel of a real mission.

Every conceivable emergency or malfunction is practiced repeatedly in the simulator. The simulators are also used for problem solving. When the oxygen tank exploded on Apollo 13, for example, ground support teams and backup astronaut crews used the simulator to work solutions and send new procedures to the crew.

Sophisticated for their time, the original simulators were installed in 1962 by the Link company, which pioneered full-flight simulators. But that was the age of room-sized mainframe computers and engineers carrying slide rules in their pockets. Neither the personal computer nor the hand calculator had been developed yet. Tools for mission training are more sophisticated today. The SMS and the SES were upgraded in 1999 with new Silicon Graphics computers and software that increased the display capability by a factor of thirty.

Virtual-Reality Simulators

NASA increasingly uses sophisticated interactive virtual-reality simulators to plan and train for space shuttle and International Space Station operations. In the Johnson Science Center's Virtual Reality Laboratory, astronauts wearing virtual-reality helmets see the payload bay, each other, and the object they are handling. They can practice handing off an object to other astronauts. Handholds for the objects are suspended from ceiling wires calibrated to mimic the object's behavior in zero gravity.

Science teams from around the world also use **virtual-reality simulations** to coordinate, plan, and execute International Space Station and experiment operations. Virtual-reality databases allow distant users to observe diverse system interactions together.

virtual-reality simulation a simulation used in training by pilots and astronauts to safely reproduce various conditions that can occur onboard a real aircraft or spacecraft

Less-Sophisticated Tools and Techniques

While NASA is now able to employ sophisticated computer technology for simulating space tasks, realism can be simulated with simpler technologies. Astronaut candidates experience weightlessness on a KC-135 airplane flown in a parabolic path that simulates twenty to thirty seconds of floating in space. Known as the "vomit comet" because of the unsettling effect of sudden weightlessness, the KC-135 simulates zero gravity for astronaut training as well as for **microgravity** experiments.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Tasks involving the manipulation of massive objects for space shuttle operations or space station construction can be simulated in NASA's Neutral Buoyancy Laboratory (NBL) at the Johnson Science Center. (Neutral buoyancy is when an object has an equal tendency to float as sink.) Astronauts suit up and train underwater with backup scuba divers for missions such as the repair of the Hubble Space Telescope. Linked with the SMS and the Mission Control Center, astronauts in the NBL can train on specific mission timelines with flight controllers and astronauts piloting in the cockpit.

To become familiar with a lunar landscape, Apollo astronauts visited volcanic and impact crater sites such as Craters of the Moon National Park and Meteor Crater. They made geological field trips to Alaska, Hawaii, and Iceland. At Sunset Crater Volcano National Monument outside of Flagstaff, Arizona, geologists created a realistic site for operating in a lunar environment by blasting craters in the **cinder field**, erecting a mockup of the lunar lander, and bringing in a lunar **rover** for the astronauts to drive.

cinder field an area dominated by volcanic rock, especially the cinders ejected from explosive volcanoes

rover vehicle used to move about on a surface

When it all comes together before a launch, the simulations and training prepare the astronauts to confidently go where no one has gone before—except in the imagination. SEE ALSO Astronaut, Types of (volume 3); Computers, Use of (volume 3); International Space Station (volumes 1 and 3); Rendezvous (volume 3); Space Shuttle (volume 3).

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Skylab

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

The 100-ton Skylab was America's first experimental **space station**, and the only one the United States deployed in the first three decades of human spaceflight. The National Aeronautics and Space Administration (NASA) announced the Skylab project on July 22, 1969, as Apollo 11 was returning to Earth from the first landing on the Moon. The Skylab assembly was not a single structure, but a cluster of four units, three of them habitable. The main body, the Orbital Workshop (OWS), was a cylinder 14.6 meters (48 feet) long and 6.7 meters (22 feet) across, with a volume of 270.4 cubic meters (9,550 cubic feet), roughly the size of a small house. The OWS was created from the remodeled shell of the propellant tank from the Saturn 5 rocket's third stage. The upper part of the OWS was equipped with food lockers, refrigerators, water tanks, and space suit lockers; the lower story contained crew quarters and an experiment station.

Attached to the OWS was the airlock module (AW), which contained the station's control and monitoring center and provided access to space for extravehicular activity (EVA). Also on that end of Skylab was the Apollo telescope mount (ATM), a solar observatory, and the multiple docking adapter (MDA), which contained docking ports for the Apollo spacecraft and controls for the ATM and other scientific equipment. The entire Skylab assembly, with the Apollo spacecraft attached, was 37 meters (120 feet) long.

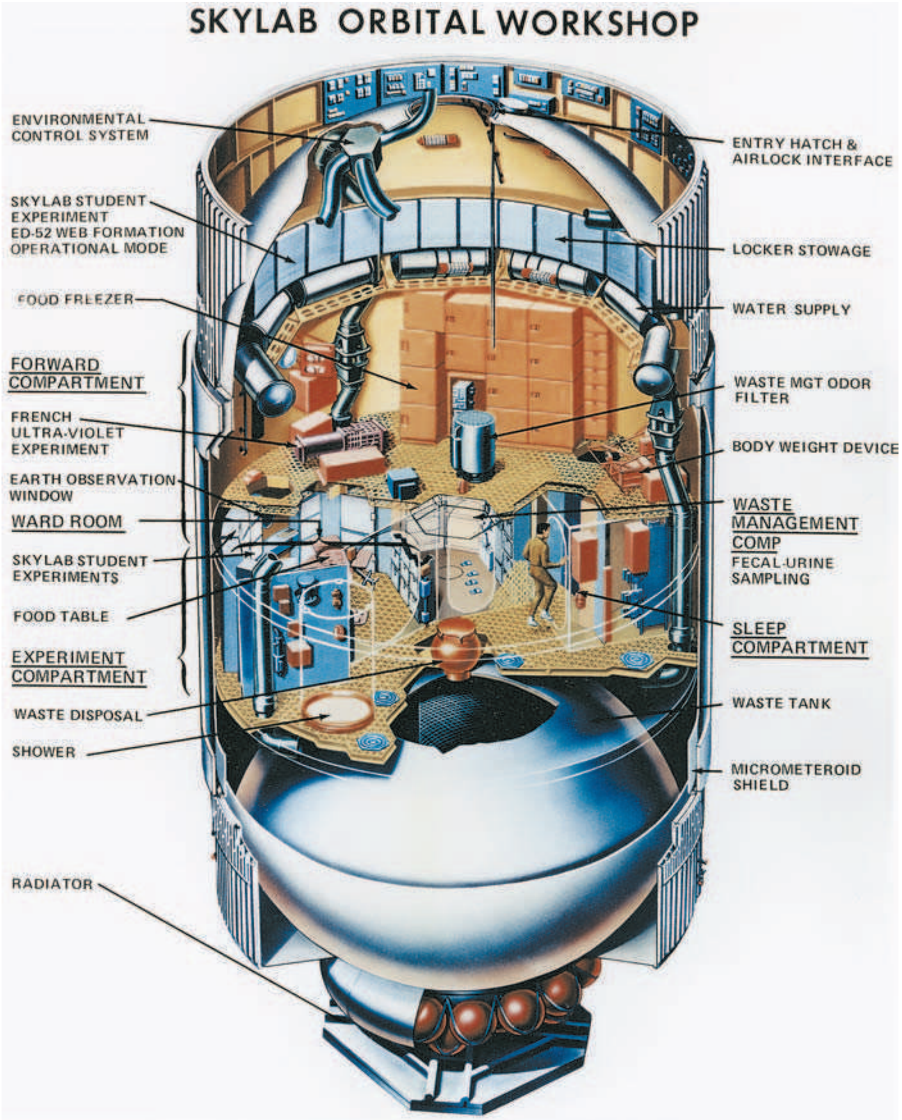
Designed for long-duration missions, the Skylab program was intended to prove that humans could live and work in space for extended periods, to expand knowledge of solar astronomy and earth science, and to provide information that could be used in the development of future space stations. In addition to its suite of cameras, Skylab was stocked with tons of scientific equipment, including coronagraphs, **spectrometers**, and **ultraviolet** and X-ray telescopes. The MDA also contained equipment for space manufacturing and externally mounted Earth resources cameras.

spectrometer an instrument with a scale for measuring the wavelength of light

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

The Missions

Skylab was launched on May 14, 1973, from NASA's Kennedy Space Center by a Saturn V launch vehicle. However, 63 seconds after liftoff, the



Cutaway illustration of the interior environment of Skylab, showing everything from sleeping quarters to waste management.

meteoroid shield, which was designed to shade Skylab's workshop, deployed accidentally. When the meteoroid shield ripped loose, it disturbed the mounting of one of the workshop's solar array "wings," causing it to partially deploy. As the launch progressed, the exhaust plume of the second stage retro-**rockets** ripped away the partially deployed solar array. In addition, debris from the meteoroid shield overlapped the other solar array wing so that it was held in a slightly opened position and was unable to generate power.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

After reaching orbit, Skylab was maneuvered so that a separate set of solar panels on the ATM faced the Sun to provide electricity. However, because of the loss of the meteoroid shield, workshop temperatures rose to a dangerously high level. Scientists, engineers, astronauts, and management personnel at NASA and elsewhere worked to devise a way to rescue Skylab. One of their first steps was to maneuver Skylab, which was seriously overheating, to maintain the most favorable balance between temperature and power generation capability. In the meantime, the launch of the first

The Skylab space station in Earth orbit. The gold heat shield on the orbital workshop was a replacement for an earlier shield that malfunctioned. The new shield allowed Skylab to complete all of its mission objectives.

Skylab crew was postponed while NASA engineers developed procedures and trained the crew to make the workshop habitable. The first crew of astronauts finally arrived at the station aboard an Apollo spacecraft on May 25, 1973, about ten days after Skylab was launched.

The initial crew, consisting of Charles "Pete" Conrad, Paul J. Weitz, and Joseph P. Kerwin, spent twenty-eight days aboard Skylab (May 25 to June 22, 1973). Most of that time was spent rigging a sunshade and making repairs to the OWS, which had been badly damaged during ascent. After substantial repairs, including deployment of the parasol-type sunshade, which cooled the inside temperatures, the workshop was declared fully operable. From then on the crew conducted solar astronomy and Earth resources experiments, medical studies, and three EVAs totaling six hours and twenty minutes.

The second crew, consisting of Alan L. Bean, Jack R. Lousma, and Owen K. Garriott, continued maintenance of the space station and conducted extensive scientific and medical experiments for fifty-nine days from July 28 to September 25, 1973. The third crew, consisting of Gerald P. Carr, William R. Pogue, and Edward G. Gibson, set a U.S. flight record of eighty-four days from November 16, 1973, to February 8, 1974. Before leaving Skylab, the crew jockeyed the station into an oval orbit of 521 by 499 kilometers (324 by 310 miles) by using the Apollo service module's engines.

The Results

Despite early mechanical difficulties, Skylab was an overwhelming success, with the three crews occupying the workshop for a total of 171 days. Skylab was the site of nearly 300 scientific and technical experiments, including medical experiments on humans' adaptability to zero gravity, solar observations, and detailed studies of Earth's resources. Both the time in space and the time spent in extravehicular activities (EVAs) exceeded the combined totals of all of the world's previous spaceflights up to that time. Additionally, the capability to conduct longer missions was conclusively demonstrated by Skylab, as evidenced by the good health and physical condition of the second and third crews. By selecting and photographing targets of opportunity on the Sun and by evaluating weather conditions on Earth and recommending Earth resources opportunities, crewmen aboard Skylab were instrumental in obtaining high-quality solar and Earth data.

The conclusion of the third mission to Skylab marked the end of the first phase of the program. It was expected that Skylab would remain in orbit for eight to ten years and would be reoccupied when the space shuttle program was under way. Gradually, however, the space station's orbit began to decay because of sunspot activity that caused Earth's atmosphere to expand. In the fall of 1977 it was determined that Skylab was no longer in a stable attitude as a result of greater than predicted solar activity. A space shuttle mission was planned for February 1980 in which astronauts would attach an inertial upper stage to Skylab and boost it into a higher orbit. However, on July 11, 1979, a year before the planned rescue mission and two years before the shuttle's first flight, Skylab plunged into the atmosphere and burned up over the Indian Ocean. Some debris fell to Earth across the southeastern Indian Ocean and a sparsely populated section of western Australia. The debris did no major damage, but Skylab's flaming plunge to Earth marked the end of the Apollo era of human spaceflight. SEE ALSO Closed Ecosystems (volume 3); Habitats (volume 3); History of Humans in Space (volume 3); Life Support (volume 3); Living in Space (volume 3); Long-Duration Spaceflight (volume 3); Mir (volume 3); Space Stations, History of (volume 3); Zero Gravity (volume 3).

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Solid Rocket Boosters

Mounted on either side of the space shuttle's external fuel tank are a pair of giant rockets with a single, two-minute purpose: to get the shuttle off the

The first two minutes of flight when the boosters are burning are generally considered the most dangerous part of the shuttle launch, with the fewest survivable options should anything go wrong.

launch pad. The rockets are called the shuttle's solid rocket boosters (SRBs) because they contain solid, as opposed to liquid, propellant. Each booster has a thrust of about 3.3 million pounds of force at launch, enough power to propel the shuttle, its external fuel tank, the boosters themselves, and the shuttle's cargo and crew into the air.

The boosters ignite 6.6 seconds after the shuttle's main engines start. If the shuttle engines are performing properly, computer commands are automatically relayed to ignite the boosters and fire explosives to break open four 71-centimeter-long (28-inch-long), 8.9-centimeter-diameter (3.5-inch-diameter) bolts that attach each booster to the launch platform. The shuttle then leaps off the launch pad in a dramatic and heart-stopping display of **pyrotechnics**. Trailing pillars of flame and smoke, the boosters fly the shuttle into the sky to an altitude of about 45,700 meters (150,000 feet). The boosters push the shuttle to speeds of more than 4,825 kilometers per hour (3,000 miles per hour). Meanwhile, temperatures inside the boosters soar to nearly 3,300°C (6,000°F), which is nearly two-thirds the temperature of the Sun's surface—and hot enough to not only melt steel, but also boil it.

pyrotechnics fireworks display; the art of building fireworks

About 123.6 seconds after liftoff, computer commands are relayed for another set of explosive bolts to detonate and separate the boosters from the orbiter's external fuel tank. The shuttle's three main engines continue burning to carry the spaceship into orbit. The boosters, however, have completed their mission. They continue to fly solo another 21,300 meters (70,000 feet) or so before their fuel is fully consumed, and the now-empty canisters begin falling back down toward the ocean.

Parachutes slow the boosters' descent and cushion their crash into the Atlantic Ocean. The spent boosters splash down about 227 kilometers (141 miles) from the launch site. They are retrieved by two special ships waiting in the area, and towed back to the Kennedy Space Center in Florida, where they are processed and returned to the manufacturer. The segmented motors are disassembled, and the cylindrical cases are cleaned, reinsulated, and refilled with propellant. The exhaust nozzles are refurbished, and other components are replaced as needed. Nose cone and aft skirt assemblies are added to turn the motor into a completed booster.

Measuring 45.4 meters (149 feet) tall and 3.7 meters (12 feet) in diameter, the shuttle's solid rocket boosters are the largest solid propellant motors ever flown. They are also the first that were designed to be reusable. The boosters are filled with a special mixture consisting of ammonium perchlorate, which is an **oxidizer**; aluminum for fuel; iron oxide, which is a polymer to bind the ingredients together; and an epoxy curing agent. This mixture is liquid when poured into the segments that form each motor. The propellant is cured over a period of four days until it solidifies. When it hardens, it has the color and consistency of a pencil eraser.

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

At launch, each booster weighs 590,200 kilograms (1.3 million pounds), which includes 499,400 kilograms (1.1 million pounds) of propellant. The other parts of the booster are the cases, igniters, nozzles, separation systems, flight instruments, recovery avionics, pyrotechnics, deceleration systems, steering equipment, and **range safety destruct systems**. Each booster is made up of four solid rocket motor segments, which are transported by special railcars to the shuttle's launch site at the Kennedy Space Center.

range safety destruct system system of procedures and equipment designed to safely abort a mission when a spacecraft malfunctions, and destroy the rocket in such a way as to create no risk of injury or property damage

The boosters were redesigned after the 1986 Challenger disaster, which claimed the lives of seven astronauts and destroyed a $2 billion orbiter. The disaster primarily was blamed on a faulty joint between two of the solid rocket fuel segments on the shuttle's right booster. A special commission that investigated the tragedy concluded that the joint had design flaws, which were exacerbated by the cold temperatures in the hours before Challenger's liftoff. A rubber O-ring seal leaked, allowing hot gases to escape and to trigger the explosion of the shuttle's fuel tank and the loss of the vehicle and the crew. SEE ALSO External Tank (volume 3); Rocket Engines (volume 1); Rockets (volume 3); Space Shuttle (volume 3).

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Space Centers

Space centers generally are associated with launch sites for spacecraft. However, many facilities operated by the National Aeronautics and Space Administration (NASA) and other space agencies are not directly related to launch activities. These centers are involved in a variety of projects that directly and indirectly contribute to the goals of each space agency.

NASA Centers

NASA has ten major centers in the United States in addition to its headquarters in Washington, DC, and several smaller facilities. NASA inherited some of these centers from its predecessor, the National Advisory Committee for Aeronautics (NACA), when NASA was created in 1958. Other centers were created after NASA was established, in large part to carry out the agency's early goal of landing a man on the Moon by the end of the 1960s.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

Perhaps the best known NASA center is the Kennedy Space Center (KSC) at Cape Canaveral, Florida. The military had been launching **rockets** from Cape Canaveral since 1950, and so it was the logical place for NASA to establish a site for launches of the giant Saturn rockets that would send the **Apollo** missions to the Moon. The Launch Operations Center was established in 1962 on land just north of the existing launch facilities at Cape Canaveral; it was renamed the Kennedy Space Center (KSC) a month after the death of President John F. Kennedy. KSC's facilities include two large launch pads originally built for the Saturn V rockets and now used for shuttle missions and the giant Vehicle Assembly Building, one of the largest buildings in the world by volume. KSC's primary responsibility today is to prepare and launch shuttles.

Shuttle missions are run from the Johnson Space Center (JSC) in Houston, Texas. The center was established by NASA in 1961 as the Manned Spaceflight Center to manage all piloted spaceflight activities; it was renamed in 1973 after the death of former president and Texas native Lyndon B. Johnson. Mission control for shuttle missions and the International Space Station (ISS) is located at JSC. The center is also home to the astronaut corps, who train for missions at the center.

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

Other centers are closely involved with human spaceflight. The Marshall Space Flight Center (MSFC) in Huntsville, Alabama, was established in 1960 when the U.S. Army transferred some facilities and personnel, including Wernher von Braun, from the Redstone Arsenal to NASA. The Saturn V rocket was developed at Marshall, along with the space shuttle's main engines, external tank, and solid rocket boosters. Marshall is also involved with the ISS and conducts research on future **reusable launch vehicles**. The Stennis Space Center in southern Mississippi, originally known as the Mississippi Test Center, was created in the early 1960s to test the engines used on Saturn V. It has also been used to test other engines, including the space shuttle's.

Although some work on the space shuttle and the ISS takes place at NASA's other centers, these facilities are primarily involved with other NASA projects. The Jet Propulsion Laboratory (JPL) in Pasadena, California operates most of NASA's robotic planetary science missions. Scientists

Aerial overview of the John C. Stennis Space Center Visitors Center and main administrative complex in Mississippi.

at nearby Caltech established JPL in the 1930s as a place to test rockets; it was supported by the U.S. Army from the time of World War II until 1958, when it was transferred to NASA. The Goddard Space Flight Center (GSFC) was created in 1959 when 160 people were transferred from the Naval Research Laboratory's Vanguard rocket project to a new facility in Greenbelt, Maryland. The center is involved primarily with astronomy and earth science missions and is home to the mission control center for the Hubble Space Telescope.

Some of NASA's centers predate the space agency itself. The Dryden Flight Research Center dates back to 1947, when NACA created the Muroc Flight Test Unit at Edwards Air Force Base, California, to test high-speed aircraft. It is used today for aeronautical research and the testing of some experimental aircraft and spacecraft. The Glenn Research Center in Cleveland, Ohio, was created by NACA in 1941 as the Aircraft Engine Research Laboratory; it was renamed the Lewis Research Center when NASA took it over in 1958 and renamed again in 1999 after the former astronaut and senator John Glenn. It is involved in a number of aviation and space technology programs. The Langley Research Center in Hampton, Virginia began in 1917 as NACA's first research center. Like Glenn, it is involved primarily in aeronautics and space technology research. The Ames Research Center in Mountain View, California, started as a NACA research laboratory in 1939. It is involved today in research in aeronautics, high-speed computing, and astrobiology.

Overseas Space Centers

Space agencies outside the United States also operate a number of space centers. The most extensive network of centers belongs to the European Space Agency (ESA). In addition to its headquarters in Paris, ESA operates five major centers. The European Space Research and Technology Centre in Noordwijk, the Netherlands, is ESA's largest center, home to Earth and space science research as well as the testing and development of spacecraft. The European Space Operations Centre in Darmstadt, Germany, serves as mission control for ESA's spacecraft missions. The European Space Research Institute near Rome is responsible for ESA's Earth observation programs and its Vega small launch vehicle project. The European Astronaut Centre in Cologne, Germany, trains European astronauts for missions on the space shuttle or on Russian Soyuz spacecraft. ESA also operates a launch site at Kourou, French Guiana, on the northeastern coast of South America.

The Russian Aviation and Space Agency, Rosaviakosmos, has a primary center in Moscow at its headquarters. It also operates the Gagarin Cosmonaut Training Center outside Moscow and has a number of small research centers and design bureaus. With the Russian military and aerospace companies, it operates the main Russian launch center at Baikonur, Kazakhstan, which is used for all piloted missions and many unpiloted flights, as well as other launch centers at Plesetsk in northern Russia and Svobodny in Siberia. The National Space Development Agency of Japan (NASDA) has its headquarters in Tokyo, a large research center in Tsukuba, a launch site at Tanegashima, and several small centers elsewhere in the country. SEE ALSO Astronauts, Types of (volume 3); History of Humans in Space (volume 3); Hypersonic Programs (volume 3); Launch Management (volume 3); Launch Sites (volume 3); Mission Control (volume 3); NASA (volume 3); Rockets (volume 3); Rocket Engines (volume 1); Vehicle Assembly Building (volume 3).

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Space Shuttle

Before the invention of the space shuttle, the world's first reusable spacecraft, **rockets** were used to put a tiny capsule carrying human space travelers into orbit. Stage by stage, booster segments would fall away during the launch as their fuel ran out. The spacecraft would go into orbit around Earth, and then the multi-stage rocket would plunge into the ocean. At that point the rocket would become space rubbish.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

In the late 1960s the federal government ordered the National Aeronautics and Space Administration (NASA) to cut costs because of the lagging economy. On January 5, 1972, after suspending several other space programs, President Richard M. Nixon gave NASA the authority to proceed with the development of the shuttle in hopes that the cost of future space travel would be reduced.

The first space shuttle orbiter, known as OV-101, rolled out of a Rockwell assembly facility in Palmdale, California on September 17, 1976. The shuttle was originally to be named Constitution, but fans of the television show *Star Trek* started a write-in campaign urging the White House to choose the name "Enterprise" instead.

The Enterprise had no engines and was built to test the shuttle's gliding and landing ability. Early glide tests that began in February 1977 were done without astronauts and with the orbiter attached to the back of a converted Boeing 747 jet airplane. This vehicle was referred to as a Shuttle Carrier Aircraft (SCA).

The Enterprise took to the air on its own on August 12, 1977, when astronauts Fred W. Haise and C. Gordon Fullerton flew the 68,000-kilogram (75-ton glider) around a course and made a flawless landing. They had separated the shuttle from the SCA at 6,950 meters (22,800 feet) and glided to a runway landing at Edwards, California. The Enterprise was retired after its fifth test.

On April 12, 1981, Columbia became the first shuttle to actually fly into space. Four sister ships joined the fleet over the next ten years: Challenger, arriving in 1982 but destroyed four years later; Discovery, arriving in 1983; Atlantis, arriving in 1985; and Endeavour, built as a replacement for Challenger in 1991.

The Space Shuttle's Mission

The shuttle has many capabilities unprecedented in human spaceflight, including the ability to retrieve or repair a satellite, house a laboratory for weeks in orbit, and deploy satellites or planetary probes.

Through its reusability, the shuttle was initially intended to provide low-cost frequent access to space. But according to NASA, the shuttle has not been able to fly often enough (only four to eight missions a year) to significantly lower launch costs. In the fiscal year 2001, the operating cost of the shuttle program was $3.165 billion, which is approximately 25 percent of NASA's entire budget.

The Structure of the Space Shuttle

The most complex machine ever built, the space shuttle has more than 2.5 million parts, including four major components: (1) the orbiter, (2) three

Space shuttle Endeavour in operation, with its payload bay doors open and mechanical arm extended.

main engines, (3) an external fuel tank, and (4) two solid rocket boosters. Combined, the weight at launch is approximately 2.1 million kilograms (4.5 million pounds). About the size of a DC-9 commercial airliner, the orbiter, which typically carries a five- to seven-person crew, is the main part of the space shuttle. Constructed primarily of aluminum, it has a length of 37 meters (121 feet) and a wingspan of 23 meters (78 feet).

The orbiter is divided into two parts: the crew cabin and the cargo bay. The crew cabin contains the flight control center and living quarters for the crew. The long middle part of the shuttle is the cargo area and contains the payload bay. Whatever is stored in this area represents the purpose for the mission and "pays" for the flight. The payload bay is 18.3 meters (60 feet) long by 4.6 meters (15 feet) in diameter and can carry 29,500 kilograms (65,000 pounds) into space.

Because the United States could not afford to construct a space workshop on its own, NASA partnered with the European Space Agency (ESA). On August 14, 1973, 14 nations contributed $500 million to build the Spacelab module, which is a portable science laboratory that could be loaded into the cargo bay.

In June 1993 the Spacehab Space Research Laboratory made its debut aboard the STS-57. Spacehab modules, which are leased to NASA by Spacehab, Inc., of Arlington, VA, provide extra space for crew-tended experiments. Spacehab is in the forward end of a shuttle orbiter's cargo bay and increases pressurized experiment space in the shuttle orbiter by 31 cubic meters (1100 cubic feet), quadrupling the working and storage area. During shuttle-*Mir*, Spacehab modules were used to carry supplies and equipment up to *Mir*. Spacehab also provides shuttle experiments with standard services such as power, temperature control, and command-data functions.

Astronauts float together in zero gravity inside the Spacehab facility onboard the space shuttle Discovery.

To get the orbiter into space, the main engines and the booster rockets ignite simultaneously to lift the shuttle. About 2 minutes after launch the boosters complete their firing sequence, separate from the external tank (ET), and by parachute fall into the Atlantic Ocean, where they are recovered and used in a later shuttle launch.

The orbiter continues its flight into space with the main engines furnishing ascent power for another 8 minutes before they are shut down just before achieving orbit. The empty ET separates and falls back to the atmosphere, where friction causes it to break up over the ocean. This is the only major part of the shuttle that is not reused after each flight.

In orbit, the shuttle circles Earth at 28,157 kilometers (17,500 miles) per hour. Each orbit takes about 90 minutes, and the crew sees a sunrise or sunset every 45 minutes.

When the mission ends and the orbiter begins to glide back through the atmosphere, special exterior insulating tiles prevent the vehicle from burning up. The 15.2-centimeter (6-inch) silica tiles shed heat so well that one side is cool enough to hold in the bare hands while the other side is red-hot and withstands temperatures of 2,300°F. Tiles occasionally get damaged during launch or landing and need to be replaced.

Spinoff Benefits of the Space Shuttle

Although it is a U.S. national asset, the shuttle has had a very international presence, flying astronauts, cosmonauts, and experiments from dozens of countries. Many benefits have come from the research and technologies developed as a result of the shuttle.

The same rocket fuel that helps launch the space shuttle has been used to save lives by destroying land mines. A flare device that uses leftover fuel donated by NASA is placed next to an uncovered land mine and is ignited from a safe distance by using a battery-triggered electric match.

Space shuttle technology has also led to medical benefits. The technology used in space shuttle fuel pumps led NASA and the heart surgeon Doctor

Michael DeBakey to develop a miniaturized ventricular assist pump. The tiny pump, which has been implanted into more than 30 people, is 5.1 centimeters (2-inches) long and 2.5 centimeters (1-inch) in diameter and weighs less than 0.11 kilogram (4 ounces). Another development has been the spin-off of special lighting technology developed for plant growth experiments on space shuttle Spacelab missions. This technology has been used to treat brain tumors in children. In addition, a non-surgical and less traumatic breast biopsy technique based on technology developed for NASA's Hubble Space Telescope saves women time, pain, scarring, radiation exposure, and money. Performed with a needle instead of a scalpel, it leaves a small puncture wound rather than a large scar.

Preparing the Space Shuttle for the Future

In 1988, when Discovery returned the fleet to space following the Challenger accident, more than 200 safety improvements and modifications had been made. The improvements included a major redesign of the solid rockets, the addition of a crew escape and bailout system, stronger landing gear, more powerful flight control computers, updated navigational equipment, and several updated avionic units.

Shuttle improvements did not stop with Discovery. Endeavour's first flight in 1992 unveiled many improvements, including a drag chute to assist braking during landing, improved steering, and more reliable power hydraulic units. Further upgrades to the shuttle system occurred when Columbia was modified to allow long-duration flights. The modifications included an improved toilet and a regenerative system to remove carbon dioxide from the air.

Future enhancements planned by NASA could double the shuttle's safety by 2005. New sensors and computer power in the main engines will detect trouble a split second before it can do harm, allowing a safe engine shutdown. A next-generation "smart cockpit" will reduce the pilot's workload in an emergency, allowing the crew to focus on critical tasks. Other improvements will make steering systems for the solid rockets more reliable.

Besides increasing safety and cutting costs, another objective in the next generation of spacecraft is to reduce the amount of preparation time and work required between launches. The shuttle currently takes an average of four months to be readied for launch. Goals for future spacecraft call for turnaround times of only a few weeks, if not days.

The space shuttle is prepared to fly until at least 2012 and perhaps as long as 2020. Each of the four shuttle vehicles was designed for 100 flights. In 2001, Discovery led the fleet with 30 completed flights. Over two-thirds of the shuttle fleet's lifetime is ahead of it. However, continuous upgrades and modifications will be required to ensure improved safety and protect against obsolete parts. SEE ALSO Astronauts, Types of (volume 3); Challenger (volume 3); Challenger 7 (volume 3); External Tank (volume 3); History of Humans in Space (volume 3); Human Spaceflight Program (volume 1); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Solid Rocket Boosters (volume 3).

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Space Stations, History of

The history of building and operating **space stations** in Earth orbit has followed two paths, which did not come together until the late twentieth century with the International Space Station. Russia (before 1991, the Soviet Union) has devoted its energies to building, launching, and operating expendable stations that could not be resupplied—a total of ten between 1971 and 1986. The United States, on the other hand, has focused on planning permanent space stations, launching only one prototype before International Space Station assembly began in 1998.

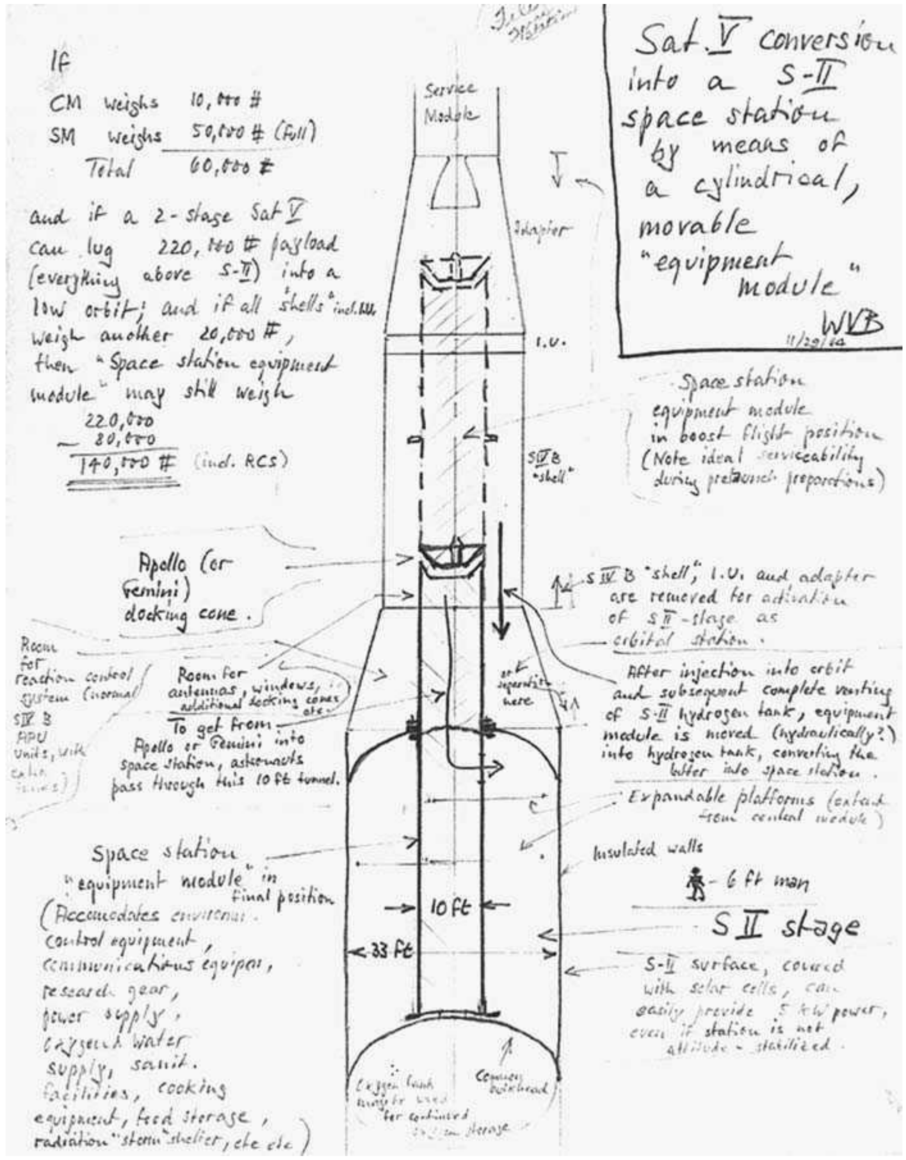
space stations large orbital outposts equipped to support a human crew and designed to remain in orbit for an extended period

Salyuts and Mir: Soviet/Russian Space Stations

In 1903 Russian schoolteacher Konstantin Tsiolkovsky (1857–1935), the father of Russian spaceflight, described Earth-orbiting space stations where humans would learn to live in space. Tsiolkovsky hoped that these would lead to space settlements and Moon and Mars voyages. Nearly seventy years later, Soviet engineers moved Tsiolkovsky's dreams a step closer to reality by launching the Salyut 1 space station.

Salyut 1 (1971) was the first of seven first-generation Soviet space stations. Three of these, including Salyut 2, failed before cosmonauts could occupy them. Cosmonauts flew to the orbiting stations aboard Soyuz spacecraft. Salyut 1 and Salyut 4 (1974–1977) were civilian; Salyut 2 (1973), Salyut 3 (1974–1975), and Salyut 5 (1976–1977) were military. The stations could not be resupplied, so they had limited lifetimes in orbit. In all, six crews lived and worked aboard Soviet first-generation space stations. The longest stay duration was sixty-one days.

The Soviets launched two second-generation space stations. Both Salyut 6 and Salyut 7 were largely civilian and included a second docking port. Soyuz spacecraft bearing visiting cosmonauts docked at the second port, as did automated Progress resupply spacecraft. Salyut 6 (1977–1982) received sixteen cosmonaut crews, including six long-duration crews and visiting citizens of seven countries. The longest stay duration on Salyut 6 was 185 days. Twelve Progress freighters delivered more than 20 tons of supplies, equipment, and fuel. Salyut 7 (1982–1991) received ten crews, including six long-duration crews, visiting citizens of two countries, and the first woman space traveler since 1963. The longest stay duration was 237 days. Salyut 7 was



Wernher von Braun sketched his vision of a space station (shown here) in November 1964.

last staffed in 1986, and it underwent uncontrolled re-entry over Argentina in 1991.

A total of three prototype space station modules docked with Salyut 6 and 7, paving the way for the third-generation Mir station (1986–2001). Mir was the first station designed for expansion to add new capabilities. During its fifteen-year life span, Mir received the Kvant (1987), Kvant 2 (1989), Kristall (1990), Spektr (1995), and Priroda (1996) expansion modules, as well as the Docking Module (1995), which permitted U.S. space shuttle dockings. These additions boosted Mir's weight from 20.4 tons at launch to about 135 tons at re-entry. Mir received thirty-one Soyuz and sixty-four Progress spacecraft and hosted twenty-eight long-duration crews. The longest stay duration was 483 days. American space shuttles docked with Mir nine times. Citizens of twelve countries, including seven Americans, lived on Mir for up to six months. Mir was deorbited over the Pacific Ocean in March 2001.

Russian-built Salyut 7 space station in Earth orbit in 1985.

Skylab: The U.S. Space Station

In 1959 the National Aeronautics and Space Administration (NASA) called for development of a space station by 1970. In 1961, however, President John F. Kennedy declared that putting a man on the Moon by 1970 should be NASA's main goal, delaying the station. It was the first of many postponements in NASA's space station plans.

A 1964 NASA proposal called for building space stations using Apollo program technology. This led to Skylab, the first U.S. space station. Skylab left Earth in May 1973 atop a Saturn V rocket similar to those that launched Apollo astronauts to the Moon. The rocket's third stage carried no fuel—instead, it was heavily modified to provide laboratory space and living quarters for three-person crews. Apollo spacecraft designed originally for lunar flights ferried astronauts to and from Skylab. Three crews lived on the station, achieving stay durations of twenty-eight, fifty-six, and eighty-four days.

Skylab was not designed for resupply or refueling, and could not boost itself to a higher orbit when its orbit decayed through friction with Earth's upper atmosphere. In July 1979 Skylab deorbited and was destroyed over Australia.

International Space Station

In 1969 NASA proposed building a space station in the late 1970s. A reusable space shuttle would deliver crews and supplies to the orbiting outpost. By 1971, however, budget cuts forced NASA to postpone space station work and concentrate on building the space shuttle, which first flew in April 1981.

With the shuttle flying, NASA again proposed a space station. Because the Saturn V was no longer in production, NASA planned to launch its station in many pieces in the cargo bay of the space shuttle. In January 1984 President Ronald Reagan called for a U.S. space station within a decade. He invited Europe, Japan, and Canada to help build it.

Unfortunately, NASA underestimated the cost and complexity of its station plan. Space Station Freedom, as Reagan named it in 1987, underwent a series of redesigns. One occurred after the Challenger disaster (in January 1986) showed that the shuttle could not fly as often as originally planned. Another occurred in 1991, after studies showed that building and maintaining Freedom would take most of the crew's efforts, leaving little time for scientific research.

In 1993 new U.S. President Bill Clinton considered canceling Freedom. Instead, he ordered another redesign and made Russian participation in the station the flagship of his policy of aiding the financially strapped Russians in exchange for assurances that they would not sell nuclear missile technology to other countries. The redesigned station was renamed the International Space Station. Though the NASA-Russia relationship was often difficult, the partners each had something the other needed: NASA had money and Russia had nearly thirty years of space station experience.

Russia launched the first International Space Station component, a propulsion module called Zarya, in November 1998. NASA paid for Zarya. The first U.S.-built module, called Unity, was carried to Zarya in the cargo bay of space shuttle Endeavour in December 1998. The Russian-built Zvezda Service Module arrived in July 2000, and the first crew, consisting of two Russians and one American, took up residence in November 2000. SEE ALSO Capsules (Volume 3); International Space Station (Volumes 1 and 3); Mir (Volume 3); Space Stations of the Future (Volume 4).

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Space Suits

Protective suits were unnecessary until airplanes achieved fast speeds and high-flight altitudes. Medical researchers then conducted a special study of human physiology during flight. New, stronger, high-temperature-resistant synthetic materials were developed. This research permitted humans to walk in space and on the Moon and made it possible to build and maintain a permanent space station.

1930s: Early Pressure Suits

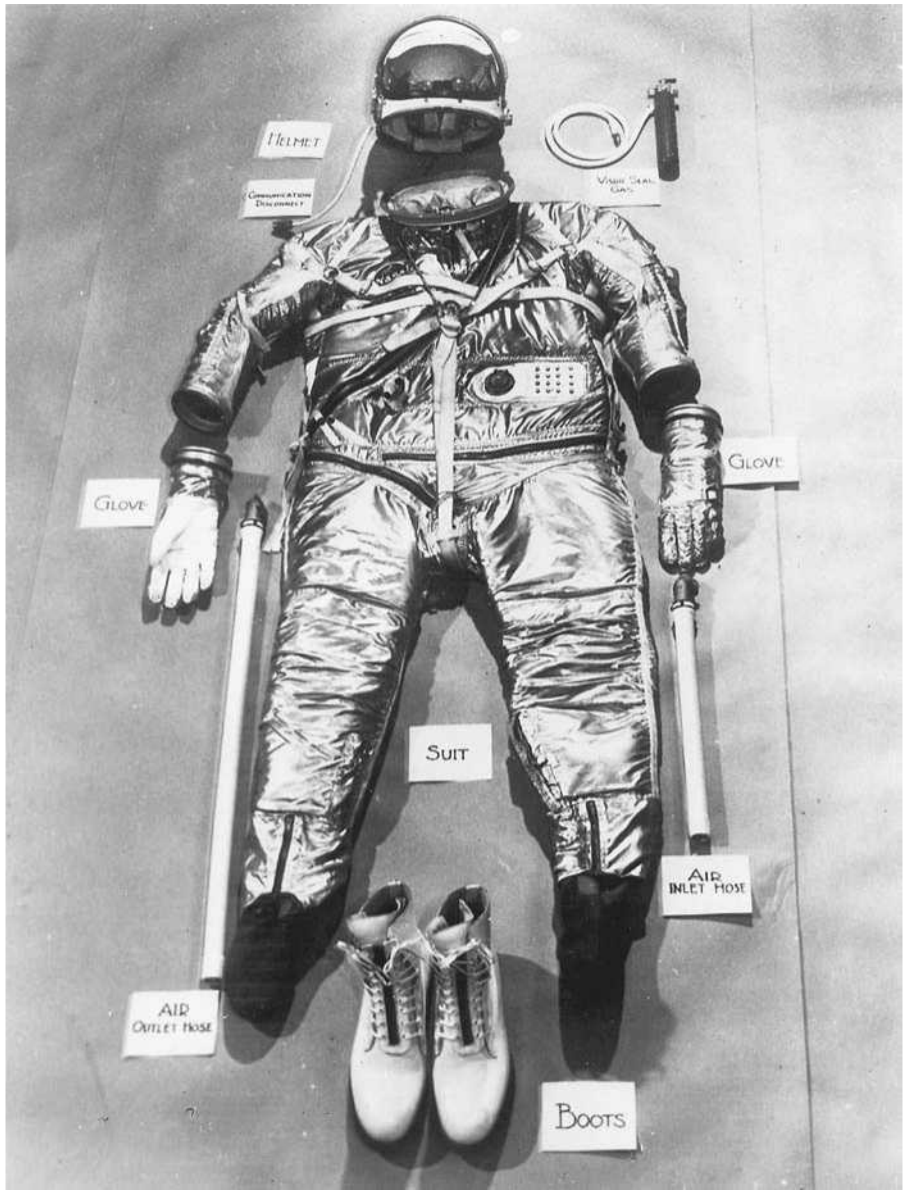
In 1933 Wiley Post, while flying air races, discovered that he could not fly in the jet stream unless he had a pressurized enclosed cabin or wore a pressurized suit. After Post contacted the B. F. Goodrich Company, engineer Russell Colley's group designed a suit that could hold 1.1 kilograms (2.4 pounds) of pressure. Two latex-dipped metal forms spliced together shaped the upper and lower torso. The outer layer of three-ply cotton fabric with arms allowed the wearer to reach the stick and throttle. Post, in this pressure suit, made several successful stratospheric flights in his plane, *The Winnie Mae.*

1940s: World War II Flight Needs

In the early 1940s, the U.S. Army and Navy became interested in Colley's work on pressure suits. After Colley saw a tomato worm in his garden turn 90 degrees without a perceptible increase in pressure anywhere on its body, the team adapted segmented bellows for the arms and legs of the suit. This gave the pilot rudimentary mobility and the ability to assume a sitting position.

But other flight problems had to be solved. B-24 and B-25 crews in mass bombing raids mysteriously crashed with no evidence of their having made attempts to escape. The concept of **G forces**, a new term for acceleration and the resulting problems, was consequently realized. A partial pressure suit developed by James Paget Henry at the University of Southern California produced the next important development. Anti-g suits based on Henry's bladder-type antigravity construction, commonly called g-suits, evolved as close-fitting garments with rubber bladders. As the plane reached a high altitude and developed greater speed, the suit automatically inflated with gas. This provided pressure to the calves, thighs, and abdomen to offset the increased pressure of acceleration on arterial blood flow in those areas. Aeromedical physicians found that blood pooled in the lower body at high altitudes and thus was not forced back toward the heart and recirculated to the head. Fatigue, loss of vision, and unconsciousness set in.

G forces the force an astronaut or pilot experiences when undergoing large accelerations



Mercury astronaut suit and its associated equipment: helmet, communications disconnect, visor seal gas, gloves, air inlet hose, air outlet hose, and boots.

Today all pilots of long-duration high-speed, and high-altitude planes wear g-suits.

1950s: Emergence of the Cold War and the Space Race

Both the United States and the Soviet Union, using captured German V-2s, pursued exploration of the upper atmosphere. On November 1, 1952, the United States detonated the world's first thermonuclear explosion; the Soviets exploded their device in 1953. This spurred intercontinental ballistic missile (ICBM) development.

On October 4, 1957, the Soviets successfully launched Sputnik 1, the first satellite in space, whereas the U.S. Explorer 1 achieved orbit on January 31, 1958. And thus, the space race was on. Unpiloted American and Soviet spacecraft carrying mice, chimpanzees, monkeys, dogs, and other small animals were sent into space and returned above modified German V-2s.

A technician outfits astronaut Scott J. Horowitz in a space shuttle launch and entry garment during an emergency egress training session.

1960s: Human Spaceflight

Modified ICBM **rockets** successfully boosted the first humans into space. On April 12, 1961, the Russian cosmonaut Yuri Gagarin aboard Vostok 1 lifted off into space to achieve the first Earth orbit. On May 5, 1961, astronaut Alan Shepard aboard Freedom 7 became the first American to complete a suborbital spaceflight.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

Shepard's space suit had zippered openings, a neoprene-coated nylon layer to prevent leakage, an airtight neck ring bearing, fabric-fluted shoulder and knee joints, and an overgarment fabricated of high-temperature-resistant aluminized nylon. The helmet locked onto the suit's special padded neck ring.

Gagarin's Sokol space suit used a similar multiple-layered construction but had a bladder system made of natural rubber instead of synthetic rubber. The Soviets also used restraint layers to give shape and attach boots, gloves, and a helmet. Hardware sealing materials were all made of natural rubber. The Russians fabricated cover layers from their version of nylon restraint materials. Both suit systems used an internal duct system to remove carbon dioxide from the helmet area and facilitate cooling.

Mid-1960s: The Gemini Program and Walks in Space

On March 18, 1965, Edward White became the first American to walk in space. His twenty-layer suit contained biomedical amplifiers to relay information about the astronaut's pulse and blood pressure. A bladder layer contained rubberized nylon to hold air during compression. Dacron cord woven like fishnet, called linknet, restrained the bladder layer. An aluminized-coated, high-temperature nylon antisnag garment covered the suit. A portable Gemini extravehicular life support system (ELSS) chest pack and umbilical provided electrical wires for communication and bioinstrumentation transmittal.

Late-1960s: Apollo to the Moon

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

For Apollo missions lunar space suits protected astronauts from lunar temperatures between −150 and 120°C (−238 and 248°F), **cosmic radiation**, and exposure to high-speed meteoroid particles in gravity one-sixth that of Earth.

The astronauts inside the spacecraft wore five-layer suits. Astronauts on extravehicular walks wore the twenty-one-layer garment over a three-layer liquid cooling garment. Mylar polyester film added tensile strength, resistance to chemicals and moisture, and the ability to withstand fluctuations in the lunar temperature. Kapton combined with Teflon provided a stable insulating material. Beta cloth with Teflon added tensile strength and abrasion resistance. A fishbowl-like helmet replaced the pilot-style closed helmet. The Apollo suit, including the primary life support system, weighed about 81 kilograms (180 pounds). Neil Armstrong and Buzz Aldrin gave the Apollo suit high marks after their July 20, 1969, Apollo 11 lunar excursions.*

***The U.S. astronauts during the Apollo missions were the first and only humans to land and walk on the Moon.**

1970s to Present Day

Reusable space shuttle suits, or extravehicular mobility units (EMU), are modular and are designed to fit both male and female astronauts. For flight, the astronaut puts on a liquid cooling and ventilation garment, a one-piece suit made of Spandex mesh covered with 91.5 meters (300 feet) of cooling water tubing. Then the lower torso assembly (pants) is pulled on. The astronaut then thrusts the arms up into the hard upper torso and backpack hanging on the wall and hooks the two pieces together. The gloves and bubble helmet assembly go on last.

The space suit alone weighs 47 kilograms (104 pounds), the primary life support system adds another 67 kilograms (148 pounds), and the helmet, lights, and camera, at 3.6 kilograms (8 pounds), bring the total weight of the EMU to 117.6 kilograms (260 pounds). The gloves, with miniature heating units, are now custom-fitted at a cost of approximately $20,000 apiece. A suit costs approximately $1.5 million.

The modular EMU used in conjunction with the construction of the International Space Station has been modified to be capable of 25 EVAs (walks in space) and can stay in orbit up to 9 months. The suits used today have a life expectancy of about 25 years.

Future Martian Exploration

ILC and Hamilton Sunstrand engineers are developing a suit that is especially nimble yet sturdy enough for long walks through difficult terrain. Astronauts need sufficient mobility to recover from falls, carry their backpacks, and complete geological experiments. The gravity on Mars is three-eighths that of Earth, compared to the one-sixth gravity on the Moon. The new suits use soft fabric and lightweight aluminum, making them lighter, cheaper, and easier to put on and take off, with greater mobility for an operational environment of fractional gravity or even zero gravity. The aluminum surface will allow higher pressure than the space shuttle/space station suits—about 8.3 psi—which is closer to Earth-like atmospheric pressures, eliminating the need to prebreathe pure oxygen. SEE ALSO Apollo (volume

3); Life Support (volume 3); Sanitary Facilities (volume 3); Space Walks (volume 3).

Lillian D. Kozloski

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Space Walks

A space walk, also known as extravehicular activity (EVA), is an activity or maneuver performed by an astronaut outside a spacecraft. Astronauts perform EVAs for a variety of reasons, including exploration, research, and construction of structures in space. The first space walks of the Soviet Union and the United States in 1965 proved that humans could venture from their spacecraft into space. To judge by the reactions of some astronauts, walking in space was an exhilarating experience. Edward White, the first American space walker, overextended his EVA, and returned to his Gemini spacecraft with great reluctance.

Nevertheless, space is a hostile environment to unprotected astronauts. It lacks oxygen and water. Without Earth's atmosphere to filter the sunlight, temperatures can reach 170°C (338°F), while in shadows the temperature can drop to –120°C (–184°F). Hazardous **micrometeoroids** and radiation also threaten spacewalkers, and with no atmosphere and therefore no atmospheric pressure, fluids in the human body would boil. To explore and work in space, human beings must take their environment with them. Inside the spacecraft, the atmosphere can be controlled so that special clothing is not needed, but when outside, humans need the protection of a space suit.

micrometeoroid any meteoroid ranging in size from a speck of dust to a pebble

In March 1965, Soviet cosmonaut Alexei Leonov became the first person to don a space suit and walk in space. His exploit was followed in June of that year by White's twenty-two-minute space walk. White was protected by a multilayer space suit that included a pressure bladder and a link-net restraint layer to make the whole suit flexible. In his hand White held a small maneuvering unit, but he remained tethered to the spacecraft. The first space walk to test whether humans could perform useful activities in space occurred during the flight of Gemini 9 in May 1966. A complicated series of

The first American to step outside his spacecraft and let go, Edward H. White floated in zero gravity for 23 minutes. A 25 foot umbilical line linked White to the spacecraft.

tasks were to be performed by astronaut Eugene Cernan as a prelude to testing a sophisticated maneuvering unit. Soon after beginning his EVA, however, Cernan became overheated and his helmet visor fogged over. Finally, after two hours, Cernan was ordered back inside. Similar problems occurred during a space walk on Gemini 11.

The experience of early spacewalkers underscored the need for detailed planning and training for an EVA. By the time of Gemini 12 in November 1966, preparations for EVA included extensive practice sessions in water tanks that simulated the effect of weightlessness. During that mission, Edwin "Buzz" Aldrin performed numerous tasks with few of the problems that struck Cernan and others. Aldrin set an EVA record of five and a half hours for a single space walk, unscrewing bolts and tightening them and checking electrical connections. He had proved that astronauts could perform useful work during a space walk.

Walking on the Moon

Walking on the Moon's surface a quarter million miles away from Earth posed new problems for spacewalkers. Not only did astronauts have to be protected from jagged rocks and the searing heat of the lunar day, but the suits also had to be flexible enough to allow the astronauts to bend over and gather samples. When Apollo 11 crew members Neil Armstrong and Buzz Aldrin set foot on the Sea of Tranquility in July 1969, their EVA suits contained a number of innovations.

Numerous layers provided protection against micrometeoroids and thermal extremes. Mobility was enhanced by bellows-like molded rubber joints at the shoulders, elbows, hips, and knees. Underneath it all was a liquid-cooling garment with a network of water-filled tubes to keep the astronaut cool. A portable life support system provided oxygen for breathing, suit pressurization, and ventilation for Moon walks lasting up to seven hours. Clad in this gear, Aldrin concluded that he was able to move about rapidly and with confidence.

Tasks for Apollo moonwalkers grew more complex as the program progressed, and modifications were made to the space suit for the Apollo 15 through Apollo 17 missions to provide greater flexibility. In July 1971, Apollo 15 astronauts David Scott and James Irwin stepped into the dazzling light of the lunar day and boarded a dune-buggy-like lunar rover at the foot of the Moon's Apennine Mountains. When they returned from their first tour, the rover's odometer had accumulated 10 kilometers (6.2 miles). The next day, the two astronauts made a 12.5-kilometer (7.8-mile) trip up the slope of the Apennines. At the end of the third EVA, Scott and Irwin had spent a highly productive eighteen and a half hours on the lunar surface and had packed away 77 kilograms (170 pounds) of rocks.

Apollo 17 launched in December 1972, marked the first time a geologist walked on the Moon. Harrison "Jack" Schmitt used his geologist's eye to spot "orange soil" initially believed to be evidence of volcanic venting of water from the Moon's interior. On the third day on the Moon, the final EVA produced a satisfyingly varied collection of samples. In all, Schmitt and mission commander Eugene Cernan conducted three Moon walks for a total of twenty-two hours and two minutes.

Construction Workers and Repairers

Apollo 17 was the last lunar flight, but **spacewalking** astronauts continued to perform important tasks in space. In 1973 astronaut Charles "Pete" Conrad literally saved America's first **space station**, Skylab, by donning his space suit and fixing a damaged solar panel. After making repairs and deploying a parasol-type sun shield, the workshop became fully operable. The second Skylab crew erected another sun shield during an EVA. These successes were testament to the growing space walk experience of the National Aeronautics and Space Administration (NASA) and advances in EVA training. NASA has increasingly relied upon simulations in water tanks as an essential tool for EVA training of astronauts and the design, testing, and development of tools and equipment. For astronauts, these facilities provide important preflight familiarization with planned crew activities and with the dynamics of body motion under weightless conditions. Major advances have also been made in space suit design to further facilitate space walk activities.

spacewalking moving around outside a spaceship or space station, also known as extravehicular activity

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

To work in the cargo bay of the space shuttle or in space, astronauts now wear the shuttle Extravehicular Mobility Unit (EMU) space suit, which was designed to be more durable and more flexible than previous space suits. The upper torso, lower torso, arms, and gloves come in different sizes and can be assembled in combination to fit men and women astronauts. In all, the EMU comprises the space suit assembly, the primary life-support system, a display and control module, and several other crew items designed for space walks and emergency life support.

The shuttle era also witnessed the first untethered space walks by U.S. astronauts in orbit. The Manned Maneuvering Unit (MMU), a one-person, nitrogen-propelled backpack, allowed astronauts to fly in or around the orbiter cargo bay or to nearby free-flying payloads or structures. Astronauts wearing MMUs have deployed, serviced, repaired, and retrieved satellites. Other spacewalkers attached to the end of the shuttle's remote manipulator arm have repaired and refurbished the Hubble Space Telescope.

Spacewalkers faced an unprecedented challenge in constructing the International Space Station. To prepare for the challenge, engineers and astronauts have been methodically practicing procedures, preparing tools, testing equipment, and gaining experience during more than a decade of shuttle space walks. Since 1991, over a dozen "practice" space walks have been conducted from the space shuttle as part of NASA's preparations. Other space walks have evaluated new tethers, tools, foot restraints, a jet-pack "life jacket," and space suit enhancements. Astronauts have also gained experience handling large masses. In addition, three servicing missions to the Hubble Space Telescope have helped prepare for the intricate work needed to build the space station.

In August 1996, NASA announced the first International Space Station EVA assembly crew of Jerry Ross and James Newman for space shuttle flight STS-88. In June 1997, five more crews of spacewalkers were named to the first six shuttle assembly missions, some of them more than two years ahead of their scheduled mission. The early naming of crew members allowed the astronauts time to train for their complex and crucial missions. Overall, about 160 space walks, totaling 960 clock hours, or 1,920 person-hours, are planned to assemble and maintain the International Space Station.

In addition to new spacewalking tools for assembly of the International Space Station, spacewalkers have an enhanced space suit that features replaceable internal parts; metal sizing rings that allow in-flight suit adjustments; new gloves with enhanced dexterity and heaters; a new radio with multiple channels; new helmet-mounted flood- and spotlights; and a jet-pack "life jacket" to allow an accidentally untethered astronaut to fly back to the space station in an emergency. In 2001, a Joint Airlock Module was attached to the space station, allowing astronauts wearing Russian or U.S. space suits to conduct space walks directly from the station.

Since Edward White stepped out of an orbiting Gemini spacecraft in 1965 to become the first American to walk in space, NASA has conducted about 400 hours of space walks. In the years to come, however, the record of space walks will grow enormously, as new generations of astronauts explore, conduct research, and build structures in orbit, on the Moon, and beyond. SEE ALSO Life Support (volume 3); Space Suits (volume 3).

John F. Kross

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Stapp, John

American Physician and Researcher
1910–

Colonel John Paul Stapp was a pioneering physician and researcher of the effects of high **G forces**. From the late 1940s through the early 1960s, he oversaw basic research on the subject of human tolerance to mechanical forces. During this period Stapp worked with human and animal subjects to determine their physical limits, and he played an important part in the high-altitude balloon flights of the ManHigh project, which explored the environment at the edge of space and investigated cosmic rays and their effects on humans.

G forces the force an astronaut or pilot experiences when undergoing large accelerations

Stapp is probably best known, however, for his rocket sled rides, during which he was accelerated to 1,017 kilometers per hour (632 miles per hour) and then decelerated to a dead stop in 1.4 seconds. As a result of Stapp's findings, the strength requirement for fighter jet seats was increased because his work showed that a pilot could walk away from crashes when properly protected by harnesses and if his seat does not break loose. Stapp also participated in windblast experiments, flying in jet aircraft at high speeds to determine whether or not it was safe for a pilot to remain with his airplane if the canopy should accidentally blow off. In addition to his pioneering work in aerospace medicine, Stapp coined the phrase "Murphy's Law," which he defined as, "If something can go wrong, it will." After retiring from active service, Stapp served as chairman of the International Space Hall of Fame Commission in New Mexico. SEE ALSO G FORCES (VOLUME 3).

John F. Kross

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Station Keeping *See Docking (Volume 3); Navigation (Volume 3); Rendezvous (Volume 3).*

Sullivan, Kathryn

American Astronaut and Geologist
1951–

Kathryn Sullivan became the first American woman to walk in space when she left the space shuttle Challenger in October 1984 to conduct experiments demonstrating the feasibility of satellite refueling. Sullivan received a bachelor of science degree with honors in earth sciences from the University of California at Santa Cruz in 1973 and a doctorate in geology from Dalhousie University in Nova Scotia in 1978.

Sullivan was selected by the National Aeronautics and Space Administration (NASA) in January 1978 as an astronaut candidate and became an astronaut in August 1979. She has flown on three shuttle missions: STS-41G in 1984, on which she performed her history-making space walk;* STS-31 in April 1990, which deployed the Hubble Space Telescope; and STS-45 in March 1992, where she served as payload commander for the first Spacelab mission dedicated to NASA's Mission to Planet Earth. During the Spacelab mission Sullivan and her crewmates measured the chemical and physical properties of Earth's atmosphere, providing scientists with information that has improved our understanding of the planet's climate and atmospheric circulation.

***A space walk is also known as an extravehicular activity or EVA.**

Sullivan left NASA in August 1992 to become chief scientist at the National Oceanic and Atmospheric Administration (NOAA). She is president and chief executive officer of the Center of Science and Industry in Columbus, Ohio. SEE ALSO History of Humans in Space (volume 3); Mission

Astronaut Kathryn D. Sullivan, 41-G mission specialist, readies her binoculars for a magnified Earth view through the forward cabin windows of Challenger. Sullivan was the first woman to walk in space.

Specialists (volume 3); Space Shuttle (volume 3); Space Suits (volume 3); Space Walks (volume 3); Women in Space (volume 3).

Nadine Barlow

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T-38 Trainers

The T-38 Talon is a twin-engine, high-altitude, supersonic jet used by NASA to train pilot astronauts. The world's only supersonic trainer, it is among the most versatile of modern aircraft, and is known for its ease of maintenance, high performance, and exceptional safety record. It is still used widely by the U.S. Air Force as well; more than 60,000 pilots have earned their wings in the T-38 since it was deployed in early 1961.

Mission Training

Space shuttle commanders and pilots receive much of their training aboard the T-38 for many reasons, not the least of which is to prepare for the physical stresses of spaceflight. The Talon can reach an altitude of 9,000 meters and its maximum speed of Mach 1.08 within one minute of takeoff. Such acceleration exerts over 5 **Gs**✶ on its two-person crew, making the T-38 useful for training astronauts for the intense G forces encountered during a mission.

G a unit of force equal to the force of gravity exerted on a body at rest

✶**A pilot subjected to five Gs would feel as though he or she weighed five times as much as normal.**

The T-38 also accustoms pilots to flying and landing a relatively cumbersome aircraft. Both the Talon and the space shuttle orbiter have a low lift-to-**drag** ratio, meaning they glide a comparatively short distance for every meter they fall. For example, a sailplane might have a lift-to-drag ratio of 40:1, but a Talon's is around 9:1, making it fall much more rapidly. This makes flying the Talon an effective training tool for handling the orbiter's steep ratio of 4:1 or 5:1, which makes many of its pilots feel like they are "flying a rock."

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

Practice time required in a T-38 varies with a shuttle crew member's position. While pilot astronauts maintain flying proficiency by flying fifteen hours per month, mission specialists (who do not ordinarily fly the orbiter) require only four hours. Shuttle pilots must fly at least 1,000 approaches and landings in the T-38 and other training craft before they are qualified to fly as shuttle mission commander.

NASA's Talons are based at Ellington Field Airport in Houston, Texas, just a short distance from the Johnson Space Center (JSC) where shuttle astronauts do part of their mission training. Astronauts often use the T-38s to travel back and forth between the JSC and the Kennedy Space Center in Florida, a flight of about 2.5 hours.

Astronaut Pamela A. Melroy sits in the forward cockpit of a T-38 jet trainer.

Other Roles

Aside from its role as an astronaut trainer, the Talon is also employed by NASA for observation and as a chase plane when the space shuttle lands. The U.S. Air Force has used the Talon in numerous training capacities for over four decades, including basic jet training, bombing practice, and for U-2/SR-71 squadrons. Pilots still use the plane when preparing to fly aircraft such as the F-15, F-16, A-10, and F-117.

The Talon first flew in 1959. It has a ceiling of more than 16,760 meters and a range of 1,760 kilometers. Its manufacturer, Northrop, delivered more than 1,100 to the U.S. Air Force during production years 1961 to 1972. About 500 Talons remain in use and modifications are expected to extend their structural life until 2020. SEE ALSO Astronauts, Types of (volume 3); Hypersonic Programs (volume 3).

Chad Boutin

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Teacher in Space Program

The Teacher in Space Program began as an extension of the National Aeronautics and Space Administration's (NASA) Space Flight Participation Program, which was designed to open space shuttle flight opportunities to a broader segment of private citizens. In August 1984 President Ronald Reagan

Teachers Christa McAuliffe (left) and Barbara Morgan during a break in shuttle simulator training in 1985.

announced that a teacher would be chosen as the first private citizen to fly into space aboard a space shuttle. During the application period (from December 1, 1984, to February 1, 1985) more than 11,000 teachers applied.

By June 1985, NASA had chosen 114 semifinalists to be the first teacher in space. This selection included two teachers from each state, the District of Columbia, Puerto Rico, the Virgin Islands, and the territories and trusts of the United States. These candidates attended a workshop and orientation program in Washington, D.C., in June 1985. Later, a review panel chosen by NASA and the Council of Chief State School Officers selected ten finalists. They reported to NASA's Johnson Space Center in Houston, Texas, for medical exams, interviews, and briefings. The NASA administrator and an evaluation committee made the final selection of the teacher who would fly and an alternate to serve as a backup.

On July 19, 1985, after the exhaustive selection process, Vice President George H. W. Bush announced NASA's final selection at a White House ceremony. Sharon Christa McAuliffe, a high school economics and history teacher in Concord, New Hampshire, was selected from among the ten finalists to fly for the Teacher in Space Program, and Barbara Radding Morgan, a third-grade teacher in McCall, Idaho, was selected as the alternate. McAuliffe and Morgan began their astronaut training at the Johnson Space Center in September in preparation for the space shuttle mission 51L, which was scheduled for launch in January 1986.

McAuliffe was to conduct two live television teaching lessons, which were to be broadcast from the space shuttle Challenger. The lessons involved experiments designed to demonstrate the effects of **microgravity** in space on magnetism, Newton's laws, effervescence, and simple machines.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Tragedy Strikes the Program

On January 28, 1986, Morgan was on the ground at Cape Canaveral, Florida, as the Teacher in Space backup for the launch of the space shuttle Challenger, which carried a crew of seven, including McAuliffe. Tragically, an explosion of the Challenger spacecraft one minute and thirteen seconds after liftoff claimed the lives of the entire crew.

After the disaster, the shuttle program and the Teacher in Space Program were put on hold while the agency investigated and recovered from the disaster. Following the space shuttle's return to flight in September 1988, periodic informal meetings were held on the status of the Teacher in Space Program. Given the hundreds of modifications made to the shuttle system as a result of the accident, NASA mangers agreed to defer serious consideration of resuming the Teacher in Space Program until all of the redesigned systems were properly validated.

Senior NASA officials held two formal reviews of the program in 1993 and 1994, but they reached no decision. Morgan remained the Teacher in Space designee. She underwent annual astronaut physicals and, until cutting back to spend more time in the classroom, traveled one week a month on education and public relations duties for the space agency.

News that astronaut-turned-senator John Glenn would return to space aboard a shuttle flight in 1998 reopened a wide-ranging public debate about flying noncareer astronauts in space. The debate included the status of Morgan, who had remained the Teacher in Space designee since 1986 even though the Teacher in Space Program and all discussion of flying civilians in space remained on hold.

On January 16, 1998, ten months before John Glenn was due to return to space, NASA announced that Morgan would report for training as a mission specialist with the seventeenth group of astronaut candidates selected by the space agency. In making this announcement, NASA administrator Daniel Goldin said, "One of the issues I personally had with the civilian-in-space program was the lack of full training. That is why [Morgan] is going to become a fully trained mission specialist." Morgan completed initial training and became a member of the astronaut corps based at Johnson Space Center in Texas. In April 2002 NASA administrator Sean O'Keefe announced the new Educator Mission Specialist Program. Barbara Morgan, the backup Teacher in Space candidate, will be the first educator mission specialist, and she is scheduled to fly to the International Space Station shortly after the construction of the core station is completed. She is expected to go to space in 2004 or 2005. SEE ALSO Astronauts, Types of

(volume 3); Challenger (volume 3); Challenger 7 (volume 3); Mission Specialists (volume 3); Space Shuttle (volume 3); Women in Space (volume 3).

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Tereshkova, Valentina

Russian Cosmonaut and Politician
1937–

In 1963 Valentina Tereshkova became the first woman to fly into space.

The Soviet Union not only launched the first human into space (Yuri Gagarin in 1961) but in June 1963 it also sent the first woman, Valentina Tereshkova. It would be another twenty years before Sally Ride became the first American woman in space. Tereshkova joined a club of amateur parachutists in 1961, shortly before interviewing with the Soviet space program. Prime Minister Nikita Khrushchev had suggested sending a woman into space before the United States. A lack of female airplane pilots made parachutists attractive candidates for the Soviet space program, and Tereshkova and three other women parachutists and a female pilot were selected to train as cosmonauts in 1962. Tereshkova was the only woman in the group who made it into space.

On June 16, 1963, Tereshkova launched aboard Vostok 6. She orbited forty-eight times over 70 hours and 50 minutes before returning to Earth. Tereshkova ejected from the capsule about 610 meters (20,000 feet) above the ground and descended in a parachute. She married fellow cosmonaut Andrian Nikolayev in 1963, and the next year their daughter Yelena became the first child of parents who had both been in space. Tereshkova later became a member of the Supreme Soviet, the former Soviet Union's national parliament. see also Cosmonauts (volume 3); History of Humans in Space (volume 3); Ride, Sally (volume 3); Vostok (volume 3); Women in Space (volume 3).

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Thrusters *See External Tank (Volume 3); Solid Rocket Boosters (Volume 3).*

Tools, Apollo Lunar Exploration

Working in a space suit is difficult because it reduces the dexterity of its wearer, so specialized tools were developed for **Apollo** astronauts to use in gathering rock and dust specimens. The grip attainable with spacesuit gloves was restricted and fatiguing for the hands, so all tools were designed with large-diameter, textured grips. Because astronauts could not bend over in their space suits, tools either had a long handle or were attached to an extension handle.

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

Specimen-Collection Tools

Tongs or a rake were used to collect rocks that were fist-sized or smaller. By raking a large area, an astronaut could quickly gather many walnut-sized rocks free of soil. The goal was to collect many small diverse rock specimens, rather than a few large ones. In contrast, dust samples were acquired by scooping. As astronauts learned about the behavior of the Moon's very fine dust in low gravity, the efficiency of the scoops evolved. The first scoop was boxy. By the Apollo 15 mission, the final design was achieved by an adjustable angle, tapered scoop.

To recover the dust preserved in original layers, as desired by the geologists, core tubes were used. The coring devices were of two types: tubes that were pounded into the ground with a hammer, called "drive tubes," and tubes that were drilled into the ground with a rotary/percussive motor, called "drill cores." Narrow, relatively thick-walled drive tubes were used on the early missions (Apollo 11, 12 and 14). The Apollo 11 drive tubes were designed to acquire "fluffy" dust, not the densely packed dust and rock fragments the astronauts encountered. Consequently, the Apollo drive tubes penetrated only about 10 centimeters (3.94 inches). By the time of the Apollo 15 mission, the drive tubes had been redesigned with larger diameters and thin walls. These tubes acquired dust and rock fragments in nearly undisturbed condition. Drive tubes were used to sample lunar regolith (the dust and rocky material covering the Moon's surface) to a depth of 0.6 meters.

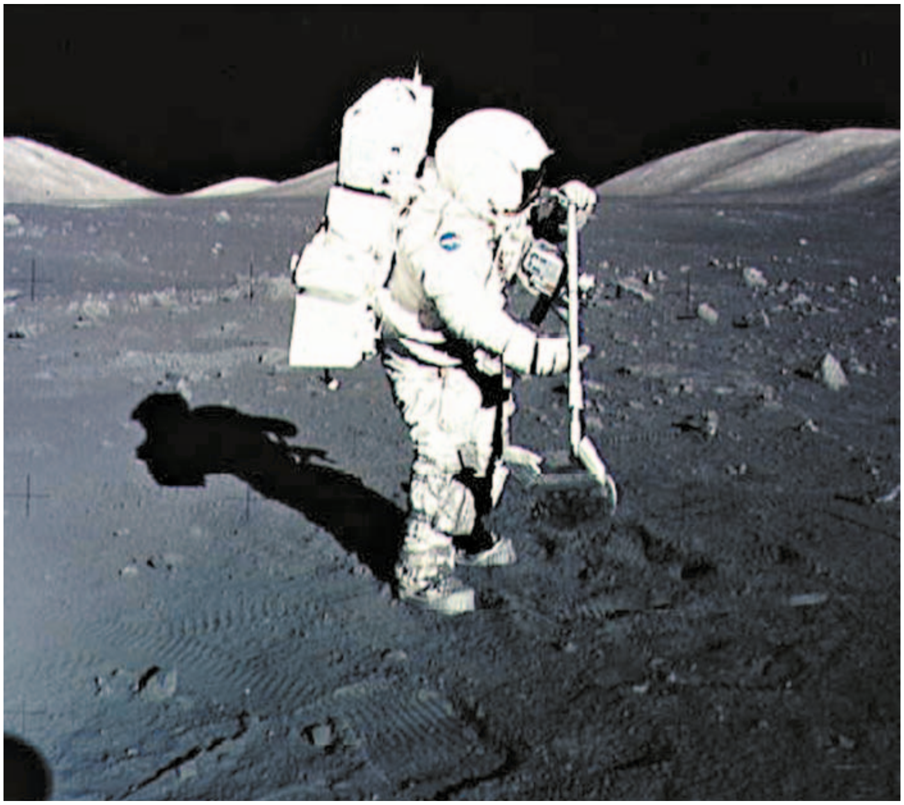
The drill core, used on the last Apollo missions, acquired regolith up to 3 meters in depth with good preservation of **stratigraphy**. These samples contained a very useful record of the cosmic ray history on the Moon. The drill motor provided a rotary/percussive action to penetrate the regolith and worked quite well. Apollo astronaut Dave Scott had great difficulty pulling the first drill core, but altering the drilling technique on later missions greatly facilitated extraction. In operating the drill, astronauts would add sections as needed to lengthen the drill stem. When extracting the drill stem, the sections would be disconnected and capped, then packaged together for the return to Earth.

stratigraphy the study of rock layers known as strata, especially the age and distribution of various kinds of sedimentary rocks

Sample Transport Containers

The basic box used to transport the samples from the **vacuum** of the lunar surface to the atmospheric pressure of Earth was carved from a single block

vacuum an environment where air and all other molecules and atoms of matter have been removed



Apollo astronaut Harrison Schmitt uses a lunar rake to collect discrete rock samples and rock chips less than one inch in size.

of aluminum and had a triple sealing mechanism consisting of a knife-edge-to-metal seal and two O-ring seals. Two of these boxes were flown on each Apollo mission. Since much more sample material was collected on the later missions, specimens that did not fit into the two boxes were brought back in tote bags.

Most of the smaller samples were placed into numbered individual sample containers before being placed into the transport boxes or bags. To preserve the pristine lunar dust and fragments, some samples were placed into gas-tight cans sealed with a knife-edge-to-metal seal. Many rock and dust samples were placed into numbered Teflon bags with fold-over closures.

Specimen Collection Accessories

A gnomon was a device the astronauts placed on the lunar surface to indicate which way was "up" and provide a color scale. With the gnomon in the pictures taken of rocks on the lunar surface, accurate sun angle and rock color could be determined. A spring scale similar to those used for weighing fish was included to estimate the total sample weight before ascent from the Moon. Little use was made of the lens/brush tool that geologists had thought would be needed to dust off the rocks and examine them through a lens.

The early Apollo missions focused on learning how to work in the lunar environment. The later missions encompassed greater sophistication in the collection of specimens, accompanied by the specialization of tools and containers. Over the course of six Apollo landings, the opportunity to adapt tools based on experience with the lunar environment was especially seen in the evolution of the drive tubes. SEE ALSO Apollo (volume 3); Apollo I Crew (volume 3); Apollo Lunar Landing Sites (volume 3); Space Suits (volume 3); Tools, Types of (volume 3).

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Tools, Types of

Just like mechanics and technicians on Earth, astronauts use a variety of manual and portable power tools in space to repair, service, and maintain spacecraft, like the space shuttle and the International Space Station (ISS), and other satellites, like the Hubble Space Telescope (HST). Space tools are divided into two main operating categories: Intravehicular Activity (IVA) tools and Extravehicular Activity (EVA) tools. IVA tools are used by astronauts inside the pressurized habitable compartments of a spacecraft for routine maintenance, repair, and unexpected tasks. EVA tools are used by space-suited astronauts outside of their pressurized spacecraft in the vacuum of space.

Intravehicular Tools

Most IVA tools are unmodified, commercial off-the-shelf, high-quality hand and power tools. These IVA tools are used for many general tasks known as in-flight maintenance (IFM), such as removing fasteners on access panels to electronics racks and repairing or adjusting mechanical and electrical equipment or experiments. These IVA tools are similar to those used by mechanics and electronics technicians on Earth. Examples of IVA tools are various sizes of wrenches and sockets, hexagonal, Phillips, and torque head drivers, pliers, and ratchets. Other general-purpose IVA tools are the hammer, pry bar, vise grips, files, and hacksaw. Special purpose IVA tool kits to repair electrical cables and connectors are also carried onboard the space shuttle and the ISS.

Extravehicular Tools

Due to the extreme thermal and vacuum environment in space, most EVA tools are specially designed hand and portable power tools that can be easily operated by an astronaut in a pressurized space suit. EVA tools must be designed with unique requirements for their successful use in repairing and servicing spacecraft. Fine motor activity is difficult when operating tools with a space suit–gloved hand. Most space tools are designed to be operated with one hand, since the other hand may be required to react to the forces generated when operating the tool. In addition, EVA tools have to be designed with handles that fit the natural shape of a pressurized space-suit glove.

The most unique and important EVA tool requirement is the need to provide a feature for tethering the tool at all times to prevent it from float-

With power ratchet in hand, astronaut Steven L. Smith prepares to service the Hubble Space Telescope, which is locked down in the space shuttle Discovery's cargo bay.

ing away if it is inadvertently released. If an EVA tool is accidentally released and cannot be retrieved, it becomes orbital space debris and a future hazard to spacecraft. Depending on the **orbital velocity** and the direction of the collision path, significant damage could occur if the space tool collided with a spacecraft. The tethering feature is usually a small ring that is built into or added to the tool. The astronaut has an equipment tether with an easily operated tether hook on each end. One hook is attached to a loop on the astronaut's wrist and the other tether hook is attached to the tool being used.

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

EVA tools on the space shuttle and the ISS can also be divided into two types: general-purpose tools and unique application tools. General-purpose tools, such as the EVA ratchet and the portable EVA power tool, are used for various repair tasks. Unique application tools are designed for special tasks or for a specific spacecraft, such as repairing the Hubble Space Telescope (HST). The early battery powered EVA power tool used for drilling in the lunar surface for core samples during the Apollo program led to the direct development of commercial cordless home use tools, such as the miniature vacuum cleaner, portable drill, and shrub trimmers.

These EVA tools are used for repairing satellites and for assembling and maintaining the ISS. Most of these EVA tools are stowed in EVA tool boxes located outside in the space shuttle **payload bay** or on the ISS airlock. Examples of general purpose EVA tools are the EVA ratchet with a 3/8-inch square drive, 7/16-inch hexagonal socket extensions of various

payload bay the area in the shuttle or other spacecraft designed to hold the experiment to be performed or cargo to be launched lengths, adjustable wrench, vise grips, compound cutters, needle nose pliers, and a hammer.

A very important EVA tool used on both the space shuttle and the ISS and to service satellites, like HST, is a battery-powered tool known as the Pistol Grip Tool. This EVA power tool is very similar to a portable electric drill and driver. The Pistol Grip tool is a self-contained, computer-controlled, battery-powered portable power tool. It is used with various socket extensions and **torque** multipliers for removing and torquing mechanical fasteners, such as bolts. Torque, speed, and the numbers of turns can be programmed into this power tool.

torque measure of a force applied to a tool handle multiplied by the distance to the center of rotation

Hubble Space Telescope Repair

Though there have been several satellite repair missions in the past, like the successful repair of the Solar Maximum Satellite during STS-41C in April 1984, the most famous satellite repair mission has been the repair mission of the HST. From the beginning, the HST was designed for servicing and upgrades of its main components and instruments by EVA astronauts during scheduled repair missions. NASA performed the first servicing mission to repair the HST during STS-61, which launched on December 2, 1993. Using a variety of EVA tools, astronauts replaced several instruments to correct the mirror aberration and electronics boxes known as orbital replacement units (ORUs). HST was completely repaired and returned to service after five space walks by the EVA astronauts.

During these servicing missions, astronauts have access to the same general purpose EVA tools carried regularly on the space shuttle. Some additional EVA tools used to repair the HST included various sizes of hexagonal and Allen heads socket extensions, electrical connector tools, torque multipliers, and the Pistol Grip Tool.

Conclusion

From the early Project Gemini to the present ISS, space tools have been used regularly to support science missions and to assemble, repair, and maintain spacecraft. One of the main benefits of having humans in space is their ability to troubleshoot and solve unexpected equipment problems, usually with the aid of various space tools. In the future, the use of both IVA and EVA tools by astronauts will become a routine part of human spaceflight. SEE ALSO Hubble Space Telescope (volume 2); Space Suits (volume 3); Space Walks (volume 3); Tools, Apollo Lunar Exploration (volume 3).

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Tracking of Spacecraft

For tracking purposes, there are two types of space objects—cooperating and noncooperating. Normal civilian satellites and some military satellites

Flight controllers monitor pre-docking operations between the space shuttle Atlantis and the International Space Station at the Mission Control Center in Houston.

use beacons and **radar** reflectors to assist ground stations in keeping track of satellite locations. Beacons are transmitters that broadcast a simple radio signal that, in essence, tells the Earth-based tracking radar, "Here I am. Here I am. Here I am." Radar reflectors are simply the normal parts of satellites that effectively reflect the radar signal. Examples of radar reflectors are solar panels and heat radiators.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

How Objects Are Tracked

The U.S. Space Command has primary responsibility for keeping track of everything in orbit. Information from radars, optical systems, and space-based sensors are integrated by the Space Control Center, which is located deep underground at Cheyenne Mountain, Colorado. As of the spring of 2001, the Space Command was keeping an eye on more than 8,300 objects in space. Of these, only about 250 were active satellites.

The primary tool for this task is the computerized Space Objects Catalogue, maintained by the Space Command, which tells the system where the thousands of objects being tracked should be at any given moment. The sensors then make observations to make sure these predictions are correct—in the jargon of the operators, to see that they have not "jumped the fence." If any object has gone outside of its scheduled flight path, more sensors are alerted to see what the object is doing and to recalculate its new orbit.

Objects in orbit change orbital paths fairly often. This happens when ground control sends a command to a satellite to fire its maneuvering thrusters,

reconnaissance a survey or preliminary exploration of a region of interest

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

coronal mass ejections large quantities of solar plasma and magnetic field launched from the Sun into space

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

aperture an opening, door, or hatch

for example, when a **reconnaissance** satellite needs to take a look at an unexpected event on Earth or when a communications satellite has its orbit adjusted to serve new customers. When these changes are detected, the Space Command must adjust its calculations to take these changes into account.

It is even more difficult to estimate the effects of Earth's upper atmosphere and the impact of radiation storms from the Sun on the behavior of space objects. In **low Earth orbit**, there are enough fragments of hydrogen and helium in the ionosphere (the part of the atmosphere located above about 50 kilometers [30 miles]) to exert a constant **drag** on all orbiting objects. This may cause objects to change orbits unexpectedly.

Coronal mass ejections send huge, unpredictable masses of energy in the form of radiation and tiny particles, toward Earth. This causes the phenomenon called the northern lights, also known as the aurora borealis. It also sometimes causes spacecraft to behave erratically, again requiring adjustments to the calculations in the Space Objects Catalogue. The Living with a Star program, launched by the National Aeronautics and Space Administration (NASA), will help scientists better understand these events.

Components of the U.S. Network

The space objects tracking network of the United States includes systems originally built to give early warning of missile attacks. The two phased-array PAVE PAWS radars, located at Otis Air Force Base on Cape Cod, Massachusetts, and at Beale Air Force Base northeast of Sacramento, California, were designed to detect submarine-launched missiles. But because a phased-array radar signal can be shaped and controlled by electronically shifting the radar's signal using the hundreds of different elements of which it is composed, the high power of this radar and its ability to electronically aim its beams in whatever direction required make it an ideal part of the space surveillance network.

In addition to the PAVE PAWS radars, the U.S. network uses the radars of the Ballistic Missile Early Warning System based at Clear in Alaska, at Thule in Greenland, and at the well-known U.S./U.K. facility at Fylingdales in Yorkshire, England. Designed to detect Soviet intercontinental **ballistic** missiles, these radars provide excellent radar coverage of Earth's northern hemisphere.

The main U.S. radar specifically designed to track space objects is located at Eglin Air Force Base in Florida. Other radars are reportedly located at Incirlik, Turkey; at Kaena Point, Hawaii; on Ascension Island in the Atlantic; and on Diego Garcia in the Indian Ocean.

The Air Force Space Command's 21st Space Wing at Peterson Air Force Base in Colorado also controls the Ground Based Electro-Optical Deep Space Surveillance System (GEODSS). Its three bases are at Socorro, New Mexico; on Maui, Hawaii; and on Diego Garcia. Each base is equipped with two 1-meter (40-inch) **aperture** telescopes and a 36-centimeter (14-inch) aperture auxiliary telescope, in addition to low-light TV cameras and computer systems.

GEODSS operates by taking pictures of the sky, combining them, and removing known stars, a process that results in the images of space objects showing up as streaks on the resulting computer-generated image. Analysis of these streaks gives the operators of the GEODSS system information on how big the object is, how fast it is moving, and in what orbit. It is claimed that the system is sensitive enough to detect basketball-sized objects in **geosynchronous orbit**, 35,786 kilometers (22,300 miles) above Earth.

Air Force Space Command took over control of the Midcourse Space Experiment (MSX) satellite, which was launched in 1996 by the Ballistic Missile Defense Organization. Originally designed to test sensors for the Missile Defense Program and to collect astronomical data, MSX is equipped with an imaging **infrared** telescope, other infrared sensors, an **ultraviolet** imager, and visible light imaging systems. After its designed life was over, control was transferred to Space Command, and the satellite began serving as the space-based element of the space tracking network.

The U.S. space object tracking system is controlled and almost entirely paid for by the U.S. Department of Defense. Its capabilities are used both by NASA and, through NASA, by other international space agencies. When other nations or international agencies need information about their satellites—for example, after a malfunction—NASA serves as a civilian intermediary between them and the Defense Department.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis; an object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

Other Nations' Tracking Networks

The former Soviet Union had a complex space tracking network of its own based, in part, on large phased-array radars. These served the needs of the Soviet Space Tracking Network, as well as those of the country's early warning and missile defense systems. By the early twenty-first century, with Russia (the successor to the Soviet Union) struggling to remain in the forefront of space exploration and development, it had become an open question whether that nation's tracking network was a real alternative to the American system.

The Europeans are working hard on the problem of tracking space debris. Their efforts are coordinated by the European Space Agency. As of mid-2002, they have not built a worldwide space object tracking system comparable to those of the United States or Russia. The Japanese have their own tracking systems but, like the Europeans, they have limited themselves to their own region. SEE ALSO Ground Infrastructure (volume 1); Guidance and Control Systems (volume 3).

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Tracking Stations

One of the key elements of spaceflight is the ability to track spacecraft and obtain telemetry that informs ground controllers of the condition of spacecraft and crew. Ground-based "tracking stations" play a key role in these

The Canberra antenna measures 70 meters (230 feet) in diameter, and is one of three antennae comprising NASA's Deep Space Network communications complexes.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

sounding rocket a vehicle designed to fly straight up and then parachute back to Earth, usually designed to take measurements of the upper atmosphere

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

functions, providing tracking and data acquisition services for vehicles in deep space and high Earth orbit and for certain missions in **low Earth orbit**. These networks of ground stations also supply launch and emergency communications for human missions in space and tracking and data acquisition for aeronautics, balloons, and **sounding rocket** programs.

The early years of the space age were marked by the creation of integrated networks of tracking stations that dotted the globe. Tracking ships were also built to provide additional coverage across oceans. In addition, special aircraft were deployed around the world to track various spacecraft. For the National Aeronautics and Space Administration (NASA), the launch of the Tracking and Data Relay Satellite System significantly reduced the number of stations needed to track space missions. Nevertheless, tracking stations still play a very important part in space activity. Today, the Ground Networks Program has responsibility for managing the tracking stations that comprise NASA's Space Flight Tracking and Data Network (STDN) and the Deep Space Network (DSN), the latter of which is supervised by the Jet Propulsion Laboratory (JPL).

For over thirty years elements of the STDN have supported robotic scientific missions as well as the human spaceflight program. Today, the STDN complex of tracking stations at Merritt Island, Florida, and on Bermuda provides real-time voice, telemetry (data), and command communications to the space shuttle, and furnishes launch support for **expendable launch vehicles**. The Merritt Island tracking facility contains thirteen antennas that track or point directly at the radio signals transmitted from a moving space vehicle. A ranging signal transmitted to the spacecraft establishes the distance by how long the two-way trip takes.

NASA's Deep Space Network is the largest and most sensitive scientific tracking and communications system and the most precise radio navigation network in the world. Its principal responsibilities are to support interplanetary spacecraft missions and radio and **radar** astronomy observations. The forerunner of the DSN was established in 1958, when JPL, then under contract to the U.S. Army, deployed portable radio tracking stations to receive telemetry and track the orbit of Explorer 1, the first successful U.S. satellite. Since 1958, the DSN has provided support for more than seventy robotic Earth-orbiting, lunar, and planetary spacecraft.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

The DSN is comprised of three complexes located in Australia, Spain, and Goldstone, California. Located around the world approximately 120 degrees apart in longitude, the facilities allow continuous coverage of distant spacecraft or interplanetary objects. Each station has one antenna 70 meters (230 feet) in diameter, plus several smaller ones, with the antennas capable of transmitting and receiving data from interplanetary and Earth-orbiting spacecraft. The antennas can be operated separately or can be combined together electronically (in a process called "arraying") to form a larger **aperture** (essentially an enormous virtual dish) to receive very weak signals from distant or impaired missions (such as the Galileo spacecraft).

aperture an opening, door, or hatch

The DSN stations have the capability to acquire, process, decode, and distribute data from deep space probes and Earth orbiters while also sending signals to control the activities of spacecraft. The DSN has also contributed to our knowledge of the solar system through radio frequency experiments performed between spacecraft and the DSN radio science system. Experiments have allowed scientists to characterize planetary atmospheres and ionospheres, planetary surfaces, and rings.

From the late 1950s to the early twenty-first century, the mission of Earth-bound tracking stations has expanded from tracing the paths of satellites to include space research and communication, command, and navigation of spacecraft beyond low Earth orbit. Tracking stations will continue to have a major role in space activities and will have their capabilities upgraded as more spacecraft are launched and technical demands grow. SEE ALSO NAVIGATION (VOLUME 3); TRACKING OF SPACECRAFT (VOLUME 3).

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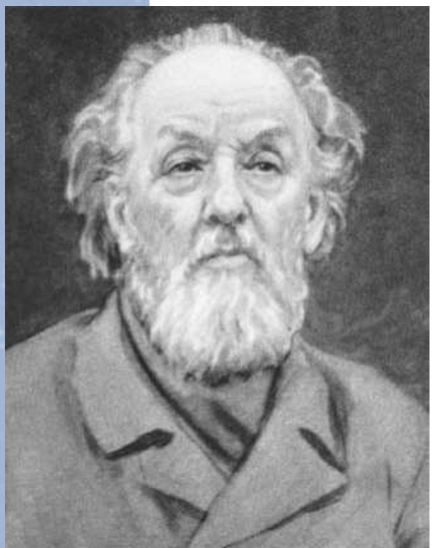
Tsiolkovsky, Konstantin

Russian Physicist and Rocket Pioneer
1857–1935



Konstantin Tsiolkovsky was a pioneer in space and rocket research.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

Konstantin Tsiolkovsky was one of the three most important early pioneers of rocketry, together with American Robert H. Goddard and German Hermann Oberth. Partially deaf since childhood because of a bout with scarlet fever, Tsiolkovsky was a Russian schoolteacher who taught himself physics and the mechanics of rocket propulsion. In his spare time, he wrote both technical papers and speculative science fiction stories.

Tsiolkovsky realized that, unlike aircraft, rockets had the ability to travel the empty realms of space, and he foresaw trips to the Moon and even considered the phenomenon of weightlessness. Tsiolkovsky also imagined Earth satellites and **space stations**. This was long before such ideas could actually be implemented.

One of Tsiolkovsky's most important achievements was to work out the theory of rockets, in which a vehicle's maximum velocity can be expressed as a function of its mass and the speed of its exhaust gases. But this theoretical work also convinced him that single-stage rockets, even if they burned energetic fuels such as liquid hydrogen and oxygen, would not be powerful enough to escape from Earth. He therefore proposed the use of multistage vehicles. These vehicles consist of stacks of rockets, in which a smaller vehicle is mounted on a larger one. In the early twenty-first century, satellites and planetary probes are routinely shot into space on multistage rockets.

Although largely ignored during his lifetime, Tsiolkovsky's work was finally recognized as the space age got underway. He is often called the Father of Space Travel, and in 1959 his name was given to a crater on the farside of the Moon. SEE ALSO GODDARD, ROBERT HUTCHINGS (VOLUME 1); OBERTH, HERMANN (VOLUME 1); ROCKETS (VOLUME 3); VON BRAUN, WERHNER (VOLUME 3).

Seth Shostak

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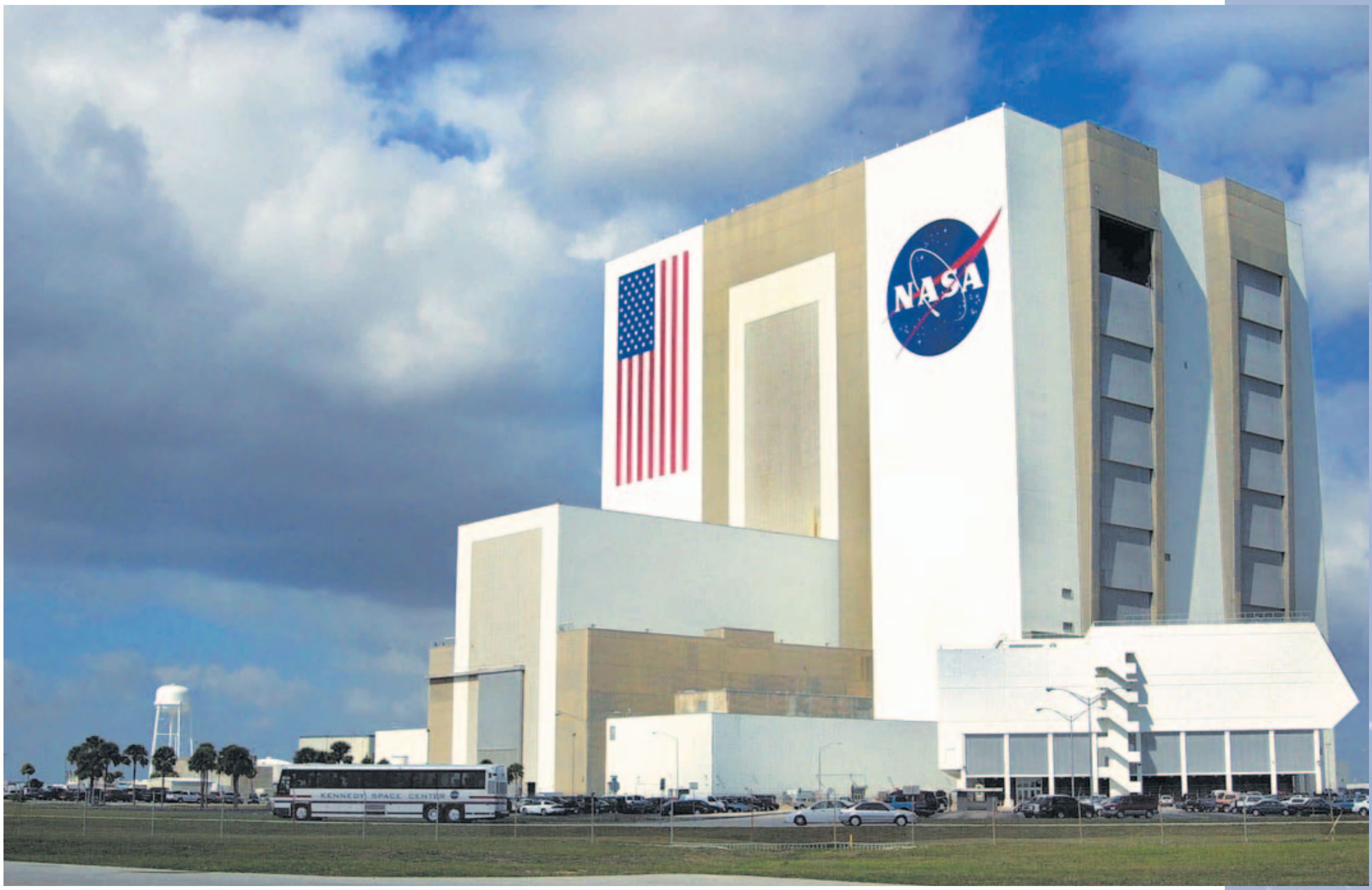
V

Vehicle Assembly Building

For more than thirty-five years the Vehicle Assembly Building (VAB) has been the last stop on Earth for most American human space missions, beginning with the Apollo missions, through Skylab, and the space shuttle. More than 600 people spend most of their working day in this building, preparing piloted vehicles to launch into space.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

In the early 1960s it was recognized that a new, massive building would be needed to evaluate and assemble the large rocket vehicles that would carry the first Americans to the Moon. This building presented many design and construction challenges. Due to an ambitious launch schedule, the VAB had to be able to house several large Saturn **rockets** at one time. It



The mammoth Vehicle Assembly Building is the first landmark visible at NASA's Kennedy Space Center in Florida. It can be seen from at least ten miles in every direction.

had to be able to withstand a gigantic nearby explosion in case one of the rockets exploded on or near the launch pad. It had to be able to withstand winds of up to 200 kilometers (125 miles) per hour in case a hurricane or tornado struck. It had to be expandable and adaptable to change. The final design called for four high bays, each of which could hold a complete Saturn 5 Moon rocket and its mobile launch platform and **crawler transporter**. A large transfer aisle would run down the center of the building to allow movement of the different stages of the vehicle during integration. Off to one side would be a low bay to house various machine shops and test areas. Construction of the VAB began in January 1963 and was completed in late 1965.

crawler transporter large, tracked vehicles used to move the assembled Apollo/Saturn from the VAB to the launch pad

The VAB stands 160 meters (525 feet) tall and is 218 meters (716 feet) long by 158 meters (518 feet) wide. The total internal volume is 3,664,993 cubic meters (129,428,000 cubic feet).✶ Over 98,500 tons of steel and 49,696 cubic meters (65,000 cubic yards) of concrete were used in its construction. The aluminum and plastic siding rests on 4,225 steel pipes driven as far as 49 meters (160 feet) down to bedrock. If these pipes were laid end-to-end, they would reach across the state of Florida to the Tampa area. Due to the high concentration of salt water in the subsoil, each pipe is welded to thick copper wire and connected to the other pipes and the steel reinforcing rods in the concrete slab. If the pipes were not connected this way, the VAB would very quickly become a large, wet-cell battery and electrolytic corrosion would rapidly deteriorate the frame. The sidesway is kept low by

✶The total internal volume of VAB is roughly equivalent to the size of 3.75 Empire State Buildings.

means of a 58-meter-tall (190 feet) structural frame along the transfer aisle over which some vehicle stages have to be lifted during integration.

The VAB is large enough to have its own weather inside, and so one or more of the high bay doors sometimes must be opened to allow outside air to circulate. Each high bay door has seven vertical leaves, each 22 meters (72 feet) wide by 15 meters (49 feet) high. At the base of the high bay doors are four horizontal leaves that cover the bottom openings. Fully opening all the leaves in each door takes almost an hour. Smaller doors allow access to the transfer aisle and provide access for personnel.

In 1976, for the two-hundredth anniversary of the United States, a large American flag and bicentennial symbol were painted on the south side of the building, where they can be seen from most of the Kennedy Space Center. The flag is 64 meters (209 feet) long by 34 meters (110 feet) wide. In 1998, the flag was repainted and the logo of the National Aeronautics and Space Administration was painted over the bicentennial symbol in commemoration of NASA's fortieth anniversary. SEE ALSO Apollo (volume 3); Launch Sites (volume 3); NASA (volume 3); Payloads (volume 3); Space Centers (volume 3); Space Shuttle (volume 3).

Roger E. Koss

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Vomit Comet ***See KC-135 Training Aircraft (Volume 3); Simulation (Volume 3).***

von Braun, Wernher

German-American Rocket Expert
1912–1977

Born in Wirsitz, Germany, on March 23, 1912, Wernher von Braun progressed from a student who failed mathematics and physics while spending too much time building his car to the world's foremost rocket engineer.

Inspired by Hermann Oberth's *Rocket into Planetary Space* (1923) and a telescope from his mother, von Braun decided to become a space pioneer by designing rockets and realized that he would need mathematics to succeed. He joined a German rocket society whose work had drawn the attention of the German army. In 1932 von Braun went to work for the ordnance department, designing **ballistic** missiles. During that period he earned a doctorate in physics, at the age of twenty-two, from the University of Berlin.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

By 1941 von Braun had designed the A-4, followed by the V-2, which was used in World War II. When he learned that his rockets were being used to kill so many people, he said it was the darkest hour of his life. At one time he was jailed for spending time exploring spaceflight, taking time away from his military rocket building. He was released after two weeks because Germany needed his leadership for its missile program. In 1945 von Braun and 500 people on his team at Peenemunde surrendered to the Americans, bringing plans and test vehicles with them. He and 116 members of the team were brought to the United States to work on the American rocket program.

Wernher von Braun led a team of German rocket scientists that developed the Mercury-Redstone rocket, which launched the first American into space.

At White Sands Proving Ground in New Mexico and later at Huntsville, Alabama, von Braun's team developed the Redstone Rocket, which was twice the size of the V-2, and the Jupiter-C, which was modified into the Juno 1 and used to launch the American answer to Sputnik, the Explorer 1 spacecraft. The Redstone rocket later was used to launch Alan Shepard, the first American in space, on his suborbital flight. When the National Aeronautics and Space Administration (NASA) was established in 1958, von Braun became the director of the Huntsville installation, now named the Marshall Space Flight Center.

When the Soviet Union shocked the world with the launch of Yuri Gagarin three weeks before Shepard's flight, President John F. Kennedy consulted with von Braun to find a goal to which the United States could beat the Soviet Union. Von Braun told him that he thought the United States could land a man on the Moon and return him to Earth by 1967 or 1968. Once President Kennedy issued his challenge to get to the Moon "within the decade," von Braun was named to develop the Saturn rocket to achieve that purpose. The Saturn V rocket has the distinction of having launched all the American Moon missions as well as the Skylab space station without a single failure.

Von Braun retired from his post as deputy associate administrator at NASA headquarters in Washington, D.C., in 1972. In 1975 he founded and became president of the National Space Institute, which was intended to promote better understanding of space exploration among the public. Shortly before von Braun died on June 15, 1977, he was awarded the National Medal of Science by President Gerald Ford. SEE ALSO CAREERS IN ROCKETRY (VOLUME 1); HISTORY OF HUMANS IN SPACE (VOLUME 3); KENNEDY, JOHN F. (VOLUME 3); KOROLEV, SERGEI (VOLUME 3); ROCKET ENGINES (VOLUME 1); ROCKETS (VOLUME 3); TSIOLKOVSKY, KONSTANTIN (VOLUME 3).

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Voskhod

Soviet engineers designed the Voskhod ("Dawn") spacecraft to keep the Soviet Union ahead in the space race of the 1960s while they developed their advanced Soyuz spacecraft. They modified the single-seat Vostok spacecraft to produce Voskhod. Voskhod's improvised design made it the riskiest piloted spacecraft ever flown. Despite the dangers they faced, Voskhod cosmonauts successfully accomplished the first multiperson spaceflight and achieved the first space walk ahead of the American Gemini astronauts.

Voskhod closely resembled Vostok. As in Vostok, the capsule carrying the cosmonauts was a 2.3-meter (7.5-foot) sphere with a round entry hatch. A second hatch covered the parachute compartment. Four metal straps and power and control cables joined the capsule to the 2.25-meter-long (7.4 feet) instrument module, which included batteries, oxygen tanks, guidance equipment, and the primary retro-rocket.

Major Voskhod innovations included extra cosmonaut couches and a backup retro-rocket on top of the capsule. Like Vostok, Voskhod reached Earth orbit on a modified R-7 missile. Voskhod weighed 5,300 kilograms (11,684 pounds), about 570 kilograms (1,260 pounds) more than Vostok, and so the Voskhod rocket was more powerful than the Vostok version. The Vostok capsule and hatch were too small to allow multiple ejection seats, and so the Voskhod cosmonauts had no way to escape if the rocket malfunctioned during launch.

An unpiloted Voskhod test flight designated Kosmos 47 (October 6 and 7, 1964) preceded Voskhod 1 (October 12 and 13, 1964). Commander Vladimir Komarov, engineer Konstantin Feoktistov, and medical doctor Boris Yegerov formed Voskhod 1's crew. Voskhod 1 was so cramped that the three cosmonauts could not wear space suits for protection. The twenty-four-hour, seventeen-minute mission produced the first multiperson spaceflight and sent the first doctor and engineer into space.

To permit a Soviet cosmonaut to perform the first space walk, Soviet engineers fitted Voskhod 2 (March 18 and 19, 1965) with an inflatable fabric airlock called Volga. Kosmos 57 (February 22 to March 31, 1965) tested Volga in space. Kosmos 57's Volga inflated and then explosively ruptured. Nevertheless, Soviet leaders refused to delay the launch. The United States planned the first Gemini space walk within months, and so Voskhod 2 could not be delayed to allow more Volga testing.

Voskhod 2's Volga performed normally. Commander Pavel Belyayev deployed the 2.5-meter-long (8.2 feet) airlock, and then Alexei Leonov closed his space helmet and squeezed inside. Belyayev closed the hatch behind him and released Volga's air. Leonov then opened Volga's outer hatch and floated out into space. The Soviets claimed that Leonov's twenty-four-minute space walk went smoothly, but it is now known that he almost died. Struggling to control his movements against the stiff space suit, Leonov overheated and became stuck in Volga while trying to return to Voskhod 2. He freed himself only after releasing air from the suit so that he could bend.

Trouble struck again during Voskhod 2's return to Earth. The automatic re-entry system failed, forcing Belyayev to pilot a manual re-entry. Voskhod 2 landed 1,000 kilometers (620 miles) off target in Siberia and bounced down a hill. A bear menaced the cosmonauts as they waited overnight for rescue. The twenty-six-hour rescue flight ended the perilous Voskhod program. SEE ALSO COSMONAUTS (VOLUME 3); HISTORY OF HUMANS IN SPACE (VOLUME 3); GEMINI (VOLUME 3); LEONOV, ALEXI (VOLUME 3); SPACE WALKS (VOLUME 3); VOSTOK (VOLUME 3).

David S. F. Portree

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Vostok

The Vostok ("East") program grew out of Cold War competition in the 1950s and 1960s between the United States and the Soviet Union. Vostok's engineering and scientific goals were secondary to the political aim of putting a man into space first but included testing basic spacecraft systems such as life support and demonstrating that humans could withstand launch, weightlessness, re-entry into the atmosphere, and landing.

The 4,730-kilogram (10,428-pound) Vostok spacecraft consisted of a capsule and an instrument module. The capsule, which carried the cosmonaut, was a 2.3-meter (7.5-foot) silver sphere with a round entry hatch. A second hatch covered the parachute compartment. Four metal straps and power and control cables joined the capsule to the 2.25-meter-long (7.4 feet) instrument module, which included batteries, oxygen tanks, guidance equipment, and a retro-rocket.

Vostok reached Earth orbit on a modified R-7 missile. At the end of the mission Vostok fired its retro-rocket to slow down and fall from orbit. The instrument module detached and burned up in the atmosphere. The heat-shield-protected capsule dropped until it reached the lower atmosphere, and a parachute opened to slow its fall. The cosmonaut ejected 4,000 meters (13,120 feet) above the ground and floated to Earth on a parachute.

Soviet engineers helped ensure that Soviet cosmonauts would beat American astronauts into space by basing Vostok on an existing unmanned satellite design. Code-named Kosmos, the satellite was designed to photograph military activities and bases around the world and then reenter the

This Vostok capsule and its SL-3 rocket booster, on display at the Cosmos Pavillion, Moscow, were used to launch the first cosmonauts into space.

atmosphere to deliver its film. Hundreds of Kosmos spy satellites flew between the 1960s and the 1990s.

Before launching a cosmonaut, Soviet engineers tested five Vostoks in the Korabl-Sputnik program (May 1960 to March 1961). Korabl-Sputnik 1 became stranded in orbit, and Korabl-Sputnik 3 reentered off course. Flight controllers commanded it to self-destruct. Korabl-Sputniks 2 through 5 carried dogs. Except for the two lost on Korabl-Sputnik 3, all the canine cosmonauts were recovered safely.

The successful Korabl-Sputnik 4 and 5 missions gave the green light for Vostok 1 (April 12, 1961). With a cry of "Poyekhali (Let's go)!" twenty-seven-year-old Yuri Gagarin lifted off for a 108-minute single-orbit flight. The first spaceflight went well until atmosphere re-entry, when cables linking the capsule and the instrument module failed to separate completely. The capsule gyrated wildly through re-entry as it dragged the instrument module behind it. The cables broke after about ten minutes, and Gagarin landed unhurt.

Vostok 2 (August 6 and 7, 1961) was a twenty-four-hour, eighteen-minute flight by Gherman Titov, who became the first person to sleep, eat, and get spacesick in orbit. Because of Titov's illness, doctors postponed Andrian Nikolayev's Vostok 3 flight until August 1962. Vostok 4 (August 12 to 15, 1962) carried Pavel Popovich to within 6.5 kilometers (4 miles) of Vostok 3.

Valeri Bykovskii's four-day, twenty-three-hour Vostok 5 flight (June 14 to 19, 1963) remains the longest solo space mission. Vostok 6 (June 16 to 19, 1963) carried Valentina Tereshkova, the first woman in space, to within 5 kilometers (3.1 miles) of Vostok 5. Soviet engineers canceled a planned one-week Vostok 7 flight so that they could concentrate on building Vostok's successor, the Voskhod spacecraft.

SEE ALSO COSMONAUTS (VOLUME 3); HISTORY OF HUMANS IN SPACE (VOLUME 3); MERCURY PROGRAM (VOLUME 3); GARGARIN, YURI (VOLUME 3); TERESHKOVA, VALENTINA (VOLUME 3); TSIOLKOVSKY, KONSTANTIN (VOLUME 3); VOSHKOD (VOLUME 3).

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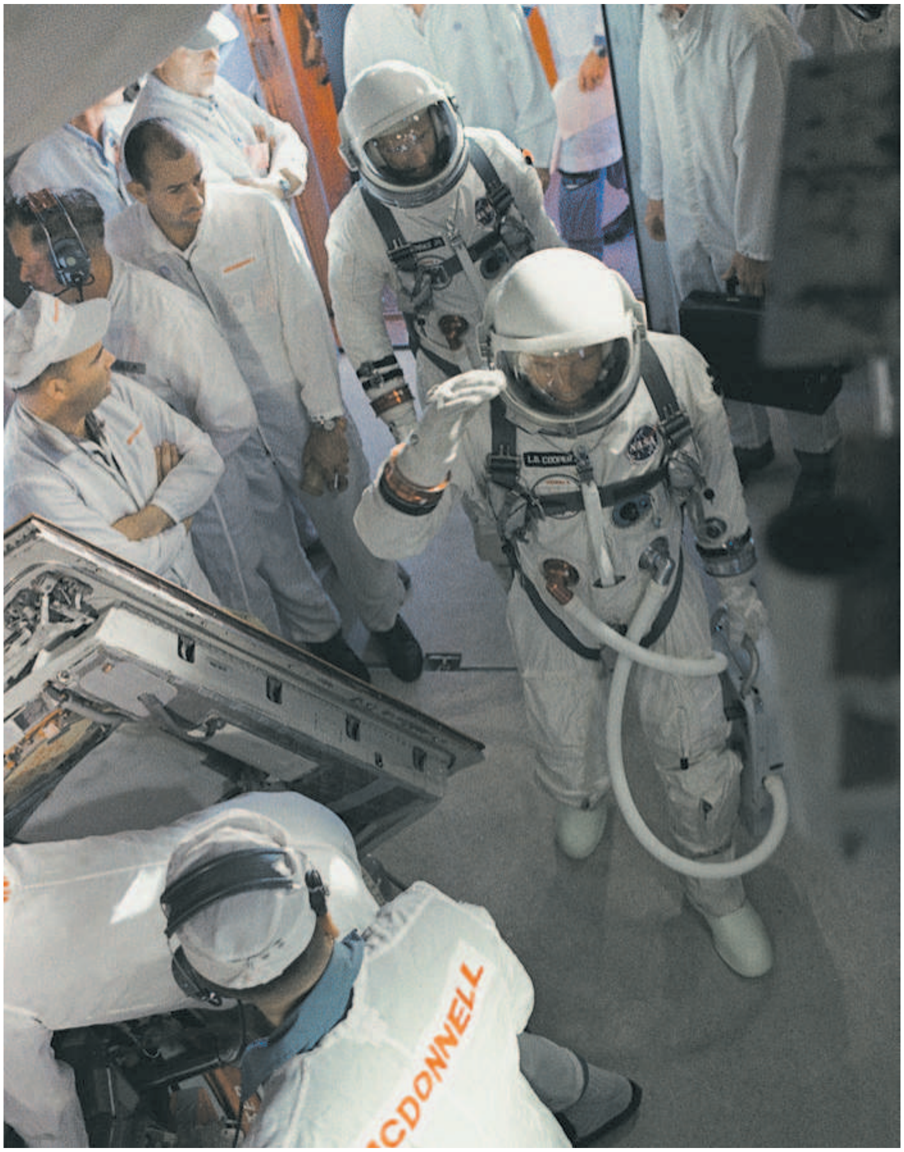
W

White Room

A "White Room"—also called a "clean room"—is a highly clean enclosed area where satellites and rocket parts are assembled and tested prior to launching. White rooms provide the necessary controlled environment to ensure that a satellite is ready for launch. Instruments onboard satellites are very sensitive to dust and degrade when exposed to oil or humidity, so a White Room maintains a constant temperature and humidity, eliminates dust, and protects the satellite during its development, construction, and testing.



Astronauts L. Gordon Cooper, Jr. (foreground) and Charles "Pete" Conrad Jr. prepare for their mission inside a prelaunch White Room during the Gemini 5 countdown on August 21, 1965.

Typically, White Rooms are also designed to guard against electromagnetic hazards. For example, the floor of a White Room might be constructed to avoid a buildup of static electricity. These precautions ensure that electronic and electrical testing of electrical systems can be carried out.

Technicians and workers wear protective gear at all times inside a White Room. Everyone entering the room must wear a "bunny suit"—special coveralls, hoods, boots, gloves, and masks. This special clothing is worn to eliminate dirt and dust from clothing, avoid flakes and hair from the scalp, and keep the satellite away from exhaled breath. The gear helps protect the sensitive flight hardware from particles that could impede performance.

There are many types of White Rooms around the world, most of which are located at launch sites and at locations where satellites are built. The Spacecraft Assembly and Encapsulation Facility is one of the Kennedy Space Center's many White Room facilities. It is used for assembly, testing, **encapsulation**, ordnance work, propellant loading, and spacecraft pressuriza-

encapsulation enclosure within a capsule tion. At another site, the Multi-Payload Processing Facility (MPPF), nonhazardous payloads go through their final assembly in preparation for launch. This includes installation of such things as solar panels, antennas, and other items shipped separately to the launch site. During a payload's stay at the MPPF, stand-alone systems testing and payload functional testing with payload-unique ground checkout equipment are conducted to ensure the payload is ready for launch.

At Kennedy Space Center's Launch Pads 39A and 39B, an environmentally controlled White Room that can accommodate up to six people is joined to the space shuttle orbiter's hatch prior to launch. It is here that the astronaut flight crew is assisted in entering the orbiter. The White Room—located at the end of the Orbiter Access Arm—remains in an extended position until about seven minutes before launch to provide an emergency exit for the crew. In an emergency, the White Room can be mechanically or manually repositioned in fifteen seconds.

An enormous White Room is located at Goddard Space Flight Center in Greenbelt, Maryland. This facility houses the 37,000-cubic-meter (48,360-cubic-yard) High Bay Clean Room, which is used to integrate and test space hardware. The largest of its kind anywhere, this White Room plays an important role in the servicing of the Hubble Space Telescope. Astronauts for several Hubble servicing missions trained in this room. Using the White Room's very precise mechanical and electrical simulators, astronauts practiced installing actual Hubble hardware. SEE ALSO Launch Sites (volume 3); Rockets (volume 3); Space Centers (volume 3).

John F. Kross

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Why Human Exploration?

Our early ancestors migrated across plains and jumped from continent to continent. Our more recent relatives set forth on great voyages of exploration, by ship and by caravan. For the past hundred years, we have been able to don deep-sea diving gear and space suits to explore places that once were inaccessible. We have already taken our first tentative steps off our home planet, and are on the verge of becoming a spacefaring species.

Human Flexibility and Creativity

Space exploration involves a finely crafted partnership between robots and people. Robots are useful in well-defined, repetitive, and predictable situations. Robots have nearly unlimited stamina and never become bored, fearful, or angry. They are not, however, flexible and creative. People can organize information in many different ways, deal with ambiguity, take advantage of unexpected opportunities, use their intuition, and apply common

Missions such as the one suggested here—human travelers at work in the Noctis Labyrinthus area of the Valles Marineris canyons of Mars—can advance scientific knowledge and enhance our understanding of the universe.

sense. In light of the work that needs to be done in space, there will always be a need for human skills.

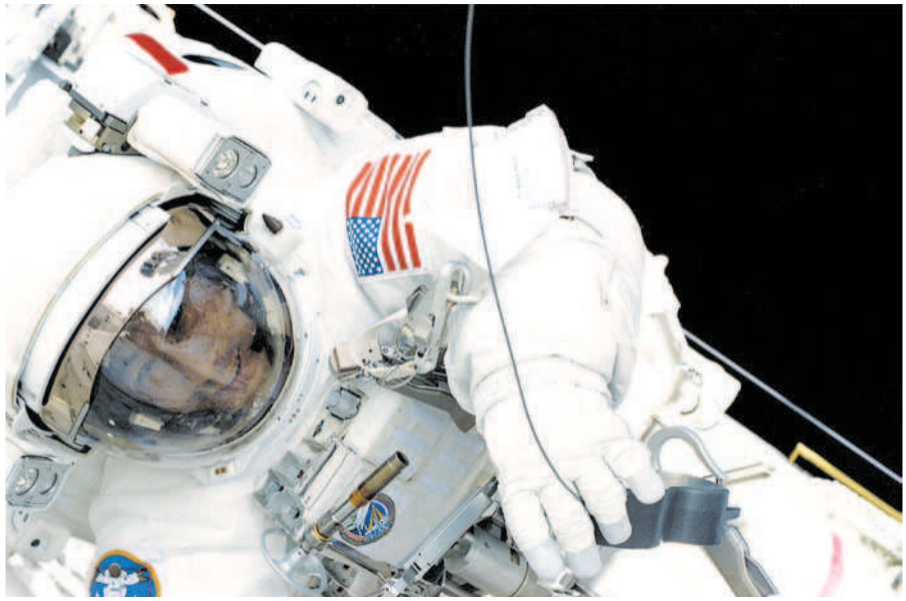
Spaceflight as a Psychological Boost

As a challenging and unique environment, space promises visitors a psychological boost. Training for and working in space allows astronauts and cosmonauts to develop their abilities, gain a sense of accomplishment, and enhance their sense of mastery over the environment. Many spacefarers, who tend to be scientists, report nearly mystical experiences as they conduct extravehicular activities or walk on the surface of the Moon. They experience feelings of wonder and awe, a new appreciation of humanity, and a sense of communion with the universe. It is doubtful that the unique and memorable experience of "being there" can be duplicated through even the most convincing form of virtual reality.

One picture of Earth taken during the Apollo Moon program shows a fragile-looking ball—a pale blue dot—partially shrouded by clouds.* Imagine what it would be like to view Earth from a distance—if not as a professional astronaut, then perhaps as a tourist in Earth orbit or on a round trip to the Moon. The Moon is a place of sharp contrasts with a stark landscape and a remarkably nearby horizon. Then there is Mars with its massive mountains, rough terrain, and powerful dust storms. It could be the perfect destination for a person who likes rugged scenery or wants to get away from it all. Over time scientists and engineers may develop the technology to transform desolate planets into attractive and friendly homes.

*** This image is known as "Earthrise" and can be seen in the article "Earth—Why Leave?" in Volume 4.**

Dennis Tito, the first paying tourist in space, visited the International Space Station in 2001, and was pleased with his destination. Surveys reveal that many people would like to follow in his footsteps. Whereas few respondents could afford the multi-million-dollar ticket, some people are will-



Humans have explored throughout history, and over the past hundred years, we have been able to don deep-sea diving gear and space suits to explore places that once were inaccessible to us.

ing to pay the equivalent of four years' salary for that experience. Several companies in the United States, Europe, and Russia are working to drive the price down, and the Russians are developing a new rocket that could give tourists a taste of space for only $100,000.

A Fresh Start on the High Frontier

In *The Case for Mars* (1997) Robert Zubrin and Richard Wagner argue that space offers people a fresh start. Because the pioneers will be few in number, each person will be valued and judged on the basis of his or her merit rather than gender or ethnic background. To grapple successfully with the challenges of life in space, the people who go there will have to be educated and creative and develop new technologies. The abundance of resources in space will give pioneers an opportunity to amass great fortunes. Those authors draw a compelling comparison between the opening of the frontier of the American West and the opening of the frontier in space. Unlike the West, space is so vast that the frontier will never close.

According to German rocket scientist Krafft A. Ehricke, the greatest limits are those that people place upon themselves. Instead of "thinking small" and limiting the use of Earth's resources, it is better to "think big," embrace technology, and exploit the universe's resources to the fullest. The choice is between stagnation and decay or unlimited growth. If people do not expand into space, human society will simply run down.

Assuring Humanity's Long-Term Survival

Ultimately, space may provide answers to threats to planet Earth, including overpopulation, depletion of fossil fuels and other natural resources, and irreversible damage to the environment. Space has vast areas of real estate for developing new communities, almost unlimited sources of energy, and many other kinds of raw materials, including precious metals such as platinum. Moving into space may reduce overcrowding, replenish resources, and separate clashing communities, eliminating many of the bases for war.

If one has looked through a telescope or binoculars at the face of the Moon, one would see that over the millennia asteroids and **meteors** have left the Moon's surface heavily cratered. Flying debris has hit Earth too. To some extent, Earth's atmosphere provides some protection against smaller incoming objects, and natural geological processes on Earth soften—and over time—eliminate the signs of ancient impacts. At some point a huge comet or asteroid could crash through Earth's atmosphere. The collision itself would be bad enough, but the resulting storm of dust and debris could turn Earth into a hopelessly dark and cold place. The establishment of humans in space could help the human species survive such a cataclysmic disaster. If people disperse widely enough, it will be possible to survive the eventual death of the Sun.

meteors physical manifestations of a meteoroid interacting with Earth's atmosphere

People explore space for many reasons: to develop an understanding of the universe, to advance science and technology, to make money, to grow psychologically, to get a fresh start, and to have fun. But most of all, people explore space because doing so is part of human nature. In *Interstellar Migration and the Human Experience* (1984) Ben Finney and Eric Jones wrote that settling space should not be thought of as fantasy, imperialism, or technology gone wild. Humans are exploring animals who have covered the home planet and now look forward to settling other worlds. The Russian rocket scientist Konstantin Tsiolkovsky expressed it with the comment that Earth is our cradle and we are ready to leave the cradle. The transition to a spacefaring species is the next leap forward, from citizens of the world to citizens of the universe. SEE ALSO EARTH—WHY LEAVE? (VOLUME 4); HUMANS VERSUS ROBOTS (VOLUME 3); IMPACTS (VOLUME 4); LUNAR BASES (VOLUME 4); MARS BASES (VOLUME 4); SOCIAL ETHICS (VOLUME 4); SPACE TOURISM, EVOLUTION OF (VOLUME 4); TOURISM (VOLUME 1).

Albert A. Harrison

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Women in Space

One cannot discuss women in the space program without mentioning the women in research and aviation who paved the way for the eventual inclusion of female astronauts. Two of the most significant people in this regard are Harriet Quimby and Pearl Young. In 1911 Quimby became the first American woman to earn a pilot's license. Just a year later, she became the first woman to fly across the English Channel. She served as a forerunner to more prominent female pilots such as Amelia Earhart. Young was the

In January 1978, the first female astronaut candidates were selected by NASA (left to right): Margaret Rhea Seddon, Kathryn Sullivan, Judith Resnik, Sally Ride, Anna Lee Fisher, and Shannon Lucid.

first female professional to work at the National Advisory Committee for Aeronautics (a precursor to the National Aeronautics and Space Administration [NASA]), paving the way for women to work directly within the U.S. space program.

First Women Astronaut Candidates

It was not until 1978, thirteen years after the official start of NASA, that the first women were selected for astronaut training. Within those thirteen years, only one astronaut screening took place that included women. Earlier, in 1961, the Mercury 13, a group consisting of female top-flight pilots, was secretly tested by an independent medical organization. This thorough testing increased the standards for women astronauts when NASA finally conducted its first tests in 1961. Whereas the men's sensory isolation tests lasted roughly three hours in a silent room, Jerrie Cobb, the first woman to undergo testing, had to endure nearly ten hours submerged in a sensory isolation tank filled with warm water. Other tests Cobb endured required the consumption of radioactive water and liquid barium, the swallowing of nearly a meter of rubber tubing, the injection of ice-cold water into her ears to check for vertigo, and the insertion of eighteen needles in her head for brainwave recording. Jane Hart, another test subject, recalled, "it seemed we went for days and days without anything to eat."

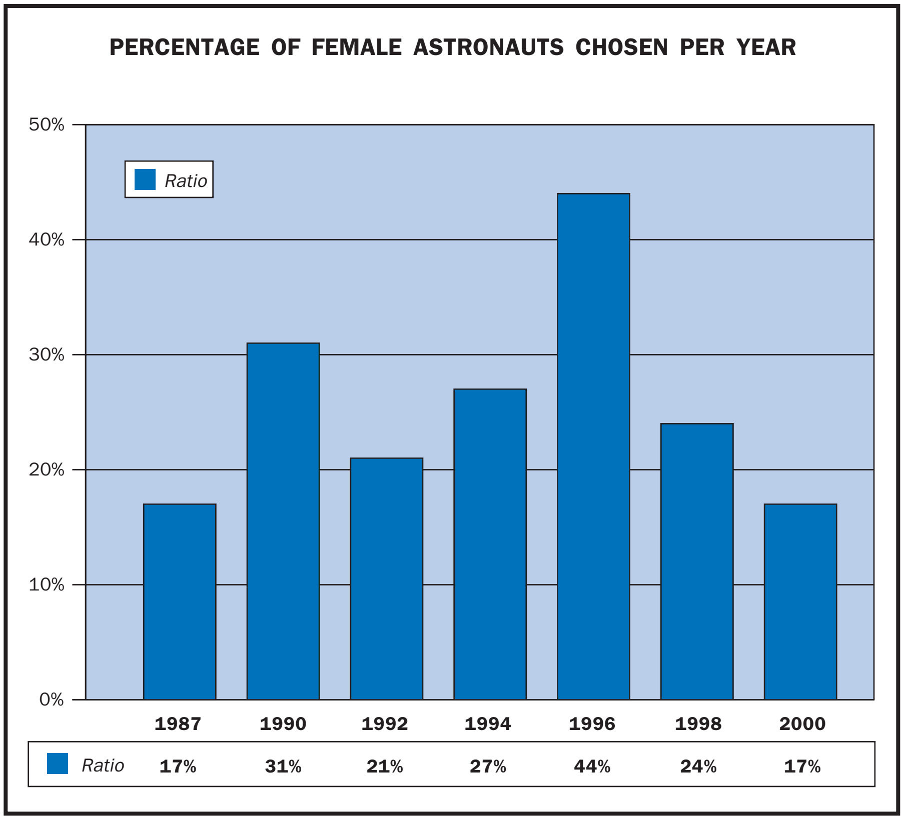
While all the women did well in the testing (and in most cases, better than the men according to one of the doctors in a public statement), NASA dismissed the women before final selections were made. Subsequent hearings in the U.S. Congress on the matter ended in the cancellation of further discussions. Following the canceled congressional hearings, astronaut John Glenn stated, "If we could find any women that demonstrated they

Name	Degree	Date	Selection Age	Type
Anna L. Fisher	Doctorate (Medicine); Masters (Chemistry)	1/78	28	Mission Specialist
Shannon W. Lucid	Doctorate/Masters (Biochemistry)	1/78	35	Mission Specialist/ Board Engineer
Judith A. Resnik*	Doctorate (Electrical Engineering)	1/78	28	Mission Specialist
Sally K. Ride	Doctorate/Masters (Physics)	1/78	26	Mission Specialist
Margaret Rhea Seddon	Doctorate (Medicine)	1/78	30	Mission Specialist/ Payload Commander
Kathryn D. Sullivan	Doctorate (Geology)	1/78	26	Mission Specialist/ Payload Commander
Mary L. Cleave	Doctorate (Civil and Environmental Engineering); Masters (Microbial Ecology)	5/80	33	Mission Specialist
Bonnie J. Dunbar	Doctorate (Mechanical/ Biomedical Engineering); Masters (Ceramic Engineering)	5/80	30	Payload Commander/ Mission Specialist
Millie Hughes-Fulford	Doctorate	1/83	51	Payload Specialist
Roberta Lynn Bondar	Doctorate (Medicine and Neurobiology); Masters (Experimental Pathology)	12/83	38	Payload Specialist
Ellen S. Baker	Doctorate (Medicine); Masters (Public Health)	5/84	31	Mission Specialist
Marsha S. Ivins	Bachelors (Aerospace Engineering)	5/84	33	Mission Specialist
Kathryn C. Thornton	Doctorate/Masters (Physics)	5/84	31	Mission Specialist
Linda M. Godwin	Doctorate/Masters (Physics)	6/85	32	Payload Commander/ Mission Specialist
Tamara E. Jernigan	Doctorate (Space Physics and Astronomy); Masters (Astronomy)	6/85	26	Payload Commander/ Mission Specialist
S. Christa Corrigan McAuliffe*	Masters (Education)	7/85	36	Payload Specialist
N. Jan Davis	Doctorate/Masters (Mechanical Engineering)	6/87	33	Payload Commander/ Mission Specialist
Mae C. Jemison	Doctorate (Medicine)	6/87	30	Mission Specialist
Eileen M. Collins	Masters (Operations Research and Space Systems Management)	1/90	33	Pilot/Commander
Nancy Jane Currie	Doctorate (Industrial Engineering); Masters (Safety)	1/90	31	Flight Engineer
Susan J. Helms	Masters (Aeronautics/ Astronautics	1/90	31	Payload Commander/ Mission Specialist/ Flight Engineer
Ellen Ochoa	Doctorate/Masters (Electrical Engineering)	1/90	31	Mission Specialist/ Payload Commander/ Flight Engineer
Janice Voss	Doctorate (Aeronautics/ Astronautics); Masters (Electrical Engineering)	1/90	33	Mission Specialist

* - Deceased

Name	Degree	Date	Selection Age	Type
Catherine G. Coleman	Doctorate (Polymer Science and Engineering)	3/92	31	Mission Specialist
Wendy B. Lawrence	Masters (Ocean Engineering)	3/92	32	Mission Specialist
Mary Ellen Weber	Doctorate (Physical Chemistry)	3/92	29	Mission Specialist
Kathryn P. Hire	Masters (Space Technology)	12/94	35	Mission Specialist
Janet Lynn Kavandi	Doctorate (Analytical Chemistry); Masters (Chemistry)	12/94	35	Mission Specialist
Susan Still-Kilrain	Masters (Aerospace Engineering)	12/94	33	Pilot
Pamela A. Melroy	Masters (Earth and Planetary Sciences)	12/94	33	Pilot
Joan E. Higginbotham	Masters (Management and Space Systems)	4/96	31	Mission Specialist
Sandra H. Magnus	Doctorate (Material Science and Engineering); Masters (Electrical Engineering)	4/96	31	Mission Specialist
Lisa M. Nowak	Masters (Aeronautical Engineering)	4/96	32	Mission Specialist
Julie Payette	Masters (Computer Engineering)	4/96	32	Mission Specialist
Heidemarie M. Stefanyshyn-Piper	Masters (Mechanical Engineering)	4/96	33	Mission Specialist
Peggy A. Whitson	Doctorate (Biochemistry)	4/96	36	Mission Specialist
Stephanie D. Wilson	Masters (Aerospace Engineering)	4/96	29	Mission Specialist
Tracy E. Caldwell	Doctorate (Physical Chemistry)	6/98	28	Mission Specialist
Barbara R. Morgan	Bachelors (Human Biology); Teaching Credential	6/98	46	Mission Specialist
Patricia C. Hilliard Robertson*	Doctorate (Medicine)	6/98	35	Mission Specialist
Sunita L. Williams	Masters (Engineering Management)	6/98	32	Mission Specialist
K. Megan McArthur	Doctorate (Oceanography)	7/00	28	Mission Specialist
Karen L. Nyberg	Doctorate/Masters (Mechanical Engineering)	7/00	30	Mission Specialist
Nicole Passonno Stott	Masters (Engineering Management)	7/00	37	Mission Specialist
Valentina Tereshkova		1962	25	Cosmonaut
Svetlana Yevgenyevna Savitskaya	Moscow Aviation Institute	1980	32	Cosmonaut
Elena V. Kondakova	Moscow Bauman High Technical College	1989	32	Flight Engineer

* - Deceased



have better qualifications [than men], we would welcome them with open arms." Congress even went so far as to support NASA's decision to have all future astronauts be drawn from military-jet test pilots, an exclusively male group until 1972.

Russian Space Program

Valentina Tereshkova, a Russian, was the first woman in space. On June 16, 1963, Tereshkova began a three-day voyage on Vostok 6 orbiting Earth. While this event was a milestone in proving that women were fully capable of participating in spaceflights, it accomplished little else. Tereshkova, a mere mill worker, received little preparation for the mission beyond some parachute jumping and became very ill while in flight. She served as a last-minute replacement for the woman originally selected.

The next female cosmonaut to travel in space, Svetlana Savitskaya, accomplished much more in her spaceflight. In 1982 she became the first woman to walk in space and later became the first woman to be sent into space twice. She was part of a group of three people who successfully connected with the Salyut space station, spending a week on the station. Despite this, she still had to endure chauvinistic male humor from one of her colleagues, Valentin Levedev. Upon boarding the station, he warmly suggested that she do the cleaning and cooking, saying, "We've got an apron ready for you, Sveta."

Women at NASA

Between the Mercury 13 tests in 1961 and the inclusion of the first female astronauts in 1978, advances were made for female roles at NASA, primarily in research. Noted accomplishments include the work of Nancy Roman (Ph.D., astronomy) and Emily Holton (Ph.D., medical science). Roman became the first chief astronomer and the first female senior executive at NASA in 1960, while Holton was the only biologist at NASA Wallops (one of the oldest launch sites in the world) in 1973.

The most significant achievement for women in the history of the U.S. space program took place in January 1978 when the first female astronaut candidates were selected. Six out of the eight candidates selected were women. From this class arguably came the most well-known female astronauts, including Sally Ride (Ph.D., physics), the first American woman in space. The launch of the space shuttle Challenger in June 1983 (STS-7) piqued the interest of the nation, as 1,600 people packed the press grandstand, forcing the posting of a "No Vacancy" sign. Not only did this serve as a media booster for NASA, Ride's performance spoke wonders for the inclusion of women astronauts. Ninety-six percent of all objectives were fulfilled, there were fewer **anomalies** than on any previous mission, and evidence suggests that the inclusion of a woman relaxed the crew and softened the curtness in conversation. Ride's fellow 1978 class member, Kathryn Sullivan (Ph.D., geology), became the first American woman to walk in space in October 1984. Judith A. Resnik (Ph.D., electrical engineering) was one of the seven astronauts who died in the Challenger disaster in 1986, and Shannon Lucid (Ph.D., biochemistry) was the first woman to live on the Russian space station Mir, setting the U.S. single-mission spaceflight endurance record at 188 days.

anomalies phenomena that are different from what is expected

The next major hurdle was overcome in 1995, when Eileen Collins (a colonel in the U.S. Air Force) became the first American woman to pilot a spaceship. Collins has frankly stated, "I'm sorry, but maybe you do have to work harder than men when you're one of the first women, one of the few women." She would later go on to be the first female to ever command a space mission in 1999.

The Future of Women in Space

While nothing can be taken away from the collective accomplishments of all of the women who have participated in the space program over the years, the significance of these accomplishments can possibly be trivialized in the future. In 1999 an all-female shuttle flight crew was proposed. Several women in the program believed this was a publicity stunt by NASA to garner attention and funding. According to an unpublished report by NASA in 2000, these fears were justified. The results of the report concluded that no significant scientific advancements could be accomplished from sending an all-female crew, and the proposed project was dropped.

In this new century, women will play a major role in advancing the space program. As stressed by Mae C. Jemison, the first African-American woman astronaut, the space program is not just "some silly male stuff going on." Women studying all facets of science and engineering and other relevant fields will be needed to continue the work started a mere half century ago. SEE ALSO Challenger (volume 3); Challenger 7 (volume 3); Collins, Eileen (volume 3); Cosmonauts (volume 3); History of Humans in Space (volume 3); NASA (volume 3); Ride, Sally (volume 3); Space Walks (vol-

ume 3); Sullivan, Kathryn (volume 3); Teacher in Space Program (volume 3); Tereshkova, Valentina (volume 3); Vostok (volume 3).

Cynthia Y. Young and Fredrick E. Thomas

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Young, John

American Astronaut
1930–

Born in San Francisco on September 24, 1930, John W. Young received a bachelor of science degree in aeronautical engineering from Georgia Institute of Technology in 1952. Following graduation Young joined the U.S. Navy. After receiving flight training he was assigned to a fighter squadron. In 1959, after passing test pilot training, Young was assigned to the Naval Air Test Center and set time-to-climb records. He retired from the Navy in 1976.

John W. Young served as the commander of the first space shuttle mission.

In 1962 the National Aeronautics and Space Administration (NASA) selected Young as an astronaut candidate. On March 23, 1965, he flew on Gemini 3 (the first piloted Gemini mission), and he was on Gemini 10 in 1966. In 1969 Young operated the command module of Apollo 10, and in 1972 he was in command of the Apollo 16 mission to Descartes.

Young served as the commander of the first space shuttle mission in April 1981. His final mission was aboard Columbia in 1983. Young's shared record for the most spaceflights, six, was broken in 2002 by Jerry Ross.

In 1973 Young became chief of the Space Shuttle Branch of the Astronaut Office. A year later he was chosen to be chief of the Astronaut Office. He is the associate director (technical) at Johnson Space Center in Houston. see also Apollo (volume 3); Apollo Lunar Landing Sites (volume 3); Gemini (volume 3); History of Humans in Space (volume 3); Lunar Rovers (volume 3); NASA (volume 3); Space Shuttle (volume 3).

Frank R. Mignone

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Z

Zero Gravity

The effects of gravity are so commonplace that people rarely notice them. People are used to living under the pressure of Earth's gravity (1 G), and so when the amount of gravitational force they experience increases or decreases, the difference becomes noticeable.

G force the force an astronaut or pilot experiences when undergoing large accelerations

The factors that cause these differences in **G forces** are mass, motion, and density. A person's mass stays the same in any location but is dependent on the amount of gravity that person is experiencing. When a person experiences zero g forces, that person's mass is unchanged but he or she still experiences weightlessness. Scientists refer to zero g as microgravity because even in zero-g environments there are small amounts of gravity. Those amounts are too small to provide significant levels of resistance for humans.

Most people believe that space travel is the only way to experience microgravity, but that is a misconception. There are ways to alter the amount of gravity a person feels on Earth, including roller coasters, jet planes, extended freefalls, and underwater environments. The turning of the riders at fast speeds on a roller coaster produces variations in the amount of gravity felt by the passengers. When the cars reach the top of a summit and begin to plummet, the passengers experience a moment of microgravity. The upward and downward gravitational forces are balanced for a split second, leading to the sensation that one is floating. When the forces are unbalanced, the car plunges downward, leaving microgravity behind.

The same principles apply to jet planes when flying specific courses. Probably the most famous plane that creates microgravity experiences is the Vomit Comet. This KC-135A plane, a modified 1950s Boeing airplane, performs a series of parabolic maneuvers that cause short, repeated periods of microgravity. Each flight on the Vomit Comet usually lasts a couple of hours and provides dozens of microgravity experiences that last 30 seconds to 2 minutes. About half of the first-time passengers on the Comet get sick from intense g forces during ascent or during the dive run that creates the microgravity experience. Every astronaut who has flown in space has first experienced microgravity on the Vomit Comet, and today scientists and students conduct zero-g experiments aboard it.

Extended freefall from high altitudes offers a near-microgravity environment. Skydivers have a few minutes while falling in which they are tricked into thinking they are floating. Despite this trick, eventually skydivers must use their parachute to help control their descent to prevent tragedy. Once the parachute is opened, divers still experience a floating sensation, but only for a brief period.

The Neurolab crew of the STS-90 shuttle mission "hang out" inside the Spacelab Science Module.

Underwater, astronauts dressed in space suits train by performing mission tasks. This is the most cost-effective training ground for microgravity experiences. The National Aeronautics and Space Administration has gigantic underwater tanks for this purpose. The natural buoyancy creates an experience similar to microgravity. SEE ALSO Living in Space (volume 3); KC-135 Training Aircraft (volume 3); Long-Duration Spaceflight (volume 3); Microgravity (volume 2).

Craig Samuels

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Zond

The Soviet Union's Zond (Russian for "probe") spacecraft series was designed to carry two cosmonauts around the Moon—that is, to conduct a circumlunar flight. Zond, also known as L-1, was a stripped-down Soyuz spacecraft. Modifications to the Soyuz design were designed primarily to reduce weight and included removal of various components, such as the third cosmonaut couch, a backup engine, and a backup parachute. Weight reduction was necessary so that Zond's chosen booster, a two-stage Proton rocket with a Block D third stage, could launch it around the Moon. In addition, Zond included a large radio antenna for communication across the 380,000 kilometers (235,600 miles) separating Earth and the Moon.

The Soviet Union conducted fourteen unpiloted Zond launches in three phases. The first four Zond tests aimed to prepare the vehicle for a piloted circumlunar flight to mark the fiftieth anniversary of the Communist Revolution in October 1967. The next six sought to prepare Zond to fly cosmonauts around the Moon before Apollo astronauts could orbit the Moon.

This phase ended with a launch failure in January 1969, a month after Apollo 8 orbited the Moon. Soon after, the cosmonauts in training for Zond flights were re-assigned. Of the remaining four Zond capsules, two served as automated probes and two as test **payloads** for the giant N1 Moon rocket.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

Kosmos 146 (March 10–18, 1967) was a successful test of the Block D stage in Earth orbit. The Kosmos 154 (April 8–19, 1967) Block D failed to reignite in Earth orbit, so Soviet engineers could not test the Zond capsule's atmosphere re-entry. The third Zond Proton rocket suffered first-stage failure; emergency escape **rockets** blasted the capsule to safety (September 29, 1967). The fourth Zond also ejected following Proton second-stage failure (November 22, 1967). This marked the end of the first phase of the Zond program.

The name Zond had been used before in the Soviet space program. Zonds 1 through 3 were automated planetary probes unrelated to the piloted circumlunar program. The next Zond flight (and the first in the second phase of circumlunar program), therefore, was named Zond 4 (March 2–9, 1968). This spacecraft flew to lunar distance, but away from the Moon. Soviet controllers destroyed it during re-entry after it veered off-course. Two Proton launch failures (April 23, 1968 and July 14, 1968) followed. Zond 5 (September 14–21, 1968) flew successfully around the Moon, but landed off-course in the Indian Ocean. Zond 6 (November 10–17, 1968) also flew around the Moon, but the capsule's air escaped during return to Earth, and it crashed. It was, however, the first Zond to return to Soviet soil. Another Proton failure (January 20, 1969) ended Soviet plans to launch cosmonauts in Zond.

The next Zond rode the first N-1 (February 20, 1969), beginning the third Zond phase. The giant rocket caught fire and crashed, but the Zond capsule successfully ejected. The second N-1 exploded on its launch pad (July 3, 1969); again the Zond ejected. Zond 7 (August 7–14, 1969) was the most successful mission. It photographed the Moon's farside before landing safely in the Soviet Union. Zond 8 (October 20–27, 1970) flew around the Moon, but suffered control problems and landed off-course in the Indian Ocean, ending the unsuccessful Zond program. SEE ALSO CAPSULES (VOLUME 3).

David S. F. Portree

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Glossary

ablation removal of the outer layers of an object by erosion, melting, or vaporization

abort-to-orbit emergency procedure planned for the space shuttle and other spacecraft if the spacecraft reaches a lower than planned orbit

accretion the growth of a star or planet through the accumulation of material from a companion star or the surrounding interstellar matter

adaptive optics the use of computers to adjust the shape of a telescope's optical system to compensate for gravity or temperature variations

aeroballistic describes the combined aerodynamics and ballistics of an object, such as a spacecraft, in flight

aerobraking the technique of using a planet's atmosphere to slow down an incoming spacecraft; its use requires the spacecraft to have a heat shield, because the friction that slows the craft is turned into intense heat

aerodynamic heating heating of the exterior skin of a spacecraft, aircraft, or other object moving at high speed through the atmosphere

Agena a multipurpose rocket designed to perform ascent, precision orbit injection, and missions from low Earth orbit to interplanetary space; also served as a docking target for the Gemini spacecraft

algae simple photosynthetic organisms, often aquatic

alpha proton X-ray analytical instrument that bombards a sample with alpha particles (consisting of two protons and two neutrons); the X rays are generated through the interaction of the alpha particles and the sample

altimeter an instrument designed to measure altitude above sea level

amplitude the height of a wave or other oscillation; the range or extent of a process or phenomenon

angular momentum the angular equivalent of linear momentum; the product of angular velocity and moment of inertia (moment of inertia = mass $\times$ radius^2)

angular velocity the rotational speed of an object, usually measured in radians per second

anisotropy a quantity that is different when measured in different directions or along different axes

annular ring-like

anomalies phenomena that are different from what is expected

anorthosite a light-colored rock composed mainly of the mineral feldspar (an aluminum silicate); commonly occurs in the crusts of Earth and the Moon

anthropocentrism valuing humans above all else

antimatter matter composed of antiparticles, such as positrons and antiprotons

antipodal at the opposite pole; two points on a planet that are diametrically opposite

aperture an opening, door, or hatch

aphelion the point in an object's orbit that is farthest from the Sun

Apollo American program to land men on the Moon; Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

asthenosphere the weaker portion of a planet's interior just below the rocky crust

astrometry the measurement of the positions of stars on the sky

astronomical unit the average distance between Earth and the Sun (152 million kilometers [93 million miles])

atmospheric probe a separate piece of a spacecraft that is launched from it and separately enters the atmosphere of a planet on a one-way trip, making measurements until it hits a surface, burns up, or otherwise ends its mission

atmospheric refraction the bending of sunlight or other light caused by the varying optical density of the atmosphere

atomic nucleus the protons and neutrons that make up the core of an atom

atrophy condition that involves withering, shrinking, or wasting away

auroras atmospheric phenomena consisting of glowing bands or sheets of light in the sky caused by high-speed charged particles striking atoms in Earth's upper atmosphere

avionics electronic equipment designed for use on aircraft, spacecraft, and missiles

azimuth horizontal angular distance from true north measured clockwise from true north (e.g., if North = 0 degrees; East = 90 degrees; South = 180 degrees; West = 270 degrees)

ballast heavy substance used to increase the stability of a vehicle

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

basalt a dark, volcanic rock with abundant iron and magnesium and relatively low silica common on all of the terrestrial planets

base load the minimum amount of energy needed for a power grid

beacon signal generator a radio transmitter emitting signals for guidance or for showing location

berth space the human accommodations needed by a space station, cargo ship, or other vessel

Big Bang name given by astronomers to the event marking the beginning of the universe when all matter and energy came into being

biocentric notion that all living organisms have intrinsic value

biogenic resulting from the actions of living organisms; or, necessary for life

bioregenerative referring to a life support system in which biological processes are used; physiochemical and/or nonregenerative processes may also be used

biosignatures the unique traces left in the geological record by living organisms

biosphere the interaction of living organisms on a global scale

bipolar outflow jets of material (gas and dust) flowing away from a central object (e.g., a protostar) in opposite directions

bitumen a thick, almost solid form of hydrocarbons, often mixed with other minerals

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

bone mineral density the mass of minerals, mostly calcium, in a given volume of bone

breccia mixed rock composed of fragments of different rock types; formed by the shock and heat of meteorite impacts

bright rays lines of lighter material visible on the surface of a body and caused by relatively recent impacts

brown dwarf star-like object less massive than 0.08 times the mass of the Sun, which cannot undergo thermonuclear process to generate its own luminosity

calderas the bowl-shaped crater at the top of a volcano caused by the collapse of the central part of the volcano

Callisto one of the four large moons of Jupiter; named for one of the Greek nymphs

Caloris basin the largest (1,300 kilometers [806 miles] in diameter) well-preserved impact basin on Mercury viewed by Mariner 10

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

carbon-fiber composites combinations of carbon fibers with other materials such as resins or ceramics; carbon fiber composites are strong and lightweight

carbonaceous meteorites the rarest kind of meteorites, they contain a high percentage of carbon and carbon-rich compounds

carbonate a class of minerals, such as chalk and limestone, formed by carbon dioxide reacting in water

cartographic relating to the making of maps

Cassini mission a robotic spacecraft mission to the planet Saturn scheduled to arrive in July 2004 when the Huygens probe will be dropped into Titan's atmosphere while the Cassini spacecraft studies the planet

catalyst a chemical compound that accelerates a chemical reaction without itself being used up; any process that acts to accelerate change in a system

catalyze to change by the use of a catalyst

cell culture a means of growing mammalian (including human) cells in the research laboratory under defined experimental conditions

cellular array the three-dimensional placement of cells within a tissue

centrifugal directed away from the center through spinning

centrifuge a device that uses centrifugal force caused by spinning to simulate gravity

Cepheid variables a class of variable stars whose luminosity is related to their period. Their periods can range from a few hours to about 100 days and the longer the period, the brighter the star

Čerenkov light light emitted by a charged particle moving through a medium, such as air or water, at a velocity greater than the phase velocity of light in that medium; usually a faint, eerie, bluish, optical glow

chassis frame on which a vehicle is constructed

chondrite meteorites a type of meteorite that contains spherical clumps of loosely consolidated minerals

cinder field an area dominated by volcanic rock, especially the cinders ejected from explosive volcanoes

circadian rhythm activities and bodily functions that recur every twenty-four hours, such as sleeping and eating

Clarke orbit geostationary orbit; named after science fiction writer Arthur C. Clarke, who first realized the usefulness of this type of orbit for communication and weather satellites

coagulate to cause to come together into a coherent mass

comet matrix material the substances that form the nucleus of a comet; dust grains embedded in frozen methane, ammonia, carbon dioxide, and water

cometary outgassing vaporization of the frozen gases that form a comet nucleus as the comet approaches the Sun and warms

communications infrastructure the physical structures that support a network of telephone, Internet, mobile phones, and other communication systems

convection the movement of heated fluid caused by a variation in density; hot fluid rises while cool fluid sinks

convection currents mechanism by which thermal energy moves because its density differs from that of surrounding material. Convection current is the movement pattern of thermal energy transferring within a medium

convective processes processes that are driven by the movement of heated fluids resulting from a variation in density

coronal holes large, dark holes seen when the Sun is viewed in X-ray or ultraviolet wavelengths; solar wind emanates from the coronal holes

coronal mass ejections large quantities of solar plasma and magnetic field launched from the Sun into space

cosmic microwave background ubiquitous, diffuse, uniform, thermal radiation created during the earliest hot phases of the universe

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

cosmocentric ethic an ethical position that establishes the universe as the priority in a value system or appeals to something characteristic of the universe that provides justification of value

cover glass a sheet of glass used to cover the solid state device in a solar cell

crash-landers or hard-lander; a spacecraft that collides with the planet, making no—or little—attempt to slow down; after collision, the spacecraft ceases to function because of the (intentional) catastrophic failure

crawler transporter large, tracked vehicles used to move the assembled Apollo/Saturn from the VAB to the launch pad

cryogenic related to extremely low temperatures; the temperature of liquid nitrogen or lower

cryptocometary another name for carbonaceous asteroids—asteroids that contain a high percentage of carbon compounds mixed with frozen gases

cryptoendolithic microbial microbial ecosystems that live inside sandstone in extreme environments such as Antarctica

crystal lattice the arrangement of atoms inside a crystal

crystallography the study of the internal structure of crystals

dark matter matter that interacts with ordinary matter by gravity but does not emit electromagnetic radiation; its composition is unknown

density-separation jigs a form of gravity separation of materials with different densities that uses a pulsating fluid

desiccation the process of drying up

detruents microorganisms that act as decomposers in a controlled environmental life support system

diffuse spread out; not concentrated

DNA deoxyribonucleic acid; the molecule used by all living things on Earth to transmit genetic information

docking system mechanical and electronic devices that work jointly to bring together and physically link two spacecraft in space

doped semiconductor such as silicon with an addition of small amounts of an impurity such as phosphorous to generate more charge carriers (such as electrons)

dormant comet a comet whose volatile gases have all been vaporized, leaving behind only the heavy materials

downlink the radio dish and receiver through which a satellite or spacecraft transmits information back to Earth

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

dunites rock type composed almost entirely of the mineral olivine, crystallized from magma beneath the Moon's surface

dynamic isotope power the decay of isotopes such as plutonium-238, and polonium-210 produces heat, which can be transformed into electricity by radioisotopic thermoelectric generators

Earth-Moon LaGrange five points in space relative to Earth and the Moon where the gravitational forces on an object balance; two points, 60 degrees from the Moon in orbit, are candidate points for a permanent space settlement due to their gravitational stability

eccentric the term that describes how oval the orbit of a planet is

ecliptic the plane of Earth's orbit

EH condrites a rare form of meteorite containing a high concentration of the mineral enstatite (a type of pyroxene) and over 30 percent iron

ejecta the pieces of material thrown off by a star when it explodes; or, material thrown out of an impact crater during its formation

ejector ramjet engine design that uses a small rocket mounted in front of the ramjet to provide a flow of heated air, allowing the ramjet to provide thrust when stationary

electrodynamic pertaining to the interaction of moving electric charges with magnetic and electric fields

electrolytes a substance that when dissolved in water creates an electrically conducting solution

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

electron a negatively charged subatomic particle

electron volts units of energy equal to the energy gained by an electron when it passes through a potential difference of 1 volt in a vacuum

electrostatic separation separation of substances by the use of electrically charged plates

elliptical having an oval shape

encapsulation enclosing within a capsule

endocrine system in the body that creates and secretes substances called hormones into the blood

equatorial orbit an orbit parallel to a body's geographic equator

equilibruim point the point where forces are in balance

Europa one of the large satellites of Jupiter

eV an electron volt is the energy gained by an electron when moved across a potential of one volt. Ordinary molecules, such as air, have an energy of about $3x10^{-2}$ eV

event horizon the imaginary spherical shell surrounding a black hole that marks the boundary where no light or any other information can escape

excavation a hole formed by mining or digging

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

extrasolar planets planets orbiting stars other than the Sun

extravehicular activity a space walk conducted outside a spacecraft cabin, with the crew member protected from the environment by a pressurized space suit

extremophiles microorganisms that can survive in extreme environments such as high salinity or near boiling water

extruded forced through an opening

failsafe a system designed to be failure resistant through robust construction and redundant functions

fairing a structure designed to provide low aerodynamic drag for an aircraft or spacecraft in flight

fault a fracture in rock in the upper crust of a planet along which there has been movement

feedstock the raw materials introduced into an industrial process from which a finished product is made

feldspathic rock containing a high proportion of the mineral feldspar

fiber-optic cable a thin strand of ultrapure glass that carries information in the form of light, with the light turned on and off rapidly to represent the information sent

fission act of splitting a heavy atomic nucleus into two lighter ones, releasing tremendous energy

flares intense, sudden releases of energy

flybys flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

fracture any break in rock, from small "joints" that divide rocks into planar blocks (such as that seen in road cuts) to vast breaks in the crusts of unspecified movement

freefall the motion of a body acted on by no forces other than gravity, usually in orbit around Earth or another celestial body

free radical a molecule with a high degree of chemical reactivity due to the presence of an unpaired electron

frequencies the number of oscillations or vibrations per second of an electromagnetic wave or any wave

fuel cells cells that react a fuel (such as hydrogen) and an oxidizer (such as oxygen) together; the chemical energy of the initial reactants is released by the fuel cell in the form of electricity

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

fusion fuel fuel suitable for use in a nuclear fusion reactor

G force the force an astronaut or pilot experiences when undergoing large accelerations

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

Galilean satellite one of the four large moons of Jupiter first discovered by Galileo

Galileo mission succesful robot exploration of the outer solar system; this mission used gravity assists from Venus and Earth to reach Jupiter, where it dropped a probe into the atmosphere and studied the planet for nearly seven years

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

Ganymede one of the four large moons of Jupiter; the largest moon in the solar system

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

general relativity a branch of science first described by Albert Einstein showing the relationship between gravity and acceleration

geocentric a model that places Earth at the center of the universe

geodetic survey determination of the exact position of points on Earth's surface and measurement of the size and shape of Earth and of Earth's gravitational and magnetic fields

geomagnetic field Earth's magnetic field; under the influence of solar wind, the magnetic field is compressed in the Sunward direction and stretched out in the downwind direction, creating the magnetosphere, a complex, teardrop-shaped cavity around Earth

geospatial relating to measurement of Earth's surface as well as positions on its surface

geostationary remaining above a fixed point above Earth's equator

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

gimbal motors motors that direct the nozzle of a rocket engine to provide steering

global change a change, such as average ocean temperature, affecting the entire planet

global positioning systems a system of satellites and receivers that provide direct determination of the geographical location of the receiver

globular clusters roughly spherical collections of hundreds of thousands of old stars found in galactic haloes

grand unified theory (GUT) states that, at a high enough energy level (about 10^{25} eV), the electromagnetic force, strong force, and weak force all merge into a single force

gravitational assist the technique of flying by a planet to use its energy to "catapult" a spacecraft on its way—this saves fuel and thus mass and cost of a mission; gravitational assists typically make the total mission duration longer, but they also make things possible that otherwise would not be possible

gravitational contraction the collapse of a cloud of gas and dust due to the mutual gravitational attraction of the parts of the cloud; a possible source of excess heat radiated by some Jovian planets

gravitational lenses two or more images of a distant object formed by the bending of light around an intervening massive object

gravity assist using the gravity of a planet during a close encounter to add energy to the motion of a spacecraft

gravity gradient the difference in the acceleration of gravity at different points on Earth and at different distances from Earth

gravity waves waves that propagate through space and are caused by the movement of large massive bodies, such as black holes and exploding stars

greenhouse effect process by which short wavelength energy (e.g., visible light) penetrates an object's atmosphere and is absorbed by the surface, which reradiates this energy as longer wavelength infrared (thermal) energy; this energy is blocked from escaping to space by molecules (e.g., H_2O and CO_2) in the atmosphere; and as a result, the surface warms

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

hard-lander spacecraft that collides with the planet or satellite, making no attempt to slow its descent; also called crash-landers

heliosphere the volume of space extending outward from the Sun that is dominated by solar wind; it ends where the solar wind transitions into the interstellar medium, somewhere between 40 and 100 astronomical units from the Sun

helium-3 a stable isotope of helium whose nucleus contains two protons and one neutron

hertz unit of frequency equal to one cycle per second

high-power klystron tubes a type of electron tube used to generate high frequency electromagnetic waves

hilly and lineated terrain the broken-up surface of Mercury at the antipode of the Caloris impact basin

hydrazine a dangerous and corrosive compound of nitrogen and hydrogen commonly used in high powered rockets and jet engines

hydroponics growing plants using water and nutrients in solution instead of soil as the root medium

hydrothermal relating to high temperature water

hyperbaric chamber compartment where air pressure can be carefully controlled; used to gradually acclimate divers, astronauts, and others to changes in pressure and air composition

hypergolic fuels and oxidizers that ignite on contact with each other and need no ignition source

hypersonic capable of speeds over five times the speed of sound

hyperspectral imaging technique in remote sensing that uses at least sixteen contiguous bands of high spectral resolution over a region of the electromagnetic spectrum; used in NASA spacecraft Lewis' payload

ilmenite an important ore of titanium

Imbrium Basin impact largest and latest of the giant impact events that formed the mare-filled basins on the lunar near side

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

impact winter the period following a large asteroidal or cometary impact when the Sun is dimmed by stratospheric dust and the climate becomes cold worldwide

impact-melt molten material produced by the shock and heat transfer from an impacting asteroid or meteorite

in situ in the natural or original location

incandescence glowing due to high temperature

indurated rocks rocks that have been hardened by natural processes

information age the era of our time when many businesses and persons are involved in creating, transmitting, sharing, using, and selling information, particularly through the use of computers

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

infrared radiation radiation whose wavelength is slightly longer than the wavelength of light

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

intercrater plains the oldest plains on Mercury that occur in the highlands and that formed during the period of heavy meteoroid bombardment

interferometers devices that use two or more telescopes to observe the same object at the same time in the same wavelength to increase angular resolution

interplanetary trajectories the solar orbits followed by spacecraft moving from one planet in the solar system to another

interstellar between the stars

interstellar medium the gas and dust found in the space between the stars

ion propulsion a propulsion system that uses charged particles accelerated by electric fields to provide thrust

ionization removing one or more electrons from an atom or molecule

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

isotopic ratios the naturally occurring ratios between different isotopes of an element

jettison to eject, throw overboard, or get rid of

Jovian relating to the planet Jupiter

Kevlar® a tough aramid fiber resistant to penetration

kinetic energy the energy an object has due to its motion

KREEP acronym for material rich in potassium (K), rare earth elements (REE), and phosphorus (P)

L-4 the gravitationally stable Lagrange point 60 degrees ahead of the orbiting planet

L-5 the gravitationally stable Lagrange point 60 degrees behind the orbiting planet

Lagrangian point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

laser-pulsing firing periodic pulses from a powerful laser at a surface and measuring the length of time for return in order to determine topography

libration point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

lichen fungus that grows symbiotically with algae

light year the distance that light in a vacuum would travel in one year, or about 9.5 trillion kilometers (5.9 trillion miles)

lithosphere the rocky outer crust of a body

littoral the region along a coast or beach between high and low tides

lobate scarps a long sinuous cliff

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

lunar maria the large, dark, lava-filled impact basins on the Moon thought by early astronomers to resemble seas

Lunar Orbiter a series of five unmanned missions in 1966 and 1967 that photographed much of the Moon at medium to high resolution from orbit

macromolecules large molecules such as proteins or DNA containing thousands or millions of individual atoms

magnetohydrodynamic waves a low frequency oscillation in a plasma in the presence of a magnetic field

magnetometer an instrument used to measure the strength and direction of a magnetic field

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

majority carriers the more abundant charge carriers in semiconductors; the less abundant are called minority carriers; for n-type semiconductors, electrons are the majority carriers

malady a disorder or disease of the body

many-bodied problem in celestial mechanics, the problem of finding solutions to the equations for more than two orbiting bodies

mare dark-colored plains of solidified lava that mainly fill the large impact basins and other low-lying regions on the Moon

Mercury the first American piloted spacecraft, which carried a single astronaut into space; six Mercury missions took place between 1961 and 1963

mesons any of a family of subatomic particle that have masses between electrons and protons and that respond to the strong nuclear force; produced in the upper atmosphere by cosmic rays

meteor the physical manifestation of a meteoroid interacting with Earth's atmosphere; this includes visible light and radio frequency generation, and an ionized trail from which radar signals can be reflected. Also called a "shooting star"

meteorites any part of a meteoroid that survives passage through Earth's atmosphere

meteoroid a piece of interplanetary material smaller than an asteroid or comet

meteorology the study of atmospheric phenomena or weather

meteorology satellites satellites designed to take measurements of the atmosphere for determining weather and climate change

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

micrometeoroid flux the total mass of micrometeoroids falling into an atmosphere or on a surface per unit of time

micrometeoroid any meteoroid ranging in size from a speck of dust to a pebble

microwave link a connection between two radio towers that each transmit and receive microwave (radio) signals as a method of carrying information (similar to radio communications)

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

missing matter the mass of the universe that cannot be accounted for but is necessary to produce a universe whose overall curvature is "flat"

monolithic massive, solid, and uniform; an asteroid that is formed of one kind of material fused or melted into a single mass

multi-bandgap photovoltaic photovoltaic cells designed to respond to several different wavelengths of electromagnetic radiation

multispectral referring to several different parts of the electromagnetic spectrum, such as visible, infrared, and radar

muons the decay product of the mesons produced by cosmic rays; muons are about 100 times more massive than electrons but are still considered leptons that do not respond to the strong nuclear force

near-Earth asteroids asteroids whose orbits cross the orbit of Earth; collisions between Earth and near Earth asteroids happen a few times every million years

nebulae clouds of interstellar gas and/or dust

neutron a subatomic particle with no electrical charge

neutron star the dense core of matter composed almost entirely of neutrons that remain after a supernova explosion has ended the life of a massive star

New Millennium a NASA program to identify, develop and validate key instrument and spacecraft technologies that can lower cost and increase performance of science missions in the twenty-first century

Next Generation Space Telescope the telescope scheduled to be launched in 2009 that will replace the Hubble Space Telescope

nuclear black holes black holes that are in the centers of galaxies; they range in mass from a thousand to a billion times the mass of the Sun

nuclear fusion the combining of low-mass atoms to create heavier ones; the heavier atom's mass is slightly less than the sum of the mass of its constituents, with the remaining mass converted to energy

nucleon a proton or a neutron; one of the two particles found in a nucleus

occultations a phenomena that occurs when one astronomical object passes in front of another

optical interferometry a branch of optical physics that uses the wavelength of visible light to measure very small changes within the environment

optical-interferometry based the use of two or more telescopes observing the same object at the same time at the same visible wavelength to increase angular resolution

optical radar a method of determining the speed of moving bodies by sending a pulse of light and measuring how long it takes for the reflected light to return to the sender

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

orbital dynamics the mathematical study of the nature of the forces governing the movement of one object in the gravitational field of another object

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

orthogonal composed of right angles or relating to right angles

oscillation energy that varies between alternate extremes with a definable period

osteoporosis the loss of bone density; can occur after extended stays in space

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

paleolake depression that shows geologic evidence of having contained a lake at some previous time

Paleozoic relating to the first appearance of animal life on Earth

parabolic trajectory trajectory followed by an object with velocity equal to escape velocity

parking orbit placing a spacecraft temporarily into Earth orbit, with the engines shut down, until it has been checked out or is in the correct location for the main burn that sends it away from Earth

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

payload bay the area in the shuttle or other spacecraft designed to carry cargo

payload fairing structure surrounding a payload; it is designed to reduce drag

payload operations experiments or procedures involving cargo or "payload" carried into orbit

payload specialists scientists or engineers selected by a company or a government employer for their expertise in conducting a specific experiment or commercial venture on a space shuttle mission

perihelion the point in an object's orbit that is closest to the Sun

period of heavy meteoroid the earliest period in solar system history (more than 3.8 billion years ago) when the rate of meteoroid impact was very high compared to the present

perturbations term used in orbital mechanics to refer to changes in orbits due to "perturbing" forces, such as gravity

phased array a radar antenna design that allows rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

phased-array antennas radar antenna designs that allow rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

photolithography printing that uses a photographic process to create the printing plates

photometer instrument to measure intensity of light

photosynthesis a process performed by plants and algae whereby light is transformed into energy and sugars

photovoltaic pertaining to the direct generation of electricity from electromagnetic radiation (light)

photovoltaic arrays sets of solar panels grouped together in big sheets; these arrays collect light from the Sun and use it to make electricity to power the equipment and machines

photovoltaic cells cells consisting of a thin wafer of a semiconductor material that incorporates a p-n junction, which converts incident light into electrical power; a number of photovoltaic cells connected in series makes a solar array

plagioclase most common mineral of the light-colored lunar highlands

planetesimals objects in the early solar system that were the size of large asteroids or small moons, large enough to begin to gravitationally influence each other

pn single junction in a transistor or other solid state device, the boundary between the two different kinds of semiconductor material

point of presence an access point to the Internet with a unique Internet Protocol (IP) address; Internet service providers (ISP) like AOL generally have multiple POPs on the Internet

polar orbits orbits that carry a satellite over the poles of a planet

polarization state degree to which a beam of electromagnetic radiation has all of the vibrations in the same plane or direction

porous allowing the passage of a fluid or gas through holes or passages in the substance

power law energy spectrum spectrum in which the distribution of energies appears to follow a power law

primary the body (planet) about which a satellite orbits

primordial swamp warm, wet conditions postulated to have occurred early in Earth's history as life was beginning to develop

procurement the process of obtaining

progenitor star the star that existed before a dramatic change, such as a supernova, occurred

prograde having the same general sense of motion or rotation as the rest of the solar system, that is, counterclockwise as seen from above Earth's north pole

prominences inactive "clouds" of solar material held above the solar surface by magnetic fields

propagate to cause to move, to multiply, or to extend to a broader area

proton a positively charged subatomic particle

pseudoscience a system of theories that assumes the form of science but fails to give reproducible results under conditions of controlled experiments

pyroclastic pertaining to clastic (broken) rock material expelled from a volcanic vent

pyrotechnics fireworks display; the art of building fireworks

quantum foam the notion that there is a smallest distance scale at which space itself is not a continuous medium, but breaks up into a seething foam of wormholes and tiny black holes far smaller than a proton

quantum gravity an attempt to replace the inherently incompatible theories of quantum physics and Einstein gravity with some deeper theory that would have features of both, but be identical to neither

quantum physics branch of physics that uses quantum mechanics to explain physical systems

quantum vacuum consistent with the Heisenberg uncertainty principle, vacuum is not empty but is filled with zero-point energy and particle-antiparticle pairs constantly being created and then mutually annihilating each other

quasars luminous objects that appear star-like but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

quiescent inactive

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

radar altimetry using radar signals bounced off the surface of a planet to map its variations in elevation

radar images images made with radar illumination instead of visible light that show differences in radar brightness of the surface material or differences in brightness associated with surface slopes

radiation belts two wide bands of charged particles trapped in a planet's magnetic field

radio lobes active galaxies show two regions of radio emission above and below the plane of the galaxy, and are thought to originate from powerful jets being emitted from the accretion disk surrounding the massive black hole at the center of active galaxies

radiogenic isotope techniques use of the ratio between various isotopes produced by radioactive decay to determine age or place of origin of an object in geology, archaeology, and other areas

radioisotope a naturally or artificially produced radioactive isotope of an element

radioisotope thermoelectric device using solid state electronics and the heat produced by radioactive decay to generate electricity

range safety destruct systems system of procedures and equipment designed to safely abort a mission when a spacecraft malfunctions, and destroy the rocket in such a way as to create no risk of injury or property damage

Ranger series of spacecraft sent to the Moon to investigate lunar landing sites; designed to hard-land on the lunar surface after sending back television pictures of the lunar surface; Rangers 7, 8, and 9 (1964–1965) returned data

rarefaction decreased pressure and density in a material caused by the passage of a sound wave

reconnaissance a survey or preliminary exploration of a region of interest

reflex motion the orbital motion of one body, such as a star, in reaction to the gravitational tug of a second orbiting body, such as a planet

regolith upper few meters of a body's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

relative zero velocity two objects having the same speed and direction of movement, usually so that spacecraft can rendezvous

relativistic time dilation effect predicted by the theory of relativity that causes clocks on objects in strong gravitational fields or moving near the speed of light to run slower when viewed by a stationary observer

remote manipulator system a system, such as the external Canada2 arm on the International Space Station, designed to be operated from a remote location inside the space station

remote sensing the act of observing from orbit what may be seen or sensed below on Earth

retrograde having the opposite general sense of motion or rotation as the rest of the solar system, clockwise as seen from above Earth's north pole

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

reusables launches that can be used many times before discarding

rift valley a linear depression in the surface, several hundred to thousand kilometers long, along which part of the surface has been stretched, faulted, and dropped down along many normal faults

rille lava channels in regions of maria, typically beginning at a volcanic vent and extending downslope into a smooth mare surface

rocket vehicle or device that is especially designed to travel through space, and is propelled by one or more engines

"rocky" planets nickname given to inner or solid-surface planets of the solar system, including Mercury, Venus, Mars, and Earth

rover vehicle used to move about on a surface

rutile a red, brown, or black mineral, primarily titanium dioxide, used as a gemstone and also a commercially important ore of titanium

satellite any object launched by a rocket for the purpose of orbiting the Earth or another celestial body

scoria fragments of lava resembling cinders

secondary crater crater formed by the impact of blocks of rock blasted out of the initial crater formed by an asteroid or large meteorite

sedentary lifestyle a lifestyle characterized by little movement or exercise

sedimentation process of depositing sediments, which result in a thick accumulation of rock debris eroded from high areas and deposited in low areas

semiconductor one of the groups of elements with properties intermediate between the metals and nonmetals

semimajor axis one half of the major axis of an ellipse, equal to the average distance of a planet from the Sun

shepherding small satellites exerting their gravitational influence to cause or maintain structure in the rings of the outer planets

shield volcanoes volcanoes that form broad, low-relief cones, characterized by lava that flows freely

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

sine wave a wave whose amplitude smoothly varies with time; a wave form that can be mathematically described by a sine function

smooth plains the youngest plains on Mercury with a relatively low impact crater abundance

soft-landers spacecraft that uses braking by engines or other techniques (e.g., parachutes, airbags) such that its landing is gentle enough that the spacecraft and its instruments are not damaged, and observations at the surface can be made

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

solar corona the thin outer atmosphere of the Sun that gradually transitions into the solar wind

solar flares explosions on the Sun that release bursts of electromagnetic radiation, such as light, ultraviolet waves, and X rays, along with high speed protons and other particles

solar nebula the cloud of gas and dust out of which the solar system formed

solar prominence cool material with temperatures typical of the solar photosphere or chromosphere suspended in the corona above the visible surface layers

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

sounding rocket a vehicle designed to fly straight up and then parachute back to Earth, usually designed to take measurements of the upper atmosphere

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period; to date, only Earth-orbiting space stations have been launched

space-time in relativity, the four-dimensional space through which objects move and in which events happen

spacecraft bus the primary structure and subsystems of a spacecraft

spacewalking moving around outside a spaceship or space station, also known as extravehicular activity

special theory of relativity the fundamental idea of Einstein's theories, which demonstrated that measurements of certain physical quantities such as mass, length, and time depended on the relative motion of the object and observer

specific power amount of electric power generated by a solar cell per unit mass; for example watts per kilogram

spectra representations of the brightness of objects as a function of the wavelength of the emitted radiation

spectral lines the unique pattern of radiation at discrete wavelengths that many materials produce

spectrograph an instrument that can permanently record a spectra

spectrographic studies studies of the nature of matter and composition of substances by examining the light they emit

spectrometers an instrument with a scale for measuring the wavelength of light

spherules tiny glass spheres found in and among lunar rocks

spot beam technology narrow, pencil-like satellite beam that focuses highly radiated energy on a limited area of Earth's surface (about 100 to 500 miles in diameter) using steerable or directed antennas

stratigraphy the study of rock layers known as strata, especially the age and distribution of various kinds of sedimentary rocks

stratosphere a middle portion of a planet's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

subduction the process by which one edge of a crustal plate is forced to move under another plate

sublimate to pass directly from a solid phase to a gas phase

suborbital trajectory the trajectory of a rocket or ballistic missile that has insufficient energy to reach orbit

subsolar point the point on a planet that receives direct rays from the Sun

substrate the surface, such as glass, metallic foil, or plastic sheet, on which a thin film of photovoltaic material is deposited

sunspots dark, cooler areas on the solar surface consisting of transient, concentrated magnetic fields

supercarbonaceous term given to P- and D-type meteorites that are richer in carbon than any other meteorites and are thought to come from the primitive asteroids in the outer part of the asteroid belt

supernova an explosion ending the life of a massive star

supernovae ejecta the mix of gas enriched by heavy metals that is launched into space by a supernova explosion

superstring theory the best candidate for a "theory of everything" unifying quantum mechanics and gravity, proposes that all particles are oscillations in tiny loops of matter only 10^{-35} meters long and moving in a space of ten dimensions

superstrings supersymmetric strings are tiny, one dimensional objects that are about 10^{-33} cm long, in a 10-dimensional spacetime. Their different vibration modes and shapes account for the elementary particles we see in our 4-dimensional spacetime

Surveyor a series of spacecraft designed to soft-land robotic laboratories to analyze and photograph the lunar surface; Surveyors 1, 3, and 5–7 landed between May 1966 and January 1968

synchrotron radiation the radiation from electrons moving at almost the speed of light inside giant magnetic accelerators of particles, called synchrotrons, either on Earth or in space

synthesis the act of combining different things so as to form new and different products or ideas

technology transfer the acquisition by one country or firm of the capability to develop a particular technology through its interactions with the existing technological capability of another country or firm, rather than through its own research efforts

tectonism process of deformation in a planetary surface as a result of geological forces acting on the crust; includes faulting, folding, uplift, and downwarping of the surface and crust

telescience the act of operation and monitoring of research equipment located in space by a scientist or engineer from their offices or laboratories on Earth

terrestrial planet a small rocky planet with high density orbiting close to the Sun; Mercury, Venus, Earth, and Mars

thermodynamically referring to the behavior of energy

thermostabilized designed to maintain a constant temperature

thrust fault a fault where the block on one side of the fault plane has been thrust up and over the opposite block by horizontal compressive forces

toxicological related to the study of the nature and effects on humans of poisons and the treatment of victims of poisoning

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

transonic barrier the aerodynamic behavior of an aircraft moving near the speed of sound changes dramatically and, for early pioneers of transonic flight, dangerously, leading some to hypothesize there was a "sound barrier" where drag became infinite

transpiration process whereby water evaporates from the surface of leaves, allowing the plant to lose heat and to draw water up through the roots

transponder bandwidth-specific transmitter-receiver units

troctolite rock type composed of the minerals plagioclase and olivine, crystallized from magma

tunnelborer a mining machine designed to dig a tunnel using rotating cutting disks

Tycho event the impact of a large meteoroid into the lunar surface as recently as 100 million years ago, leaving a distinct set of bright rays across the lunar surface including a ray through the Apollo 17 landing site

ultramafic lavas dark, heavy lavas with a high percentage of magnesium and iron; usually found as boulders mixed in other lava rocks

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

ultraviolet radiation electromagnetic radiation with a shorter wavelength and higher energy than light

uncompressed density the lower density a planet would have if it did not have the force of gravity compressing it

Universal time current time in Greenwich, England, which is recognized as the standard time that Earth's time zones are based

vacuum an environment where air and all other molecules and atoms of matter have been removed

vacuum conditions the almost complete lack of atmosphere found on the surface of the Moon and in space

Van Allen radiation belts two belts of high energy charged particles captured from the solar wind by Earth's magnetic field

variable star a star whose light output varies over time

vector sum sum of two vector quantities taking both size and direction into consideration

velocity speed and direction of a moving object; a vector quantity

virtual-reality simulations a simulation used in training by pilots and astronauts to safely reproduce various conditions that can occur on board a real aircraft or spacecraft

visible spectrum the part of the electromagnetic spectrum with wavelengths between 400 nanometers and 700 nanometers; the part of the electromagnetic spectrum to which human eyes are sensitive

volatile ices (e.g., H_2O and CO_2) that are solids inside a comet nucleus but turn into gases when heated by sunlight

volatile materials materials that easily pass into the vapor phase when heated

wavelength the distance from crest to crest on a wave at an instant in time

X ray form of high-energy radiation just beyond the ultraviolet portion of the spectrum

X-ray diffraction analysis a method to determine the three-dimensional structure of molecules

Volume 3 Index

*Page numbers in **boldface type** indicate article titles; those in italic type indicate illustrations. A cumulative index, which combines the terms in all volumes of* Space Sciences, *can be found in volume 4 of this series.*

B

C

J

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L

space sciences

space sciences

VOLUME 4
Our Future in Space

Pat Dasch, Editor in Chief

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Preface

Astronomers have studied the heavens for more than two millennia, but in the twentieth century, humankind ventured off planet Earth into the dark vacuum void of space, forever changing our perspective of our home planet and on our relationship to the universe in which we reside.

Our explorations of space—the final frontier in our niche in this solar system—first with satellites, then robotic probes, and finally with humans, have given rise to an extensive space industry that has a major influence on the economy and on our lives. In 1998, U.S. space exports (launch services, satellites, space-based communications services, and the like) totaled $64 billion. As we entered the new millennium, space exports were the second largest dollar earner after agriculture. The aerospace industry directly employs some 860,000 Americans, with many more involved in subcontracting companies and academic research.

Beginnings

The Chinese are credited with developing the rudiments of rocketry—they launched rockets as missiles against invading Mongols in 1232. In the nineteenth century William Congrieve developed a rocket in Britain based on designs conceived in India in the eighteenth century. Congrieve extended the range of the Indian rockets, adapting them specifically for use by armies. Congrieve's rockets were used in 1806 in the Napoleonic Wars.

The Birth of Modern Space Exploration

The basis of modern spaceflight and exploration came with the writings of Konstantin Tsiolkovsky (1857–1935), a Russian mathematics teacher. He described multi-stage rockets, winged craft like the space shuttle developed in the 1970s, space stations like Mir and the International Space Station, and interplanetary missions of discovery.

During the same period, space travel captured the imagination of fiction writers. Jules Verne wrote several novels with spaceflight themes. His book, *From the Earth to the Moon* (1865), describes manned flight to the Moon, including a launch site in Florida and a spaceship named Columbia—the name chosen for the Apollo 11 spaceship that made the first lunar landing in July 1969 and the first space shuttle, which flew in April 1981. In the twentieth century, Arthur C. Clarke predicted the role of communications satellites and extended our vision of human space exploration while

television series such as *Star Trek* and *Dr. Who* challenged the imagination and embedded the idea of space travel in our culture.

The first successful test of the V-2 rocket developed by Wernher von Braun and his team at Peenemünde, Germany, in October 1942 has been described as the "birth of the Space Age." After World War II some of the Peenemünde team under von Braun came to the United States, where they worked at the White Sands Missile Range in New Mexico, while others went to Russia. This sowed the seeds of the space race of the 1960s. Each team worked to develop advanced rockets, with Russia developing the R-7, while a series of rockets with names like Thor, Redstone, and Titan were produced in the United States.

When the Russians lofted Sputnik, the first artificial satellite, on October 4, 1957, the race was on. The flights of Yuri Gagarin, Alan Shepard, and John Glenn followed, culminating in the race for the Moon and the Apollo Program of the 1960s and early 1970s.

The Emergence of a Space Industry

The enormous national commitment to the Apollo Program marked a new phase in our space endeavors. The need for innovation and technological advance stimulated the academic and engineering communities and led to the growth of a vast network of contract supporters of the aerospace initiative and the birth of a vibrant space industry. At the same time, planetary science emerged as a new geological specialization.

Following the Apollo Program, the U.S. space agency's mission remained poorly defined through the end of the twentieth century, grasping at major programs such as development of the space shuttle and the International Space Station, in part, some argue, to provide jobs for the very large workforce spawned by the Apollo Program. The 1980s saw the beginnings of what would become a robust commercial space industry, largely independent of government programs, providing communications and information technology via space-based satellites. During the 1990s many thought that commercialization was the way of the future for space ventures. Commercially coordinated robotic planetary exploration missions were conceived with suggestions that NASA purchase the data, and Dennis Tito, the first paying space tourist in 2001, raised hopes of access to space for all.

The terrorist attacks on the United States on September 11, 2001 and the U.S. recession led to a re-evaluation of the entrepreneurial optimism of the 1990s. Many private commercial space ventures were placed on hold or went out of business. Commentators suggested that the true dawning of the commercial space age would be delayed by up to a decade. But, at the same time, the U.S. space agency emerged with a more clearly defined mandate than it had had since the Apollo Program, with a role of driving technological innovation—with an early emphasis on reducing the cost of getting to orbit—and leading world class space-related scientific projects. And military orders, to fill the needs of the new world order, compensated to a point for the downturn in the commercial space communications sector.

It is against this background of an industry in a state of flux, a discipline on the cusp of a new age of innovation, that this encyclopedia has been prepared.

Organization of the Material

The 341 entries in *Space Sciences* have been organized in four volumes, focusing on the business of space exploration, planetary science and astronomy, human space exploration, and the outlook for the future exploration of space. Each entry has been newly commissioned for this work. Our contributors are drawn from academia, industry, government, professional space institutes and associations, and nonprofit organizations. Many of the contributors are world authorities on their subject, providing up-to-the-minute information in a straightforward style accessible to high school students and university undergraduates.

One of the outstanding advantages of books on space is the wonderful imagery of exploration and achievement. These volumes are richly illustrated, and sidebars provide capsules of additional information on topics of particular interest. Entries are followed by a list of related entries, as well as a reading list for students seeking more information.

Acknowledgements

I wish to thank the team at Macmillan Reference USA and the Gale Group for their vision and leadership in bringing this work to fruition. In particular, thanks to Hélène Potter, Cindy Clendenon, and Gloria Lam. My thanks to Associate Editors Nadine Barlow, Leonard David, and Frank Sietzen, whose expertise, commitment, and patience have made *Space Sciences* possible. My thanks also go to my husband, Julius, for his encouragement and support. My love affair with space began in the 1970s when I worked alongside geologists using space imagery to plan volcanological field work in remote areas of South America, and took root when, in the 1980s, I became involved in systematic analysis of the more than 3,000 photographs of Earth that astronauts bring back at the end of every shuttle mission. The beauty of planet Earth, as seen from space, and the wealth of information contained in those images, convinced me that space is a very real part of life on Earth, and that I wanted to be a part of the exploration of space and to share the wonder of it with the public. I hope that *Space Sciences* conveys the excitement, achievements, and potential of space exploration to a new generation of students.

Pat Dasch
Editor in Chief

For Your Reference

The following section provides information that is applicable to a number of articles in this reference work. Included in the following pages is a chart providing comparative solar system planet data, as well as measurement, abbreviation, and conversion tables.

SOLAR SYSTEM PLANET DATA

	Mercury	Venus[2]	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Mean distance from the Sun (AU): [1]	0.387	0.723	1	1.524	5.202	9.555	19.218	30.109	39.439
Siderial period of orbit (years):	0.24	0.62	1	1.88	11.86	29.46	84.01	164.79	247.68
Mean orbital velocity (km/sec):	47.89	35.04	29.79	24.14	13.06	9.64	6.81	5.43	4.74
Orbital essentricity:	0.206	0.007	0.017	0.093	0.048	0.056	0.047	0.009	0.246
Inclination to ecliptic (degrees):	7.00	3.40	0	1.85	1.30	2.49	0.77	1.77	17.17
Equatorial radius (km):	2439	6052	6378	3397	71492	60268	25559	24764	1140
Polar radius (km):	same	same	6357	3380	66854	54360	24973	24340	same
Mass of planet (Earth = 1):[3]	0.06	0.82	1	0.11	317.89	95.18	14.54	17.15	0.002
Mean density (gm/cm ^{3}):	5.44	5.25	5.52	3.94	1.33	0.69	1.27	1.64	2.0
Body rotation period (hours):	1408	5832.R	23.93	24.62	9.92	10.66	17.24	16.11	153.3
Tilt of equator to orbit (degrees):	0	2.12	23.45	23.98	3.08	26.73	97.92	28.8	96

[1]AU indicates one astronomical unit, defined as the mean distance between Earth and the Sun (~1.495 x 10^8 km).
[2]R indicates planet rotation is retrograde (i.e., opposite to the planet's orbit).
[3]Earth's mass is approximately 5.976 x 10^{26} grams.

SI BASE AND SUPPLEMENTARY UNIT NAMES AND SYMBOLS

Physical Quality	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
Plane angle	radian	rad
Solid angle	steradian	sr

Temperature

Scientists commonly use the Celsius system. Although not recommended for scientific and technical use, earth scientists also use the familiar Fahrenheit temperature scale (°F). 1°F = 1.8°C or K. The triple point of H_2O, where gas, liquid, and solid water coexist, is 32°F.

- To change from Fahrenheit (F) to Celsius (C):
  °C = (°F-32)/(1.8)
- To change from Celsius (C) to Fahrenheit (F):
  °F = (°C x 1.8) + 32
- To change from Celsius (C) to Kelvin (K):
  K = °C + 273.15
- To change from Fahrenheit (F) to Kelvin (K):
  K = (°F-32)/(1.8) + 273.15

UNITS DERIVED FROM SI, WITH SPECIAL NAMES AND SYMBOLS

Derived Quantity	Name of SI Unit	Symbol for SI Unit	Expression in Terms of SI Base Units
Frequency	hertz	Hz	s-1
Force	newton	N	m kg s-2
Pressure, stress	Pascal	Pa	N m-2 =m-1 kg s-2
Energy, work, heat	Joule	J	N m =m2 kg s-2
Power, radiant flux	watt	W	J s-1 =m2 kg s-3
Electric charge	coulomb	C	A s
Electric potential, electromotive force	volt	V	J C-1 =m-2 kg s-3 A-1
Electric resistance	ohm	_	V A-1 =m2 kg s-3 A-2
Celsius temperature	degree Celsius	C	K
Luminous flux	lumen	lm	cd sr
Illuminance	lux	lx	cd sr m-2

UNITS USED WITH SI, WITH NAME, SYMBOL, AND VALUES IN SI UNITS

The following units, not part of the SI, will continue to be used in appropriate contexts (e.g., angtsrom):

Physical Quantity	Name of Unit	Symbol for Unit	Value in SI Units
Time	minute	min	60 s
	hour	h	3,600 s
	day	d	86,400 s
Plane angle	degree	°	(π/180) rad
	minute	'	(π/10,800) rad
	second	"	(π/648,000) rad
Length	angstrom	Å	10^{-10} m
Volume	liter	l, L	1 dm^3 = 10^{-3} m^3
Mass	ton	t	1 mg = 10^3 kg
	unified atomic mass unit	u (=m_a(^{12}C)/12)	≈1.66054 x 10^{-27} kg
Pressure	bar	bar	10^5 Pa = 10^5 N m^{-2}
Energy	electronvolt	eV (= e X V)	≈1.60218 x 10^{-19} J

CONVERSIONS FOR STANDARD, DERIVED, AND CUSTOMARY MEASUREMENTS

Length

1 angstrom (Å)	0.1 nanometer (exactly) 0.000000004 inch
1 centimeter (cm)	0.3937 inches
1 foot (ft)	0.3048 meter (exactly)
1 inch (in)	2.54 centimeters (exactly)
1 kilometer (km)	0.621 mile
1 meter (m)	39.37 inches 1.094 yards
1 mile (mi)	5,280 feet (exactly) 1.609 kilometers
1 astronomical unit (AU)	1.495979×10^{13} cm
1 parsec (pc)	206,264.806 AU 3.085678×10^{18} cm 3.261633 light-years
1 light-year	9.460530×10^{17} cm

Area

1 acre	43,560 square feet (exactly) 0.405 hectare
1 hectare	2.471 acres
1 square centimeter (cm^2)	0.155 square inch
1 square foot (ft^2)	929.030 square centimeters
1 square inch (in^2)	6.4516 square centimeters (exactly)
1 square kilometer (km^2)	247.104 acres 0.386 square mile
1 square meter (m^2)	1.196 square yards 10.764 square feet
1 square mile (mi^2)	258.999 hectares

MEASUREMENTS AND ABBREVIATIONS

Volume

1 barrel (bbl)*, liquid	31 to 42 gallons
1 cubic centimeter (cm^3)	0.061 cubic inch
1 cubic foot (ft^3)	7.481 gallons 28.316 cubic decimeters
1 cubic inch (in^3)	0.554 fluid ounce
1 dram, fluid (or liquid)	⅛ fluid ounce (exactly) 0.226 cubic inch 3.697 milliliters
1 gallon (gal) (U.S.)	231 cubic inches (exactly) 3.785 liters 128 U.S. fluid ounces (exactly)
1 gallon (gal) (British Imperial)	277.42 cubic inches 1.201 U.S. gallons 4.546 liters
1 liter	1 cubic decimeter (exactly) 1.057 liquid quarts 0.908 dry quart 61.025 cubic inches
1 ounce, fluid (or liquid)	1.805 cubic inches 29.573 mililiters
1 ounce, fluid (fl oz) (British)	0.961 U.S. fluid ounce 1.734 cubic inches 28.412 milliliters
1 quart (qt), dry (U.S.)	67.201 cubic inches 1.101 liters
1 quart (qt), liquid (U.S.)	57.75 cubic inches (exactly) 0.946 liter

* There are a variety of "barrels" established by law or usage. For example, U.S. federal taxes on fermented liquors are based on a barrel of 31 gallons (141 liters); many state laws fix the "barrel for liquids" as 31½ gallons (119.2 liters); one state fixes a 36-gallon (160.5 liters) barrel for cistern measurment; federal law recognizes a 40-gallon (178 liters) barrel for "proof spirts"; by custom, 42 gallons (159 liters) comprise a barrel of crude oil or petroleum products for statistical purposes, and this equivalent is recognized "for liquids" by four states.

Units of mass

1 carat (ct)	200 milligrams (exactly) 3.086 grains
1 grain	64.79891 milligrams (exactly)
1 gram (g)	15.432 grains 0.035 ounce
1 kilogram (kg)	2.205 pounds
1 microgram (μg)	0.000001 gram (exactly)
1 milligram (mg)	0.015 grain
1 ounce (oz)	437.5 grains (exactly) 28.350 grams
1 pound (lb)	7,000 grains (exactly) 453.59237 grams (exactly)
1 ton, gross or long	2,240 pounds (exactly) 1.12 net tons (exactly) 1.016 metric tons
1 ton, metric (t)	2,204.623 pounds 0.984 gross ton 1.102 net tons
1 ton, net or short	2,000 pounds (exactly) 0.893 gross ton 0.907 metric ton

Pressure

1 kilogram/square centimeter (kg/cm^2)	0.96784 atmosphere (atm) 14.2233 pounds/square inch (lb/in^2) 0.98067 bar
1 bar	0.98692 atmosphere (atm) 1.02 kilograms/square centimeter (kg/cm^2)

Milestones in Space History

c. 850	The Chinese invent a form of gunpowder for rocket propulsion.
1242	Englishman Roger Bacon develops gunpowder.
1379	Rockets are used as weapons in the Siege of Chioggia, Italy.
1804	William Congrieve develops ship-fired rockets.
1903	Konstantin Tsiolkovsky publishes *Research into Interplanetary Science by Means of Rocket Power*, a treatise on space travel.
1909	Robert H. Goddard develops designs for liquid-fueled rockets.
1917	Smithsonian Institute issues grant to Goddard for rocket research.
1918	Goddard publishes the monograph *Method of Attaining Extreme Altitudes.*
1921	Soviet Union establishes a state laboratory for solid rocket research.
1922	Hermann Oberth publishes *Die Rakete zu den Planetenräumen*, a work on rocket travel through space.
1923	Tsiolkovsky publishes work postulating multi-staged rockets.
1924	Walter Hohmann publishes work on rocket flight and orbital motion.
1927	The German Society for Space Travel holds its first meeting.
	Max Valier proposes rocket-powered aircraft adapted from Junkers G23.
1928	Oberth designs liquid rocket for the film *Woman in the Moon.*
1929	Goddard launches rocket carrying barometer.
1930	Soviet rocket designer Valentin Glusko designs U.S.S.R. liquid rocket engine.

1931	Eugene Sänger test fires liquid rocket engines in Vienna.
1932	German Rocket Society fires first rocket in test flight.
1933	Goddard receives grant from Guggenheim Foundation for rocket studies.
1934	Wernher von Braun, member of the German Rocket Society, test fires water-cooled rocket.
1935	Goddard fires advanced liquid rocket that reaches 700 miles per hour.
1936	Glushko publishes work on liquid rocket engines.
1937	The Rocket Research Project of the California Institute of Technology begins research program on rocket designs.
1938	von Braun's rocket researchers open center at Pennemünde.
1939	Sänger and Irene Brendt refine rocket designs and propose advanced winged suborbital bomber.
1940	Goddard develops centrifugal pumps for rocket engines.
1941	Germans test rocket-powered interceptor aircraft Me 163.
1942	V-2 rocket fired from Pennemünde enters space during ballistic flight.
1943	First operational V-2 launch.
1944	V-2 rocket launched to strike London.
1945	Arthur C. Clarke proposes geostationary satellites.
1946	Soviet Union tests version of German V-2 rocket.
1947	United States test fires Corporal missile from White Sands, New Mexico.
	X-1 research rocket aircraft flies past the speed of sound.
1948	United States reveals development plan for Earth satellite adapted from RAND.
1949	Chinese rocket scientist Hsueh-Sen proposes hypersonic aircraft.
1950	United States fires Viking 4 rocket to record 106 miles from USS Norton Sound.
1951	Bell Aircraft Corporation proposes winged suborbital rocket-plane.
1952	Wernher von Braun proposes wheeled Earth-orbiting space station.
1953	U.S. Navy D-558II sets world altitude record of 15 miles above Earth.
1954	Soviet Union begins design of RD-107, RD-108 ballistic missile engines.
1955	Soviet Union launches dogs aboard research rocket on suborbital flight.

1956	United States announces plan to launch Earth satellite as part of Geophysical Year program.
1957	U.S. Army Ballistic Missile Agency is formed.
	Soviet Union test fires R-7 ballistic missile.
	Soviet Union launches the world's first Earth satellite, Sputnik-1, aboard R-7.
	United States launches 3-stage Jupiter C on test flight.
	United States attempts Vanguard 1 satellite launch; rocket explodes.
1958	United States orbits Explorer-1 Earth satellite aboard Jupiter-C rocket.
	United States establishes the National Aeronautics and Space Administration (NASA) as civilian space research organization.
	NASA establishes Project Mercury manned space project.
	United States orbits Atlas rocket with Project Score.
1959	Soviet Union sends Luna 1 towards Moon; misses by 3100 miles.
	NASA announces the selection of seven astronauts for Earth space missions.
	Soviet Union launches Luna 2, which strikes the Moon.
1960	United States launches Echo satellite balloon.
	United States launches Discoverer 14 into orbit, capsule caught in midair.
	Soviet Union launches two dogs into Earth orbit.
	Mercury-Redstone rocket test fired in suborbital flight test.
1961	Soviet Union tests Vostok capsule in Earth orbit with dummy passenger.
	Soviet Union launches Yuri Gagarin aboard Vostok-1; he becomes the first human in space.
	United States launches Alan B. Shepard on suborbital flight.
	United States proposes goal of landing humans on the Moon before 1970.
	Soviet Union launches Gherman Titov into Earth orbital flight for one day.
	United States launches Virgil I. "Gus" Grissom on suborbital flight.
	United States launches first Saturn 1 rocket in suborbital test.

1962	United States launches John H. Glenn into 3-orbit flight.
	United States launches Ranger to impact Moon; craft fails.
	First United States/United Kingdom international satellite launch; Ariel 1 enters orbit.
	X-15 research aircraft sets new altitude record of 246,700 feet.
	United States launches Scott Carpenter into 3-orbit flight.
	United States orbits Telstar 1 communications satellite.
	Soviet Union launches Vostok 3 and 4 into Earth orbital flight.
	United States launches Mariner II toward Venus flyby.
	United States launches Walter Schirra into 6-orbit flight.
	Soviet Union launches Mars 1 flight; craft fails.
1963	United States launches Gordon Cooper into 22-orbit flight.
	Soviet Union launches Vostok 5 into 119-hour orbital flight.
	United States test fires advanced solid rockets for Titan 3C.
	First Apollo Project test in Little Joe II launch.
	Soviet Union orbits Vostok 6, which carries Valentina Tereshkova, the first woman into space.
	Soviet Union tests advanced version of R-7 called Soyuz launcher.
1964	United States conducts first Saturn 1 launch with live second stage; enters orbit.
	U.S. Ranger 6 mission launched towards Moon; craft fails.
	Soviet Union launches Zond 1 to Venus; craft fails.
	United States launches Ranger 7 on successful Moon impact.
	United States launches Syncom 3 communications satellite.
	Soviet Union launches Voshkod 1 carrying three cosmonauts.
	United States launches Mariner 4 on Martian flyby mission.
1965	Soviet Union launches Voshkod 2; first space walk.
	United States launches Gemini 3 on 3-orbit piloted test flight.
	United States launches Early Bird 1 communications satellite.
	United States launches Gemini 4 on 4-day flight; first U.S. space walk.

	United States launches Gemini 5 on 8-day flight.
	United States launches Titan 3C on maiden flight.
	Europe launches Asterix 1 satellite into orbit.
	United States Gemini 6/7 conduct first space rendezvous.
1966	Soviet Union launches Luna 9, which soft lands on Moon.
	United States Gemini 8 conducts first space docking; flight aborted.
	United States launches Surveyor 1 to Moon soft landing.
	United States tests Atlas Centaur advanced launch vehicle.
	Gemini 9 flight encounters space walk troubles.
	Gemini 10 flight conducts double rendezvous.
	United States launches Lunar Orbiter 1 to orbit Moon.
	Gemini 11 tests advanced space walks.
	United States launches Saturn IB on unpiloted test flight.
	Soviet Union tests advanced Proton launch vehicle.
	United States launches Gemini 12 to conclude two-man missions.
1967	Apollo 1 astronauts killed in launch pad fire.
	Soviet Soyuz 1 flight fails; cosmonaut killed.
	Britain launches Ariel 3 communications satellite.
	United States conducts test flight of M2F2 lifting body research craft.
	United States sends Surveyor 3 to dig lunar soils.
	Soviet Union orbits anti-satellite system.
	United States conducts first flight of Saturn V rocket (Apollo 4).
1968	Yuri Gagarin killed in plane crash.
	Soviet Union docks Cosmos 212 and 213 automatically in orbit.
	United States conducts Apollo 6 Saturn V test flight; partial success.
	Nuclear rocket engine tested in Nevada.
	United States launches Apollo 7 in three-person orbital test flight.
	Soviet Union launches Soyuz 3 on three-day piloted flight.
	United States sends Apollo 8 into lunar orbit; first human flight to Moon.
1969	Soviet Union launches Soyuz 4 and 5 into orbit; craft dock.
	Largest tactical communications satellite launched.

	United States flies Apollo 9 on test of lunar landing craft in Earth orbit.
	United States flies Apollo 10 to Moon in dress rehearsal of landing attempt.
	United States cancels military space station program.
	United States flies Apollo 11 to first landing on the Moon.
	United States cancels production of Saturn V in budget cut.
	Soviet lunar rocket N-1 fails in launch explosion.
	United States sends Mariner 6 on Mars flyby.
	United States flies Apollo 12 on second lunar landing mission.
	Soviet Union flies Soyuz 6 and 7 missions.
	United States launches Skynet military satellites for Britain.
1970	China orbits first satellite.
	Japan orbits domestic satellite.
	United States Apollo 13 mission suffers explosion; crew returns safely.
	Soviet Union launches Venera 7 for landing on Venus.
	United States launches military early warning satellite.
	Soviet Union launches Luna 17 to Moon.
	United States announces modifications to Apollo spacecraft.
1971	United States flies Apollo 14 to Moon landing.
	Soviet Union launches Salyut 1 space station into orbit.
	First crew to Salyut station, Soyuz 11, perishes.
	Soviet Union launches Mars 3 to make landing on the red planet.
	United States flies Apollo 15 to Moon with roving vehicle aboard.
1972	United States and the Soviet Union sign space cooperation agreement.
	United States launches Pioneer 10 to Jupiter flyby.
	Soviet Union launches Venera 8 to soft land on Venus.
	United States launches Apollo 16 to moon.
	India and Soviet Union sign agreement for launch of Indian satellite.
	United States initiates space shuttle project.
	United States flies Apollo 17, last lunar landing mission.

1973	United States launches Skylab space station.
	United States launches first crew to Skylab station.
	Soviet Union launches Soyuz 12 mission.
	United States launches second crew to Skylab space station.
1974	United States launches ATS research satellite.
	Soviet Union launches Salyut 3 on unpiloted test flight.
	Soviet Union launches Soyuz 12, 13, and 14 flights.
	Soviet Union launches Salyut 4 space station.
1975	Soviet Union launches Soyuz 17 to dock with Salyut 4 station.
	Soviet Union launches Venera 9 to soft land on Venus.
	United States and Soviet Union conduct Apollo-Soyuz Test Project joint flight.
	China orbits large military satellite.
	United States sends Viking 1 and 2 towards landing on Martian surface.
	Soviet Union launches unpiloted Soyuz 20.
1976	Soviet Union launches Salyut 5 space station.
	First space shuttle rolls out; Enterprise prototype.
	Soviet Union docks Soyuz 21 to station.
	China begins tests of advanced ballistic missile.
1977	Soyuz 24 docks with station.
	United States conducts atmospheric test flights of shuttle Enterprise.
	United States launches Voyager 1 and 2 on deep space missions.
	Soviet Union launches Salyut 6 space station.
	Soviet Soyuz 25 fails to dock with station.
	Soyuz 26 is launched and docks with station.
1978	Soyuz 27 is launched and docks with Salyut 6 station.
	Soyuz 28 docks with Soyuz 27/Salyut complex.
	United States launches Pioneer/Venus 1 mission.
	Soyuz 29 docks with station.
	Soviet Union launches Progress unpiloted tankers to station.
	Soyuz 30 docks with station.
	United States launches Pioneer/Venus 2.
	Soyuz 31 docks with station.

1979	Soyuz 32 docks with Salyut station.
	Voyager 1 flies past Jupiter.
	Soyuz 33 fails to dock with station.
	Voyager 2 flies past Jupiter.
1980	First Ariane rocket launches from French Guiana; fails.
	Soviet Union begins new Soyuz T piloted missions.
	STS-1 first shuttle mission moves to launching pad.
1981	Soviet Union orbits advanced Salyut stations.
	STS-1 launched on first space shuttle mission.
	United States launches STS-2 on second shuttle flight; mission curtailed.
1982	United States launches STS-5 first operational shuttle flight.
1983	United States launches Challenger, second orbital shuttle, on STS-6.
	United States launches Sally Ride, the first American woman in space, on STS-7.
	United States launches Guion Bluford, the first African-American astronaut, on STS-8.
	United States launches first Spacelab mission aboard STS-9.
1984	Soviet Union tests advanced orbital station designs.
	Shuttle Discovery makes first flights.
	United States proposes permanent space station as goal.
1985	Space shuttle Atlantis enters service.
	United States announces policy for commercial rocket sales.
	United States flies U.S. Senator aboard space shuttle Challenger.
1986	Soviet Union launches and occupies advanced Mir space station.
	Challenger—on its tenth mission, STS-51-L—is destroyed in a launching accident.
	United States restricts payloads on future shuttle missions.
	United States orders replacement shuttle for Challenger.
1987	Soviet Union flies advanced Soyuz T-2 designs.
	United States' Delta, Atlas, and Titan rockets grounded in launch failures.
	Soviet Union launches Energyia advanced heavy lift rocket.

1988	Soviet Union orbits unpiloted shuttle Buran.
	United States launches space shuttle Discovery on STS-26 flight.
	United States launches STS-27 military shuttle flight.
1989	United States launches STS-29 flight.
	United States launches Magellan probe from shuttle.
1990	Shuttle fleet grounded for hydrogen leaks.
	United States launches Hubble Space Telescope.
1992	Replacement shuttle Endeavour enters service.
	United States probe Mars Observer fails.
1993	United States and Russia announce space station partnership.
1994	United States shuttles begin visits to Russian space station Mir.
1995	Europe launches first Ariane 5 advanced booster; flight fails.
1996	United States announces X-33 project to replace shuttles.
1997	Mars Pathfinder lands on Mars.
1998	First elements of International Space Station launched.
1999	First Ocean space launch of Zenit rocket in Sea Launch program.
2000	Twin United States Mars missions fail.
2001	United States cancels shuttle replacements X-33 and X-34 because of space cutbacks.
	United States orbits Mars Odyssey probe around Mars.
2002	First launches of United States advanced Delta IV and Atlas V commercial rockets.

Frank Sietzen, Jr.

Human Achievements in Space

The road to space has been neither steady nor easy, but the journey has cast humans into a new role in history. Here are some of the milestones and achievements.

Oct. 4, 1957 The Soviet Union launches the first artificial satellite, a 184-pound spacecraft named Sputnik.

Nov. 3, 1957 The Soviets continue pushing the space frontier with the launch of a dog named Laika into orbit aboard Sputnik 2. The dog lives for seven days, an indication that perhaps people may also be able to survive in space.

Jan. 31, 1958 The United States launches Explorer 1, the first U.S. satellite, and discovers that Earth is surrounded by radiation belts. James Van Allen, who instrumented the satellite, is credited with the discovery.

Apr. 12, 1961 Yuri Gagarin becomes the first person in space. He is launched by the Soviet Union aboard a Vostok rocket for a two-hour orbital flight around the planet.

May 5, 1961 Astronaut Alan Shepard becomes the first American in space. Shepard demonstrates that individuals can control a vehicle during weightlessness and high gravitational forces. During his 15-minute suborbital flight, Shepard reaches speeds of 5,100 mph.

May 24, 1961 Stung by the series of Soviet firsts in space, President John F. Kennedy announces a bold plan to land men on the Moon and bring them safely back to Earth before the end of the decade.

Feb. 20, 1962 John Glenn becomes the first American in orbit. He flies around the planet for nearly five hours in his Mercury capsule, Friendship 7.

June 16, 1963 The Soviets launch the first woman, Valentina Tereshkova, into space. She circles Earth in her Vostok spacecraft for three days.

Nov. 28, 1964 NASA launches Mariner 4 spacecraft for a flyby of Mars.

Mar. 18, 1965 Cosmonaut Alexei Leonov performs the world's first space walk outside his Voskhod 2 spacecraft. The outing lasts 10 minutes.

Mar. 23, 1965 Astronauts Virgil I. "Gus" Grissom and John Young blast off on the first Gemini mission and demonstrate for the first time how to maneuver from one orbit to another.

June 3, 1965 Astronaut Edward White becomes the first American to walk in space during a 21-minute outing outside his Gemini spacecraft.

Mar. 16, 1966 Gemini astronauts Neil Armstrong and David Scott dock their spacecraft with an unmanned target vehicle to complete the first joining of two spacecraft in orbit. A stuck thruster forces an early end to the experiment, and the crew makes America's first emergency landing from space.

Jan. 27, 1967 The Apollo 1 crew is killed when a fire breaks out in their command module during a prelaunch test. The fatalities devastate the American space community, but a subsequent spacecraft redesign helps the United States achieve its goal of sending men to the Moon.

Apr. 24, 1967 Tragedy also strikes the Soviet space program, with the death of cosmonaut Vladimir Komarov. His new Soyuz spacecraft gets tangled with parachute lines during reentry and crashes to Earth.

Dec. 21, 1968 Apollo 8, the first manned mission to the Moon, blasts off from Cape Canaveral, Florida. Frank Borman, Jim Lovell and Bill Anders orbit the Moon ten times, coming to within 70 miles of the lunar surface.

July 20, 1969 Humans walk on another world for the first time when astronauts Neil Armstrong and Edwin "Buzz" Aldrin climb out of their spaceship and set foot on the Moon.

Apr. 13, 1970 The Apollo 13 mission to the Moon is aborted when an oxygen tank explosion cripples the spacecraft. NASA's most serious inflight emergency ends four days later when the astronauts, ill and freezing, splash down in the Pacific Ocean.

June 6, 1971 Cosmonauts blast off for the first mission in the world's first space station, the Soviet Union's Salyut 1. The crew spends twenty-two days aboard the outpost. During reentry, however, a faulty valve leaks air from the Soyuz capsule, and the crew is killed.

Jan. 5, 1972 President Nixon announces plans to build "an entirely new type of space transportation system," pumping life into NASA's dream to build a reusable, multi-purpose space shuttle.

Dec. 7, 1972 The seventh and final mission to the Moon is launched, as public interest and political support for the Apollo program dims.

May 14, 1973 NASA launches the first U.S. space station, Skylab 1, into orbit. Three crews live on the station between May 1973 and February 1974. NASA hopes to have the shuttle fly-

ing in time to reboost and resupply Skylab, but the outpost falls from orbit on July 11, 1979.

July 17, 1975 In a momentary break from Cold War tensions, the United States and Soviet Union conduct the first linking of American and Russian spaceships in orbit. The Apollo-Soyuz mission is a harbinger of the cooperative space programs that develop between the world's two space powers twenty years later.

Apr. 12, 1981 Space shuttle Columbia blasts off with a two-man crew for the first test-flight of NASA's new reusable spaceship. After two days in orbit, the shuttle lands at Edwards Air Force Base in California.

June 18, 1983 For the first time, a space shuttle crew includes a woman. Astronaut Sally Ride becomes America's first woman in orbit.

Oct. 30, 1983 NASA's increasingly diverse astronaut corps includes an African-American for the first time. Guion Bluford, an aerospace engineer, is one of the five crewmen assigned to the STS-8 mission.

Nov. 28, 1983 NASA flies its first Spacelab mission and its first European astronaut, Ulf Merbold.

Feb. 7, 1984 Shuttle astronauts Bruce McCandless and Robert Stewart take the first untethered space walks, using a jet backpack to fly up to 320 feet from the orbiter.

Apr. 9–11, 1984 First retrieval and repair of an orbital satellite.

Jan. 28, 1986 Space shuttle Challenger explodes 73 seconds after launch, killing its seven-member crew. Aboard the shuttle was Teacher-in-Space finalist Christa McAuliffe, who was to conduct lessons from orbit. NASA grounds the shuttle fleet for two and a half years.

Feb. 20. 1986 The Soviets launch the core module of their new space station, Mir, into orbit. Mir is the first outpost designed as a module system to be expanded in orbit. Expected lifetime of the station is five years.

May 15, 1987 Soviets launch a new heavy-lift booster from the Baikonur Cosmodrome in Kazakhstan.

Oct. 1, 1987 Mir cosmonaut Yuri Romanenko breaks the record for the longest space mission, surpassing the 236-day flight by Salyut cosmonauts set in 1984.

Sept. 29, 1988 NASA launches the space shuttle Discovery on the first crewed U.S. mission since the 1986 Challenger explosion. The shuttle carries a replacement communications satellite for the one lost onboard Challenger.

May 4, 1989 Astronauts dispatch a planetary probe from the shuttle for the first time. The Magellan radar mapper is bound for Venus.

Nov. 15, 1989 The Soviets launch their space shuttle Buran, which means snowstorm, on its debut flight. There is no crew onboard, and unlike the U.S. shuttle, no engines to help place it into orbit. Lofted into orbit by twin Energia heavy-lift boosters, Buran circles Earth twice and lands. Buran never flies again.

Apr. 24, 1990 NASA launches the long-awaited Hubble Space Telescope, the cornerstone of the agency's "Great Observatory" program, aboard space shuttle Discovery. Shortly after placing the telescope in orbit, astronomers discover that the telescope's prime mirror is misshapen.

Dec. 2, 1993 Space shuttle Endeavour takes off for one of NASA's most critical shuttle missions: repairing the Hubble Space Telescope. During an unprecedented five space walks, astronauts install corrective optics. The mission is a complete success.

Feb. 3, 1994 A Russian cosmonaut, Sergei Krikalev, flies aboard a U.S. spaceship for the first time.

Mar. 16, 1995 NASA astronaut Norman Thagard begins a three and a half month mission on Mir—the first American to train and fly on a Russian spaceship. He is the first of seven Americans to live on Mir.

Mar. 22, 1995 Cosmonaut Valeri Polyakov sets a new space endurance record of 437 days, 18 hours.

June 29, 1995 Space shuttle Atlantis docks for the first time at the Russian space station Mir.

Mar. 24, 1996 Shannon Lucid begins her stay aboard space aboard Mir, which lasts 188 days—a U.S. record for spaceflight endurance at that time.

Feb. 24, 1997 An oxygen canister on Mir bursts into flames, cutting off the route to the station's emergency escape vehicles. Six crewmembers are onboard, including U.S. astronaut Jerry Linenger.

June 27, 1997 During a practice of a new docking technique, Mir commander Vasily Tsibliyev loses control of an unpiloted cargo ship and it plows into the station. The Spektr module is punctured, The crew hurriedly seals off the compartment to save the ship.

Oct. 29, 1998 Senator John Glenn, one of the original Mercury astronauts, returns to space aboard the shuttle.

Nov. 20, 1998 A Russian Proton rocket hurls the first piece of the International Space Station into orbit.

Aug. 27, 1999 Cosmonauts Viktor Afanasyev, Sergei Avdeyev, and Jean-Pierre Haignere leave Mir. The station is unoccupied for the first time in almost a decade.

Oct. 31, 2000 The first joint American-Russian crew is launched to the International Space Station. Commander Bill Shepherd requests the radio call sign "Alpha" for the station and the name sticks.

Mar. 23, 2001 The *Mir* space station drops out of orbit and burns up in Earth's atmosphere.

Apr. 28, 2001 Russia launches the world's first space tourist for a week-long stay at the International Space Station. NASA objects to the flight, but is powerless to stop it.

Irene Brown

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Antimatter Propulsion

A

Imagine an energy source that is more powerful than nuclear **fission** or even nuclear **fusion**. Antimatter-matter reactions could offer an amount of energy that is not comparable to today's energy sources. When particles of matter and particles of antimatter collide, large amounts of energy are produced as a by-product. Because matter can neither be created nor destroyed, it is turned into tremendous amounts of energy.

fission act of splitting a heavy atomic nucleus into two lighter ones, releasing tremendous energy

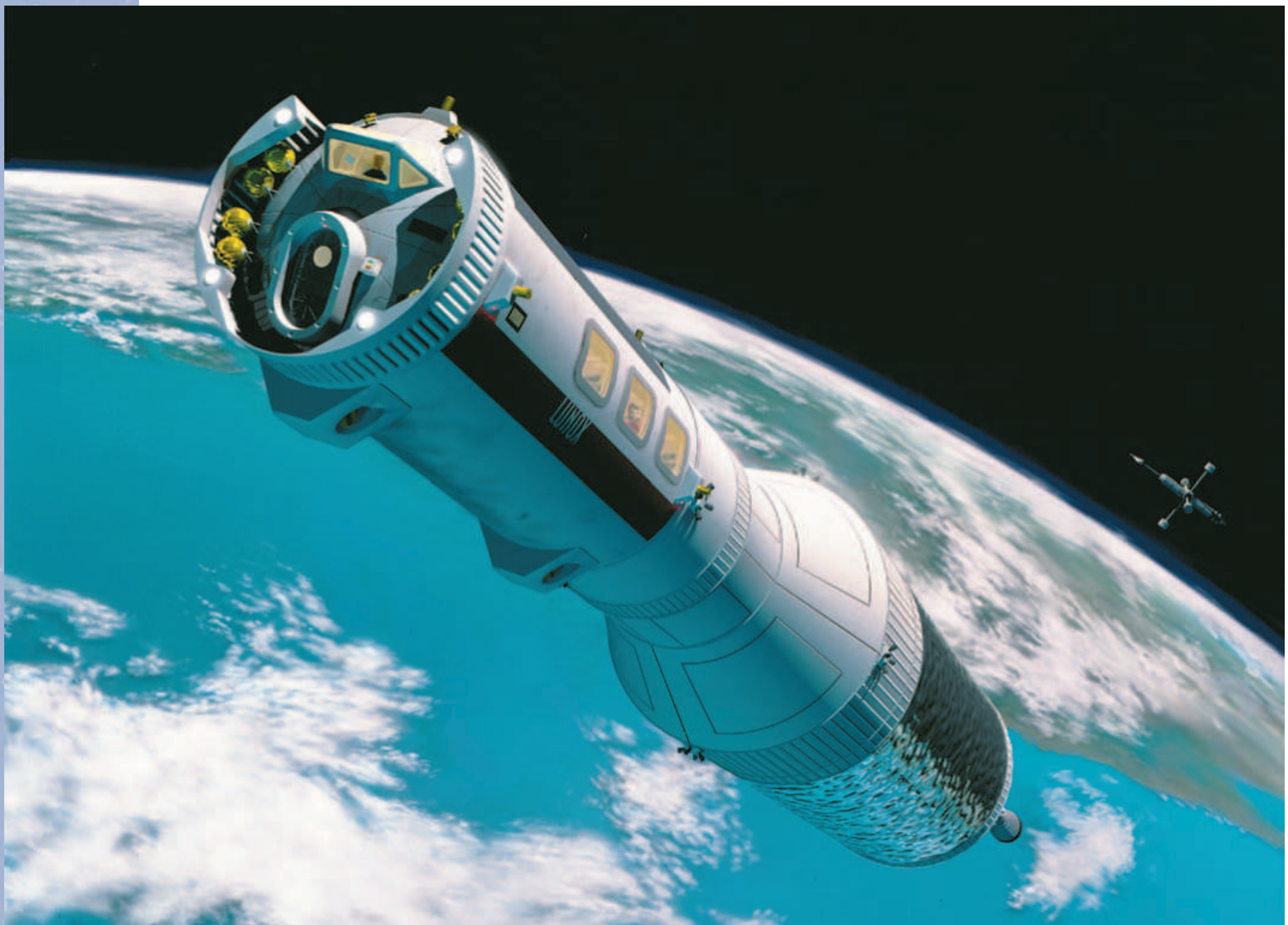
fusion releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

Antimatter is the exact opposite of normal matter. Whereas a proton is a positively-charged particle, its antimatter counterpart, called an antiproton, is negatively charged. The antimatter counterpart to the negatively-charged electron is the positron, which is positively charged. All of the sub-atomic particles' charges are reversed, forming antiatoms. These antiatoms were first theorized in 1928 by Paul A. M. Dirac, a British physicist. In 1932 the first antimatter particle was created in a laboratory experiment by Carl Anderson, who is credited with coining the word "positron." Speculation continued throughout the 1950s, but because of the complexity of creating these particles, astrophysicists were unable to produce antimatter atoms until the late 1990s.

Antimatter particles are difficult to produce because of their very nature. When a particle or atom of antimatter comes into contact with a particle or atom of normal matter, both are annihilated and energy is released. The synthesized antiatoms have lasted only 40 billionths of a second before their annihilation. The particles were accelerated at close to the speed of light. Antihydrogen is the simplest antimatter atom to produce, yet, that feat took decades of research and billions of dollars. Even the European Organization for Nuclear Research (CERN), the laboratory in which the experiment was performed, admitted that this method of creating antimatter is far too expensive and difficult to be subject to mass production. Instead, cheaper and faster methods must be developed to make antimatter more than a dream of the future.

Developing antimatter is worth the effort because the energy created by sustainable matter-antimatter reactions would be so powerful that many people believe that faster-than-light travel, or "warp speed," could be achieved. Other possible uses include powering long-term spaceflight for humans and probes.

The main hope for antimatter is that one day this energy source could be used as a fuel. Hydrogen would be annihilated with anti-hydrogen, and



Flights to the Moon could employ detachable crew modules atop nuclear thermal transfer vehicles.

rocket vehicle or device especially designed to travel through space, propelled by one or more engines

the energy would be funneled into a magnetic nozzle of a **rocket**. Such energy would propel the ship or probe at tremendous speeds compared to today's methods of propulsion. One of the problems with this model is that much of the energy is given off as neutrally charged particles that cannot be harnessed. To make use of the majority of the energy produced, these particles would have to be captured.

The amount of thrust produced by the space shuttle's boosters is equal to the energy released from 71 milligrams of antimatter. The benefits of antimatter propulsion will be worth the effort when this energy can be used to explore the universe in a way that has only been dreamed of so far. SEE ALSO FASTER-THAN-LIGHT TRAVEL (VOLUME 4); INTERSTELLAR TRAVEL (VOLUME 4); NUCLEAR PROPULSION (VOLUME 4); ROCKETS (VOLUME 3).

Craig Samuels

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Asteroid Mining

Future large-scale space operations, including space hotels, solar power satellites, and orbital factories, will require volatiles such as water, methane, ammonia, and carbon dioxide.✶ These materials can be used to produce propellant, metal for facility construction (such as nickel-iron alloy), semiconductors for manufacturing **photovoltaic** power systems (such as silicon, arsenic, and germanium), and simple mass for **ballast** and **shielding**. The cost to transport these commodities from Earth today is $10,000 per kilogram. In the future, the extraction of these materials from easy-access asteroids will become a competitive option.

All of these resources are present in asteroids. About 10 percent of the near-Earth asteroids (NEAs) are more accessible than the Moon, requiring a velocity increase (delta-v) from **low Earth orbit** of less than 6 kilometers per second (km/s; 3.75 miles per second) for rendezvous, with a return departure delta-v of 1 km/s or less. A few are extremely accessible, only marginally more demanding to reach than a launch or a satellite to **geostationary orbit**.

The return of asteroidal materials using propellant derived from the target asteroid will enable potentially unlimited mass availability in low Earth orbit. That will break the logistical bottleneck and cost constraints of launching from Earth. Asteroid-sourced raw materials will enable and catalyze the development of an Earth-Moon space economy and humankind's expansion into the solar system.

The growing recognition of the "impact threat" to Earth has prompted several successful NEA search programs, with approximately 1,800 NEAs now identified (as of April 2002), up from about 30 NEAs twenty years ago. Some 400 are classified as potentially hazardous asteroids (PHAs) that come to within 7.5 million kilometers (4.7 million miles) of Earth orbit on occasion. New potential mining targets are found every month.

Based on meteorite studies, astronomers recognize that NEAs have diverse compositions, including silicate, carbonaceous and hydrocarbon-bearing, metallic, and ice-bearing materials. Some may be loose rubble piles held together only by self-gravity.

Insights from comet modeling, studies of orbital dynamics, and observation of comet-asteroid transition objects indicate that 30 to 40 percent of NEAs may be extinct or dormant comets.

There has recently been major work on modeling of the development on comets of a crust or **regolith** of dust, fragmented rock, and **bitumen** that has been prompted by the Giotto spacecraft's observations of Halley's comet in 1986 and other comets. This insulating "mantle," if allowed to

✶**Volatiles easily pass into the vapor stage when heated.**

photovoltaic pertaining to the direct generation of electricity from electromagnetic radiation (light)

ballast heavy substance used to increase the stability of a vehicle

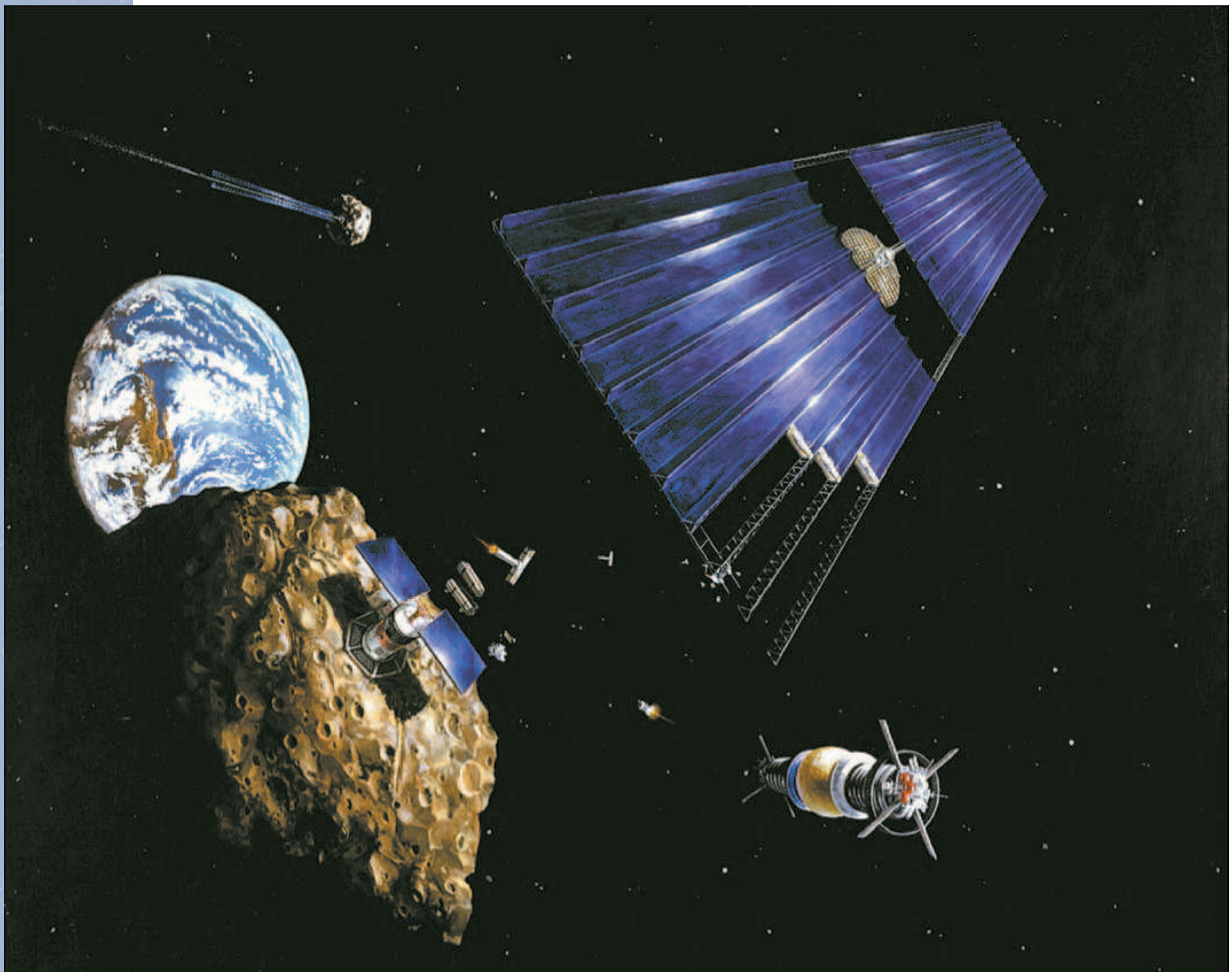
shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis

THE IMPACT OF NICKEL-IRON PRODUCTION

A by-product of asteroidal nickel-iron production will be the increased availability of platinum group metals for export to Earth for use as catalysts in an expanding fuel-cell energy economy. These metals include platinum, palladium, and rhodium.



In this rendering of a mining operation on an asteroid traveling near Earth, the unit on the asteroid is doing the actual mining, while power and other necessities are supplied by an orbital construction platform in conjunction with the surrounding solar arrays.

regolith upper few meters of a body's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

bitumen a thick, almost solid form of hydrocarbons, often mixed with other minerals

cometary outgassing vaporization of the frozen gases that form a comet nucleus as the comet approaches the Sun and warms

grow to completion, eliminates **cometary outgassing**, and the object then takes on the appearance of an inactive asteroid. These **cryptocometary** bodies, if in near-Earth orbits, will stabilize with a deep-core temperature of about −50°C. The deep core would probably be depleted of CO and CO_2 and highly porous but would retain water ice in crystalline form and in combination with silicates as well as bituminous hydrocarbons. This ice could be extracted by drilling and circulation of hot fluid or by mining with subsequent heat processing.

Photographs of the asteroids Gaspra, Ida and Dactyl, Mathilde, Braille, and Eros by various space probes and radar images of Castalia, Toutatis, 1998 KY26, Kleopatra, 1999 JM8, and Geographos reveal a varied, bizarre, and poorly understood collection of objects. Many images show evidence of a thick loose regolith or gravel/sand/silt layer that could be collected easily by scooping or shoveling. Eros shows slump sheets in the sides of craters where fresh material has been uncovered, a lack of small craters, an abundance of boulders, and pooled dust deposits in the bases of craters.

Eros and Mathilde have improbably low densities, suggesting that they have large internal voids or are highly porous; Mathilde has craters so large that their generating impacts should have split it asunder. Both Toutatis and Castalia appear to be contact binaries: twin asteroids in contact with each other. Eros and Geographos are improbably elongated, shaped like sweet potatoes. Kleopatra is a 140-kilometer-long (87.5 miles) dog-bone shape. 1998 KY26 is tiny and spins so fast that any loose material on its surface must be flung off into space, implying that it must be a monolithic solid object under tension.

Asteroids contain many of the major elements that provide the basis for life and industry on Earth.

cryptocometary asteroids that contain a high percentage of carbon compounds mixed with frozen gases

tunnelborer a mining machine designed to dig a tunnel using rotating cutting disks

in situ in the natural or original location

comet matrix material the substances that form the nucleus of a comet; dust grains embedded in frozen methane, ammonia, carbon dioxide, and water

Mining Concepts

The choice of mining and processing methods is driven by what and how much is desired, difficulty of separation, duration of mining season, and propulsion demands in returning the product to the nominated orbit. Minimization of project cost and technical risk, together with maximization of returns in a short timeframe, will be major factors in project planning.

If the required product is water, which can be used as the propellant for the return journey, underground rather than surface mining will be required because of the dryness of the asteroid surface. Some sort of **tunnelborer** will be needed, or a large-diameter auger-type drill. If the product is nickel-iron metal sand, surface regolith collection by scraping or shoveling is indicated. Surface reclaim is threatened by problems of containment and anchoring. **In situ** volatilization (melting and vaporizing ice at the bottom of a drill hole for extraction as steam) has been proposed for mining **comet matrix material** but is subject to fluid loss and blowouts.

The processing methods depend on the desired product. If it is water and other volatiles, a heating and condensation process is essential. If it is nickel-iron sand, then density, magnetic, or electrostatic separation will be used to produce a concentrate from the collected regolith. Terrestrial centrifugal grinding mills and **density-separation jigs** can be adapted for this work.

Initial asteroid mining operations will probably be carried out by small, low-cost, robotic, remotely controlled or autonomous integrated miner-processors designed to return a few hundred to a few thousand tons of product per mission, with propulsion systems using asteroid-derived material for propellant.

Conclusion

The knowledge and technologies required to develop the resources of asteroids and enable the industrialization and colonization of the inner solar system will provide humankind with the ability to protect society and Earth from threats of asteroid and comet impacts. SEE ALSO Asteroids (volume 2); Close Encounters (volume 2); Getting to Space Cheaply (volume 1); Hotels (volume 4); Impacts (volume 4); Solar Power Systems (volume 4); Space Resources (volume 4).

Mark J. Sonter

WHAT IS THE DELTA-V?

The measure of the energy needed to transfer from one orbit to another, or the difficulty of carrying out a space mission, is the delta-v: the velocity change, or boost, needed to achieve the required new trajectory. The delta-v necessary to achieve low Earth orbit is 8 km/s (5 miles/sec); to go from low Earth orbit to Earth-escape velocity (achieve an orbit around the Sun, free of the Earth's gravity) requires an extra 3.2 km/s (2 miles/sec). The delta-v to achieve geostationary orbit from low Earth orbit is 3.6 km/s (2.25 miles). The most accessible asteroids have a delta-v as low as 4 km/s (2.5 miles/sec).

density-separation jigs a form of gravity separation of materials with different densities that uses a pulsating fluid

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Astrobiology

Astrobiology is a new interdisciplinary science that studies the origin, evolution, distribution, and destiny of life in the cosmos. Other terms that have been used to describe the search for life beyond Earth include exobiology, exopaleontology, and bioastronomy. Astrobiology is a broadly based, interdisciplinary science that embraces the fields of biology and microbiology, microbial ecology, molecular biology and biochemistry, geology and paleontology, space and gravitational biology, planetology, and astronomy, among others.

The development of astrobiology as a discipline began in the early 1990s with the recognition of a growing synergy between various sciences in seeking answers to the question of extraterrestrial life. The National Aeronautics and Space Administration (NASA) promoted the development of astrobiology by funding a research institute (the NASA Astrobiology Institute, or NAI), which consists of interdisciplinary teams of scientists from fifteen separate institutions in the United States, including both government laboratories and universities. Important scientific discoveries have changed the way scientists think about the origin, evolution, and persistence of life on Earth. These discoveries have helped fuel the growth of astrobiology by defining the broad conceptual framework and scope of the field and by opening up new possibilities for the existence of extraterrestrial life.

Earth's Microbial Biosphere

biosphere the interaction of living organisms on a global scale

Since the late 1980s, advances in genetics and molecular biology have radically altered scientists' view of the **biosphere** and the contribution of microbial life to planetary biodiversity. The opportunity to compare gene sequences from a wide variety of living organisms and environments has shown that living organisms cluster into one of three biological domains: the Archaea, Bacteria, or Eukarya. Each of these domains is made up of dozens of biological kingdoms, the vast majority of which are microbial. Species inferred to be the most primitive forms so far discovered are all found at high temperatures (greater than 80°C [176°F]) where they use simple forms of chemical energy. However, knowledge of Earth's biodiversity is still very much a work in progress. While biologists have sampled a wide range of environments, it is estimated that only a small fraction, perhaps 1 to 2 percent of the total biodiversity present, has so far been captured. Still, the three-domain structure has remained stable. New organisms are being discovered each year, adding diversity to each domain, but many discoveries still lie ahead.

These advances in biology have led to a growing awareness that Earth is overwhelmingly dominated by microscopic life and that these simple forms have dominated nearly the entire history of the biosphere. Indeed, advances in paleontology have now pushed back the record of microbial life to within half a billion years of the time scientists believe Earth first became inhabitable. This suggests that once the conditions necessary for life's origin were in place, it arose very quickly. Exactly how quickly is not yet known, but in geologic terms, it was a much shorter period than previously thought. This view significantly improves the possibility that life may have originated on other planets such as Mars, where liquid water may have been present at the surface for only a few hundred million years, early in the planet's history.

NASA's Controlled Ecology Life Support System studies self-contained systems for applications related to future space colony environments. These sealed flasks contain shrimp, algae, and other microorganisms capable of generating their own water, oxygen, and food.

✶ **Oxygen currently makes up 21 percent of Earth's atmosphere.**

The Evolution of Complex Life

Studies of the fossil record have revealed that complex, multicellular forms of life (plants and animals) did not appear on Earth until about 600 million years ago, which is recent in geological history. Animals are multicellular consumers that require oxygen for their metabolism. Scientists believe that their late addition to the biosphere was triggered by the buildup of oxygen in the oceans and atmosphere to a threshold of about 10 percent of the present atmospheric level.✶ It is clear that the high level of oxygen found in the atmosphere today could have been generated only through photosynthesis, a biological process that captures sunlight and uses the energy to convert carbon dioxide and water to organic matter and oxygen. Clearly, oxygen-evolving photosynthesis has had a profound effect on the biosphere. If oxygen was required for the appearance of complex animal life, then a detailed understanding of photosynthetic processes and their evolution is crucial to create a proper context for evaluating the cosmological potential for life to evolve to the level of sentient beings and advanced technologies elsewhere in the cosmos. This research also provides a context for the SETI program (Search for Extraterrestrial Intelligence), which is currently exploring the heavens for advanced civilizations elsewhere in the galaxy by monitoring radio waves.

Basic Requirements for Life

The most basic requirement of living systems is liquid water, the universal medium that organisms use to carry out the chemical reactions of metabolism. Water is a unique dipolar compound (positively charged on one side and negatively charged on the other) with special solvent properties that allow it to act as a universal medium of transport and exchange in chemical reactions. In addition, the physical properties of water allow it to remain liquid over a very broad range of temperatures, thus enhancing its availability to living systems. In exploring for life elsewhere in the cosmos, the recognition of the importance of liquid water as a requirement for life is reflected in NASA's basic exploration strategy, which seeks to "follow the water."

But to exist, living systems also require sources of nutrients and energy. The common biogenic elements (carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur), which comprise the basic building blocks of life, appear to be widely distributed in the universe. These elements are forged in the

Mouse-ear cress plants were part of the Plant Growth Investigations in the Microgravity 1 experiment aboard the space shuttle Columbia.

nuclear fusion the combining of low-mass atoms to create heavier ones; the heavier atom's mass is slightly less than the sum of the mass of its constituents, with the remaining mass converted to energy

supernova an explosion ending the life of a massive star; caused by core collapse or the sudden onset of nuclear fusion

hydrothermal relating to high temperature water

desiccation the process of drying up

interiors of stars through **nuclear fusion** reactions, and through normal processes they produce elements with masses up to that of iron—56. The heavier metallic elements, some of which living systems also require, are formed only in very massive stars during **supernova** explosions. A key question of astrobiology concerns the distribution of massive stars in galaxies, which in turn may control the distribution of heavy elements essential for life.

By applying new methods of molecular biology and genetics over a broad range of environmental extremes, scientists' knowledge of the environmental limits of life on Earth (and the ways that organisms obtain nutrients and energy) has expanded dramatically. This area of inquiry comprises a relatively new area of biology known as extremophile (extreme-loving) research. This research has revealed that microbial species thrive in environments with broad extremes of temperature, ranging from deep-sea, **hydrothermal** vents (about 114°C [237°F]) to Siberian permafrost (−15°C [5°F]). (Above about 130°C [266°F], complex organic molecules become unstable and begin to break down. This temperature may comprise an absolute upper limit for life based on the limitations of carbon chemistry.) In addition, microorganisms occupy nearly the entire pH range from about 1.4 (extremely acid) to about 13.5 (extremely alkaline). Microbial life also occupies an equally broad salinity range from freshwater to saturated brines (containing about 300 percent dissolved solids) where salt (NaCl) precipitates. Finally, organisms also survive at very low water availability by creating **desiccation**-resistant structures that can survive for prolonged inclement periods.

Alternative Energy Sources

Within the basic constraint of liquid water, barriers to life appear to be few. However, it is important to understand that the level of productivity possible for living systems is strictly constrained by the quality of the energy sources they are able to exploit. On Earth, more than 99 percent of the energy powering the biosphere is derived from photosynthesis. This is not surprising given that, per unit area of Earth's surface, energy from the Sun is several hundred times more abundant than the thermal and chemical energy sources derived from *within* Earth. Clearly, there is a great advantage (energetically speaking) in exploiting solar energy. But the potential importance of chemical sources was also made clear in 1977 when American oceanographers Jack Corliss and Robert Ballard piloted the deep submersible, *Alvin*, to hydrothermal springs on the seafloor located more than 2.4 kilometers (1.5 miles) deep. At this depth, no sunlight exists for photosynthesis, and yet complex ecosystems were found there in which the organisms (including large, multicelled animals) derived their energy entirely from chemical sources provided by the hot fluids. This discovery shocked biologists, as they realized that even though photosynthesis provides much more energy, simple forms of chemical energy are still capable of supporting complex ecosystems. Since 1977, many other examples of deep-sea vent ecosystems have been found in virtually every ocean basin on Earth.

Several impact craters on Mars show evidence of having held lakes at some time in the past. This image of Gusev crater shows the rim of the crater cut by a channel that likely deposited water in the floor of the crater.

A Deep Subsurface Biosphere

As methods of exploration and observation have improved, life's environmental limits have continued to expand. In 1993 American biochemist Thomas Gold suggested that single-celled forms of life survive and grow in the deep subsurface of Earth, residing within tiny pore spaces and fractures in **indurated rocks**. In fact, volumetrically, such subsurface life forms could comprise more than half of Earth's biomass. Microscopic life is also thought to exist in a deep subglacial lake called Vostoc, which lies more than 3 kilometers (1.9 miles) beneath the ice cap of Antarctica. While many subsurface microbes appear to depend on photosynthetically derived organic matter that washes down from the surface, some species can make their own organic molecules from inorganic sources. Called lithoautotrophs (which literally means "self-feeding on rocks"), these organisms use the byproducts of simple weathering processes in which carbon dioxide dissolved in groundwater reacts with rocks to yield hydrogen. Hydrogen in turn is exploited for available energy. These organisms hold special importance for astrobiology because their existence allows the possibility that subsurface life can exist completely independently of surface (photosynthetic) production. Such lifestyles hold important implications for Mars and Europa (one of Jupiter's largest moons), where deep subsurface habitats are postulated to exist.

Studies of **extremophiles** have revealed that terrestrial life occupies virtually every imaginable habitat where liquid water, chemical nutrients, and simple forms of energy coexist. This observation has dramatically expanded the range of habitats available to life as well as the potential for life elsewhere in the solar system or beyond.

HOW VIABLE ARE MICROBES UNDER HARSH CONDITIONS?

In addition to an astounding range of ecological adaptations, many microbial species have been shown to survive in a state of stasis under inclement conditions for prolonged periods of time. In even the driest deserts on Earth, some species survive by living inside porous rocks where they find a safe haven from ultraviolet radiation, springing to life only occasionally, when water needed for growth becomes available. An even more interesting example is bacteria that have been germinated from spores preserved in Dominican amber dated at more than 30 million years old. Given this propensity for prolonged survival, the potential for microorganisms to survive under extreme conditions, for example on Mars, has been greatly enhanced.

Exploring for a Martian Biosphere

Liquid water is unstable in surface environments on Mars today, thus imposing a formidable barrier to the development and survival of Martian life. Nevertheless, models suggest that a global groundwater system could exist on Mars today at a depth of several kilometers below the surface. Indeed,

Clouds and sunlight glint over the Indian Ocean, as seen from the space shuttle Discovery. Liquid water is the basic requirement for life, and Earth's abundant supply supports millions of organisms.

indurated rocks rocks that have been hardened by natural processes

extremophiles microorganisms surviving in extreme environments such as high salinity or near boiling water

biosignatures the unique traces left in the geological record by living organisms

the Viking orbiters revealed many ancient channel features on Mars that formed when groundwater escaped and flooded onto the surface. But could groundwater still exist there today? In 2001 planetary scientists Michael Malin and Kenneth Edgett, using a high resolution camera onboard the Mars Global Surveyor mission, detected more than 140 sites on Mars where water appears to have seeped out of the subsurface, carving small channels in the surface. Under current conditions, average crustal temperatures on Mars are well below the freezing point of freshwater almost everywhere on the surface. Such surface springs of liquid water, however, could be sustained by warm, saline brines (salt lowers the freezing point of water) derived from deep hydrothermal sources. If this hypothesis is proven, the presence of liquid water—even hot, salty water—will substantially enhance the biological potential of Mars.

On Earth, scientists have found fossil **biosignatures** in sedimentary rocks going as far back as there are sedimentary sequences to sample. By studying the processes that govern the preservation of fossil biosignatures in similar environments on Earth, scientists are continuing to refine their understanding of the factors that govern fossil preservation. This provides a basis for the strategic selection of sites on Mars to explore with future landed missions and for sample returns. Due to the lack of plate tectonic recycling and extensive aqueous weathering on Mars, rocks preserved in the heavily cratered, ancient highlands appear to extend back to the earliest history of the planet. The rocks of these old crustal regions could be much better preserved on Mars than they are on Earth. In fact, a meteorite of

SEARCHING FOR LIFE ON MARS

Although present surface conditions on Mars appear unfavorable for life, orbital images of Mars show numerous water-carved channels and possible paleolake basins where water may have once ponded. Geological relationships suggest that during the early history of the planet, liquid water was widespread over the surface. Some scientists have even suggested that during this time a large ocean existed on the northern plains of Mars. Indications are that liquid water disappeared from the surface of Mars about 3 billion years ago, perhaps as a result of gradual losses of the atmosphere by crustal weathering processes (which sequester CO_2 in rocks and soils) and losses to space. If surface life developed on Mars during an early Earth-like period, it quite likely left behind a fossil record. As on Earth, this record should be preserved in ancient, water-formed sedimentary rocks.

Given the complexity and scale of the problem, one cannot expect to land just anywhere on Mars and find evidence of past or present life. The astrobiology community has recommended a phased approach in which global reconnaissance is combined with preliminary surface missions to target the best sites for detailed surface investigations and sample return. The basic goal is to locate sites where there is evidence of past or present water activity and geologic environments that were favorable for the capture and preservation of fossil biosignatures.

In exploring for extant life-forms, there is an interest in finding habitable zones of liquid water in the shallow subsurface that can be accessed by drilling from robotic platforms. This may prove challenging given that models for a groundwater system on Mars suggest that if present, it should be located at a depth of several kilometers, requiring deep drilling technologies that are currently undeveloped. It may actually be simpler to discover a record of ancient life by targeting water-formed sedimentary deposits laid down by ancient hydrothermal systems or in paleolake basins. A key step in implementing this approach is to better understand the mineralogy of the Martian surface. The Thermal Emission Spectrometer instrument began mapping from Mars orbit in 1999 and in 2000 discovered coarse-grained ("specular") hematite deposits at Sinus Meridiani. Hematite is a form of iron-oxide, which in a coarse-grained form strongly suggests the past activity of water. This site has been targeted for possible landed missions in the future.

Martian origin (ALH 84001), which has been dated at about 4.56 billion years, shows very little evidence of aqueous weathering.

Searching for Life in the Outer Solar System

The discovery that life can survive in deep subsurface environments on Earth, where no sunlight exists, has dramatically reshaped the ways scientists think about the potential for subsurface life on other planets. In the outer reaches of the solar system, energy from sunlight is inadequate to maintain the temperatures required for liquid water at the surface, much

LIFE IN A MARTIAN METEORITE?

In 1996 a team of scientists proposed a very intriguing hypothesis regarding the possible biological origin of about a half-dozen features observed in a Martian meteorite, ALH 84001. In part, the hypothesis involved tiny grains of the naturally magnetic mineral magnetite, which is commonly found in basalt (a high-temperature volcanic rock that makes up oceanic crust). While most magnetite on Earth is inorganic, some bacteria have discovered ways to make minute grains of geochemically pure, low-temperature magnetite, which they organize into chains within their cells to use as a kind of directional compass. This enables cells to better control their movement in the environment and to track favorable environmental conditions. Some of the magnetites found in the Martian meteorite bear a strong resemblance to the magnetites formed by terrestrial bacteria. But is the population of magnetites in the meteorite a reliable indicator of life? Scientists are still debating this question.

less for photosynthesis. However, where internal heat sources exist, liquid water could in principle be present in the subsurface.

Three of the larger satellites of Jupiter (Io, Europa, and Ganymede) appear to possess actively heated interiors that are maintained by gravitational tidal forces. These forces continually distort the shapes of these moons, creating internal friction that is capable of melting rock. In one of Jupiter's satellites, Io, the internal heating is manifested as widespread, active volcanic activity at the surface. On Europa, however, interior heating is manifested in a complexly fractured and largely uncratered (constantly renewed) outer shell of water ice. In many places, blocks of crust have drifted apart and liquid water or warm ice has welled up from below and frozen out in between, forming long, narrow ridges in the spaces between. Over time, some ridge segments have shifted laterally, offsetting older ridge segments along **faults**. Other more localized areas appear to have melted over broad regions and blocks of ice have foundered, tilted, and become refrozen. At an even finer scale, there are smaller, mounded features that are thought to have formed as ice "volcanoes" erupted water or warm ice erupted water from the subsurface.

While the concept of a Europan ocean is still controversial, measurements of the magnetic field of the moon obtained during the Galileo mission have strengthened the case. In order to account for the induced magnetism measured by Galileo, it is likely that a salty ocean exists beneath the water ice crust. (Similar arguments have also been made for two other large satellites of Jupiter, Ganymede and Callisto.) The idea of an ocean of brine beneath the icy crust is consistent with **infrared** spectral data from orbit, which suggest that magnesium and/or sodium sulfate salts are present in surface ices.

In assessing the potential for life on Europa, the presence of liquid water is regarded as crucial, both as a medium for biochemical processes and as a source for the chemical energy necessary to sustain life. There does not appear to be enough solar energy at the surface of Europa to support life. However, in 2001 planetary scientist Chris Chyba proposed a model that predicts that chemical energy sources for supporting life may exist from radiation processing of Europa's surface ice, in combination with the decay of radioactive potassium. Together, these processes could decompose water to hydrogen and oxygen (with the hydrogen escaping to space) and the chemical disequilibrium created potentially exploited for energy by organisms.

fault a fracture in rock in the upper crust of a planet along which there has been movement

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

extrasolar planets planets orbiting stars other than the Sun

Habitable Environments Beyond the Solar System

The discovery of planets orbiting other Sun-like stars in the galaxy is a key scientific discovery that has played a central role in the astrobiological revolution. The original discoveries, made in the mid-1990s, have continued. By the early twenty-first century, **extrasolar planets** have been found orbiting almost seventy solar-mass stars in the nearby region of the galaxy. Six of these discoveries are of planetary systems with two or more planets. Present discovery methods are based on the detection of a slight shift or "wobble" in the position of the star that results from the gravitational pull of an orbiting planet(s). With existing technologies, this method allows for the detection of planets that are Jupiter-sized or larger. Some of the extrasolar planets detected occupy orbits within the habitable zone where liquid water could exist. Gas giants (such as Jupiter and Saturn) are planets that lack a solid surface, but they could contain interior zones of liquid water, or might have large (undetectable) satellites with solid surfaces and liquid water. These discoveries have revealed planets around other stars to be commonplace in the Milky Way, thus widening the possibilities for life elsewhere in the cosmos. SEE ALSO Extrasolar Planets (volume 2); Jupiter (volume 2); Mars (volume 2); Mars Missions (volume 4); Planetary Protection (volume 4); Scientific Research (volume 4); SETI (volume 2); Terraforming (volume 4).

Jack D. Farmer

EXPLORING EUROPA

The next Europa mission, planned for launch sometime after 2009, is expected to carry high-resolution spectrometers to map the surface and determine the mineralogical and organic composition of the surface ice. In addition, radar sounding will be used to probe the subsurface from orbit in search of zones of liquid water. This will allow a more thorough test of the hypothesis of a subsurface ocean and help identify the best sites for surface exploration. If a subsurface ocean is in fact found, the next step could be to send robotic landers to search for biosignatures preserved in the ice. Eventually we may be able to deploy small "cryobots" that would melt their way through the ice, deploying minisubmarines to explore for signs of life or organic chemistry.

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Biotechnology

B

Biotechnology research in space is predicated on understanding and exploiting the effects of the unique **microgravity** environment on chemical and biological systems. The results of these experiments could point the way not only to commercial enterprises in space but also to new research directions for laboratories on Earth. Protein crystallization and cell biology are two areas in which microgravity research is particularly promising.

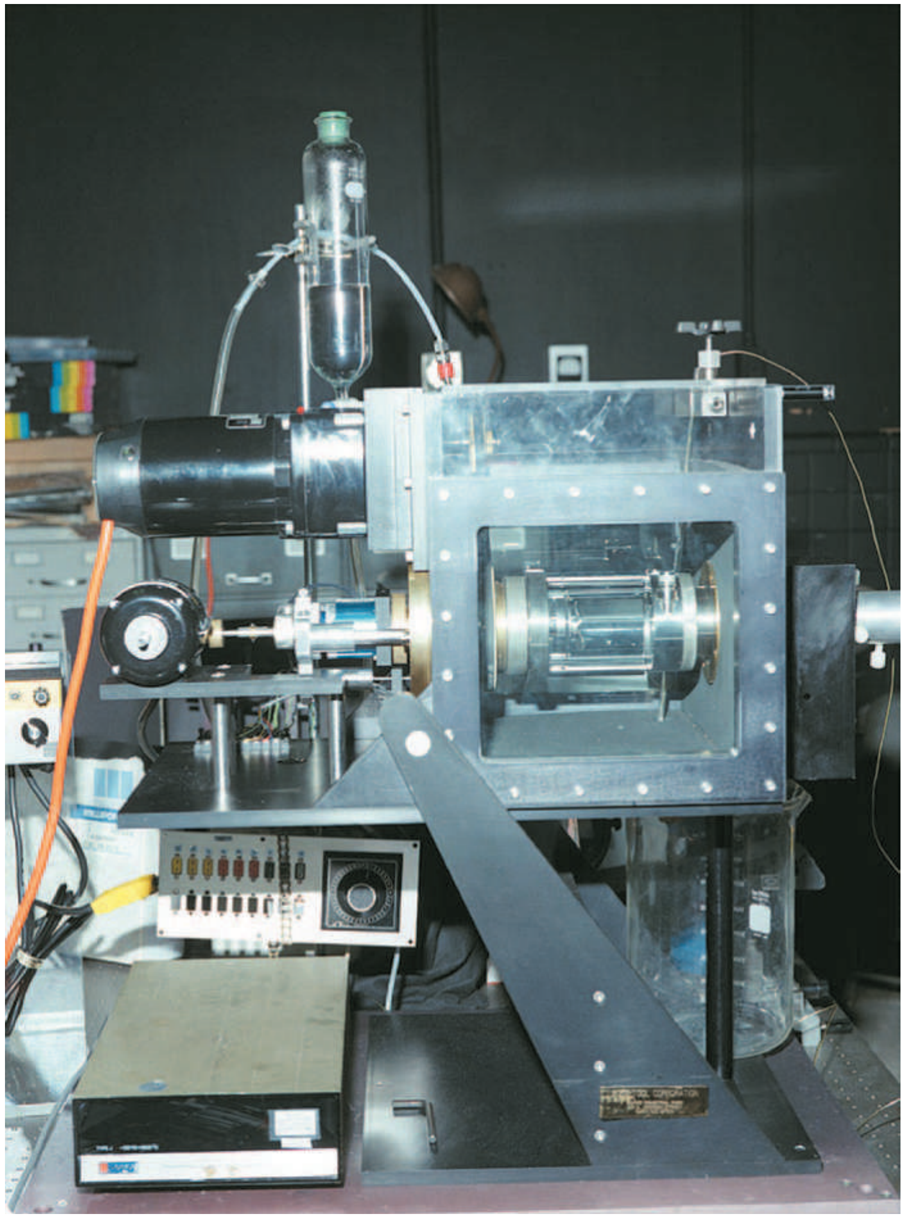
microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Protein Crystallization

Researchers are interested in determining the structure of proteins because the twists and folds of these complex molecules provide clues to their specific functions and how they have evolved over time. However, for scientists to study their structures, the molecules must be "held in place" through crystallization. Large, good-quality crystals are valued by structural biologists, but some organic molecules are easier to crystallize than others are. In some cases the resolution of important biological questions awaits the ability to produce adequate crystals for structural analysis.

For more than fifteen years it has been known that with other conditions being equal, protein crystals grown in a microgravity environment are

NASA-sponsored bioreactor research has been instrumental in helping scientists better understand normal and cancerous tissue development.



larger than those grown on Earth. However, the impact of this realization has been limited because of the irregular, short-term nature of space shuttle flights and the lack of a permanent laboratory with adequate vibration control.

Facilities aboard the International Space Station (ISS) may be able to address this need. Even if there is only an incremental increase in quality when crystals are produced in orbiting rather than Earth laboratories, that increase may make the difference in terms of being able to determine the structure of some proteins, providing new knowledge of biological mechanisms. An X-ray **crystallography** facility planned for the ISS would provide robotic equipment not only for growing the crystals but also for initial testing. Only the most promising specimens would be stored in the station's limited freezer space to be brought back to Earth aboard a shuttle.

crystallography the study of the internal structure of crystals

Cell Biology

Cell biology is another area in which space-based research may produce valuable findings. In this case the key attribute of the microgravity environment is the ability to grow three-dimensional **cell cultures** that more closely mimic the way the cells would behave in the organism.

cell culture a means of growing mammalian (including human) cells in the research laboratory under defined experimental conditions

When cells are grown, or "cultured," for experiments on Earth, gravity encourages them to spread out in two-dimensional sheets. For most tissues this is not a particularly realistic configuration. As a result, the interactions between the cells and the biological processes within them are different from what would be seen in nature. At a molecular level this is seen as differences in gene expression, the degree to which a particular gene is "turned on" to make a protein that serves a specific function in the organism.

In a microgravity environment it is easier to get the cells to adopt the same three-dimensional form that they have during normal growth and development. This means that the gene expression pattern in the cultured cells is more like the pattern that occurs in nature. In addition, it suggests the possibility of culturing not only realistic three-dimensional tissues but entire organs that could have both research and clinical applications.

Because of the potential importance of this work, scientists have attempted to duplicate the microgravity environment on Earth. They have done this by placing tissue cultures in rotating vessels called bioreactors where the **centrifuge** effect cancels out the force of gravity.

centrifuge a device that uses centrifugal force to separate substances of different density

Some success has been experienced with small cultures when the rotating vessel technique has been used. However, as the cultures grow larger, the vessel must be spun faster and faster to balance out their weight and keep them in suspension. At that point rotational effects such as shear forces damage the cells and cause their behavior to diverge from what is seen in the organism. This is a problem that could be solved if the experiments were done in space.

Technology and Politics

However, in considering the potential for biotechnology in space, it is important to understand the technological and political context. Researchers are making rapid progress in both protein crystallization and three-dimensional tissue culture in laboratories on Earth, generally at significantly lower cost than that associated with space programs. Any perception that coveted research funds are being diverted to space-based programs without adequate justification causes resentment of such programs within the scientific community.

In addition, the difficulties of funding a large, expensive space station over the many years of planning and construction have resulted in numerous changes to the ISS's design, facilities, and staffing. Refrigerator and freezer space, for example, has been reduced, creating a potential problem for biology research. Exacerbating the problem is uncertainty in the schedule on which shuttles will be available to transport specimens. Another change of major concern to scientists contemplating participation in the program is a possible reduction in crew size, at least initially, from the planned complement of ten to a "skeleton crew" of only three.

The reduced crew size drastically limits the ability of astronauts to assist with the research, meaning that the experiments that will be flown must require little to no local human intervention. However, the overall budget instability also has affected hardware development funds so that it is more difficult to provide the advanced automation, monitoring, and ground-based control capabilities that are needed.

There are promising applications for biotechnology in the microgravity of space. However, the extent to which these applications will be realized depends on whether they are seen to accelerate the pace of research or whether the situation is viewed as a "zero-sum game" in which resources are diverted that might be better used on Earth. Finally, it remains to be seen whether the political and economic climate will result in an orbiting platform with the staffing and facilities needed to address real research needs. SEE ALSO CRYSTAL GROWTH (VOLUME 3); INTERNATIONAL SPACE STATION (VOLUMES 1 AND 3); MICROGRAVITY (VOLUME 2); RESOURCE UTILIZATION (VOLUME 4); SPACE STATIONS OF THE FUTURE (VOLUME 4).

Sherri Chasin Calvo

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Bonestell, Chesley

American Artist
1888–1986

Astronautics is unique among the sciences in that it owes so much of its existence to literature and art. On the one hand was the seminal influence of Jules Verne (1828–1905); on the other, the work of artist Chesley Bonestell, who inspired an entire generation of astronomers and space scientists and may have been instrumental in jump-starting the American space program.

Born in San Francisco on New Year's Day, 1888, Bonestell studied architecture at Columbia University in New York before dropping out to work as a designer and architectural renderer for several New York and California architectural firms. During this period, Bonestell made significant contributions to the design of American icons such as the Chrysler Building and the Golden Gate Bridge. After a stint as an illustrator in London, Bonestell returned to the United States, moving to Hollywood in the late 1930s as a special effects matte artist and working on films such as *Citizen Kane* and *The Hunchback of Notre Dame.* Combining the photorealistic techniques he learned from matte painting with his lifelong interest in astronomy, Bonestell produced a series of paintings of Saturn that were published in *Life* magazine in 1944. Nothing like them had ever been seen before, and Bonestell found himself instantly famous and in demand. More extraordinary magazine appearances eventually led to a book in collaboration with the space expert Willy Ley: the classic *The Conquest of Space* (1949). More

Photographed in his Carmel, California, studio in 1978, Chesley Bonestell specialized in images of outer space.

books followed, as well as work on a series of classic space films for the producer George Pal, such as *Destination Moon* (1950).

Bonestell's greatest influence on public awareness of space travel resulted from his work with Wernher von Braun on a series of articles for *Collier's* magazine (1952–1954). Those articles outlined a coherent, step-by-step space program from robotic satellites, to a piloted lunar landing, to an expedition to Mars. For the first time Americans became aware that spaceflight was not a matter of the far future but was literally around the corner, that it was much less a matter of technology than one of money and will. This came at the most fortuitous time possible: the very beginning of the "space race," when it was imperative to rally public support for what had previously been dismissed as "that Buck Rogers stuff."

Several more books on the future of space exploration followed, extending Bonestell's artistry into hundreds of magazines and other publications. When most people in the 1950s and early 1960s visualized space travel, it was in terms of Bonestell's imagery. His paintings influenced many careers. Carl Sagan once said, "I didn't know what other worlds looked like until I saw Bonestell's paintings of the solar system." Arthur C. Clarke wrote that "Chesley Bonestell's paintings had a colossal impact on my thinking about space travel." In addition to the scientists, astronauts, and astronomers Bonestell inspired, he helped create the genre of illustration called space art. SEE ALSO Artwork (volume 1); Rawlings, Pat (volume 4); Verne, Jules (volume 1); von Braun, Wernher (volume 3).

Ron Miller

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C

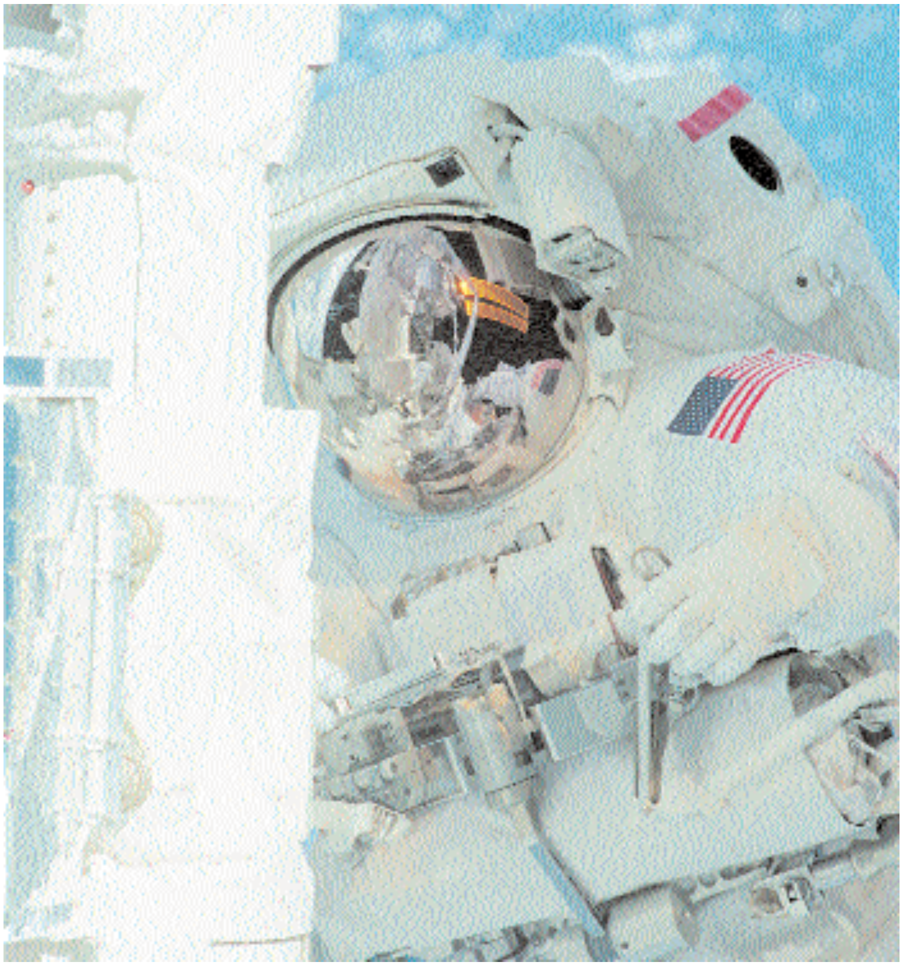
Careers in Space

Humankind is taking its first tentative steps toward a permanent presence in space after retreating from that goal in the late twentieth century, when the American lunar program ended. The goal then consisted only of a piloted round trip to the Moon, a mission prompted by rivalry between the global superpowers of the United States and the Soviet Union. In the future the mission will be the inhabitation of space and other worlds, a mission prompted by a variety of goals.

Since the start of the "space race" in the late 1950s, when the Soviet Union launched the first satellite, Sputnik, and the United States took up the challenge to go to the Moon in the 1960s, each generation has found inspiration that has urged it on towards space and motivated it to join the effort. At each step, a new generation of thinkers and pioneers has come forward to meet the challenge.

The initial inspiration was the beeping signal broadcast from Sputnik. Then came U.S. President John F. Kennedy's challenge to visit Earth's nearest neighbor: "I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth." It was a momentous achievement when, in 1969, astronaut Neil Armstrong stepped onto the Moon and said: "One small step for man, one giant leap for mankind." However, the piloted effort that culminated with the Apollo Moon landings seemed to flounder and retreat into science fiction, which was where people turned next for inspiration.

That inspiration came from *Star Trek* ("Space: the final frontier.") and *Star Wars* ("In a galaxy, far, far away. . ."), and soon a space industry sprang up. This industry is based primarily on missiles and satellites for military



Mission specialist Linda M. Godwin works during a 4-hour, 12-minute session of extravehicular activity.

and communications purposes. But the desire to return people to space lived on, in part through the development of the shuttle program and through the former Soviet Union, which operated the **space station** Mir. Mir was allowed to fall back to Earth to make way for the International Space Station. The international collaboration involved in the space station reflects the high costs of the effort. This collaboration extends to unpiloted missions. Recent **payloads** to Mars on American, Soviet, Japanese, and European missions have also been international.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

To secure an off-world presence, skilled individuals from a variety of professions will be needed to meet the challenges that arise. The next and future generations will require all of the skills that got humanity into Earth orbit and onto the Moon. People from many different professions, some clearly space-related and others less obviously associated, will be needed. Professions that helped humanity reach the Moon include astronautics, rocketry, space medicine, and space science.

Foremost are the dreamers who fire each generation's imagination, including visionary scientists and science fiction writers. They meld what is and what has been with what could be. Using new scientific knowledge, they imagine concepts such as human settlements on planets in this solar system and distant solar systems, propulsion systems capable of near-lightspeed, and years-long missions with crews that are hibernating or even embryonic, to be raised and educated at the destination in order to minimize the consumption of supplies during the long trip.

Scientific research conducted in space will add fuel to these fires of the imagination, and will provide work for astronomers and planetary scientists. The work of these scientists could lead to discoveries that provide further incentive for a human presence in space. Much of this research will use astronomical observations from new generations of telescopes that look not only at visible light but also at nonvisible portions of the **electromagnetic spectrum** such as **infrared** rays, **ultraviolet** rays, and **X rays**. These space- and Moon-based astronomical observatories will be the successors to the Hubble Space Telescope, which has been used to discover planets in distant solar systems. Free of the fog of Earth's atmosphere, the new observatories will be able to peer farther into deep space and allow chemical analysis of the atmospheres of planets in distant solar systems, an important step toward finding remote worlds capable of sustaining life.

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

X rays high-energy radiation just beyond the ultraviolet portion of the electromagnetic spectrum

The prophecies of dreamers make their way into people's awareness through the mass media. Journalists, authors, screenwriters, and filmmakers fall into this category, as do those who work in public relations. Although these are broad fields, they include areas of specialty that are space-related. In addition to this role as messengers of new space developments, the media play a vital role in educating the public about ongoing efforts and gathering support for them.

Following close behind the dreamers are the practitioners, the technical and nontechnical workers who turn the dreams into realities. Overseeing the efforts are program managers. These are practical thinkers who strive to make sensible and affordable compromises and alterations to the dreams. Most of these people work in government and defense jobs because the human presence in space is largely the legacy of competition between the United States and the Soviet Union, and remains a risky and extremely expensive enterprise.

Professions Needed for the Future

Because we want to establish a long-term future in space rather than continue to make short excursions, the projects that will anchor humankind in space will be more ambitious and costly than any single nation can afford. They will therefore need to span national boundaries and rely on international cooperation and participation by commercial enterprises to provide the necessary funding and talent. Like the extensive dam systems and interstate highway networks in the United States that have been funded by the government, these international space efforts will probably be large **infrastructure** projects, such as launch centers, space stations, and new generations of astronomical observatories.

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

Although early efforts likely will continue to rely on governments and defense departments, in the long run a significant part of this enterprise will probably need to be handled by entrepreneurs who can make the space venture pay its own way and keep it self-sustaining. Such projects will probably depend heavily on the infrastructure built by the international coalition. The mass media will also play a significant role by evaluating the public projects in each country and advertising the products of the private businesses. The teams that will build these projects and populate these companies will include engineers, scientists, medical experts, accountants, lawyers, and astronauts.

Current suggestions for space-based industries include mining the Moon, asteroids, and comets for metal ores, water, and isotopes that are rare on Earth and producing materials at sites where the manufacturing process can benefit from the low-gravity characteristics of space. Each type of industry will call for professionals such as geologists (sometimes referred to as planetary scientists in this setting) and engineers specializing in mining, drilling, and chemistry.

Other engineers will design safe space and planetary habitats for the astronauts who will blaze the trail for tourists and businesspeople. Rocketry engineers will design launchers and spacecraft aimed at making space travel inexpensive and routine. There will be an ongoing need for astronauts to pilot existing spacecraft and test new vehicles.

Scientists will continue to research space and near-Earth settings and apply the knowledge gained from those efforts toward making space safer for habitation. Medical experts will determine how to keep bodies and minds healthy during long trips and in the gravitational conditions of space and other worlds. Nutrition scientists will work on making food in space and planetary habitations to avoid having to transport these resources. This will be an important step toward making off-world activities self-sustaining.

Exobiologists—experts on life that could exist beyond Earth—will be needed as people visit planets and moons in the solar system that are capable of supporting some sort of life. The discovery of life in the solar system would be one of the most important events in human history, and this prospect alone is an important incentive to increase the human presence in space.

Business and accounting professions will play a significant role in this effort. These professions include marketing and sales, contract administration, law and licensing, accounting, proposal coordination, and human resources. These professions assure the smooth operation of any endeavor that relies on money and business transactions and will be no less important in space-based efforts. As humankind moves farther from Earth, communications innovators and communications expertise will be at a premium.

There is a lot of work to be done to secure humanity's place in space and on other worlds, and it calls for many types of people. Like the efforts to explore and settle unknown lands, humanity will send out adventurous pioneers and follow them with more ordinary individuals who want to live and work there. SEE ALSO Career Astronauts (volume 1); Careers in Astronomy (volume 2); Careers in Business and Program Management (volume 1); Careers in Rocketry (volume 1); Careers in Space Law (volume 1); Careers in Space Medicine (volume 1); Careers in Space Science (volume 2); Careers in Writing, Photography, and Filmmaking (volume 1).

Richard G. Adair

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Franklin Chang-Díaz was instrumental in the formation of the Astronaut Science Colloquium Program and the Astronaut Science Support Group.

Chang-Díaz, Franklin

American Astronaut
1950–

Born in San José, Costa Rica, on April 5, 1950, Franklin R. Chang-Díaz immigrated to the United States at the age of eighteen with the goal of someday becoming an astronaut. After learning English as a senior high school student in Hartford, Connecticut, he earned a bachelor of science degree in mechanical engineering from the University of Connecticut in 1973, and a doctoral degree in applied plasma physics from the Massachusetts Institute of Technology in 1977. Chang-Díaz then became an astronaut for the National Aeronautics and Space Administration (NASA) in 1981, and flew on six space shuttle missions.

Chang-Díaz's missions have included the launch of the Galileo spacecraft to Jupiter in 1989 and the final shuttle visit to the Russian Mir space station in 1998. The recipient of numerous medals and awards, Chang-Díaz directs the NASA Advanced Space Propulsion Laboratory at the Johnson Space Center in Houston, Texas. His research team (which includes graduate students at several universities) is developing the Variable Specific Impulse Magnetoplasma Rocket (VASIMR). VASIMR is expected to greatly increase the speed with which humans can travel in space. In addition to his research, Chang-Díaz is organizing more direct involvement in space activities by the countries of Latin America. SEE ALSO Astronauts, Types of (volume 3); Ion Propulsion (volume 4); Jupiter (volume 2).

Michael S. Kelley

Internet Resources

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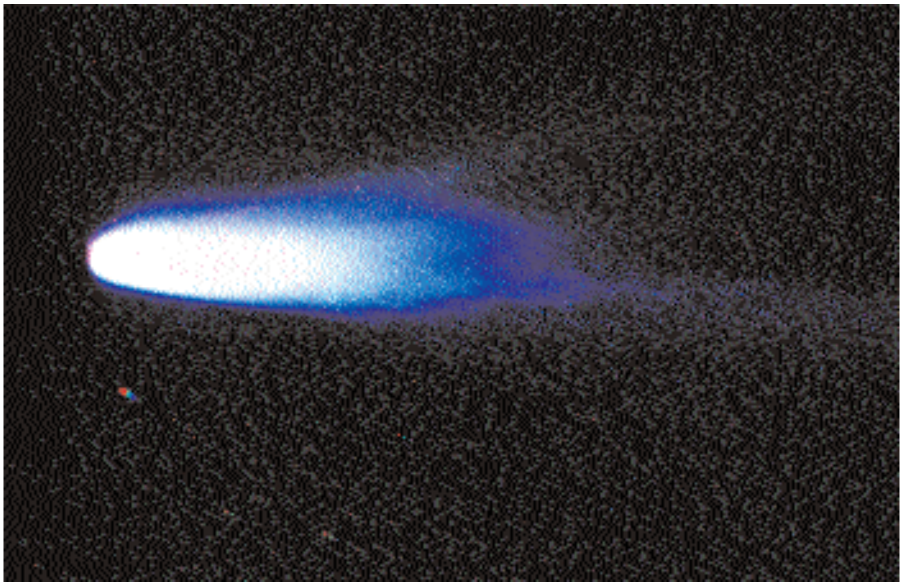
volatile ices (e.g. H_2O and CO_2) that are solids inside a comet nucleus but turn into gases when heated by sunlight

near-Earth asteroids asteroids whose orbits cross the orbit of Earth

Comet Capture

Comets are the most **volatile**-rich minor bodies in the solar system. It has been suggested that impacts with comets and asteroids provided Earth with much of its water. Although most comets are less accessible than **near-Earth**



Comets have a high water content, which makes them an economically attractive resource for space mining.

asteroids, their high water content makes them an economically attractive resource for space mining. The possibility that some near-Earth asteroids are extinct or dormant cometary nuclei means that this water-rich resource may be more accessible than was once thought.

Recent spacecraft- and ground-based studies of comets have confirmed and refined Whipple's "dirty snowball" model for cometary nuclei. Cometary material is composed principally of water ice and other ices (including CO, CO_2, CH_4, C_2H_6, and CH_3OH) mixed with cosmic dust grains. The passages of most Oort cloud comets through the inner solar system are not predictable. In addition, the highly elongated and inclined **trajectories** of these comets make them difficult targets with which to match orbits. In contrast, Jupiter-family comets tend to have predictable, well-determined orbits with short periods and low inclinations. Therefore, a future mining mission would most likely target a Jupiter-family comet.

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

The capture of an active comet as a source of water and other volatile elements is a difficult proposition. In the vicinity of Earth the jet-like gas that flows from a comet's nucleus would have a stronger influence on its trajectory than any force humans could apply to the comet. This behavior would make transporting an active comet into a suitable near-Earth orbit, and maintaining it there, very unlikely. The Earth-impact hazard posed by a sizable comet* or comet fragment in an unstable near-Earth orbit would be unacceptable. For example, even if the trajectory of a cometary fragment could be manipulated to produce capture into a high-Earth orbit, bringing the material down to low-Earth orbit (e.g., to the space station) would be difficult. The Moon's gravitational pull would make the trajectory extremely difficult to predict and control.

***A "sizable" comet in this context means greater than about 100 meters, depending on the density of the material.**

Capture into a lunar orbit would also be problematical. Lunar orbits tend to be unstable because of gravitational influences from Earth and the Sun. Another difficulty that must be resolved is the current uncertainty about the consistency of cometary nuclei. Not only is the bulk density of cometary nuclei unknown (estimates range from 0.3 g/cm^3 to greater than 1 g/cm^3;

WHERE DO COMETS COME FROM?

Comets are thought to have formed in the outer solar system. Two sources have been identified for the comets that are seen today: the Oort cloud and the Edgeworth-Kuiper belt (also known simply as the Kuiper belt). The Oort cloud is a roughly spherical shell located about a third of the distance to the nearest star. The Kuiper belt is a disk-like distribution of icy bodies extending beyond Pluto's orbit. Most bright new comets, such as Comet Hale-Bopp, come from the Oort cloud and have orbits that are highly inclined with respect to Earth's orbit. Most short-period or Jupiter-family comets have low inclination orbits (i.e., their orbits lie nearly in the same plane as Earth's orbit) and are believed to originate in the Kuiper belt.

liquid water has a density of 1 g/cm^3), we do not know the cohesiveness of this material. Such uncertainties make it impossible to predict the mechanical properties of cometary material and the way a comet nucleus would react to a "nudge" to change its trajectory. A comet nucleus may or may not behave as a rigid object does; it might instead break up into fragments when a force is applied to change its orbit.

A more attractive approach to harvesting cometary material would be to send a robotic spacecraft to mine the comet. Returning fine-grained material and/or liquid water to Earth orbit would greatly lower the risks. A cargo spacecraft would be easier to control than a comet fragment, and even if an uncontrolled atmospheric entry occurred, the water and/or fine-grained material would vaporize or rain down harmlessly onto Earth's surface. SEE ALSO ASTEROID MINING (VOLUME 4); COMETS (VOLUME 2); KUIPER BELT (VOLUME 2); LIVING ON OTHER WORLDS (VOLUME 4); OORT CLOUD (VOLUME 2); NATURAL RESOURCES (VOLUME 4); RESOURCE UTILIZATION (VOLUME 4); TERRAFORMING (VOLUME 4).

Humberto Campins

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Communications, Future Needs in

Space programs, whether unpiloted space probes or human spaceflight missions, must be able to send large amounts of data to and from space. In the past, data might consist of navigational and spacecraft control information, radio conversations, and data collected by onboard experiments. But with today's permanent human presence in space, and for most future missions, the amount of data is much larger. For example, video transmissions are now common, and many spacecraft that conduct experiments are collecting richer sets of data over longer periods, owing in part to greater onboard data storage capacity. Hence, the major challenges in space communications of the future are handling the larger quantities of transmitted data and extending the Internet into space.

New Generation Satellites

The need to support more data transmissions has spawned the development of a new generation of space communications satellites. The mainstay of space communications since the early 1980s has been the Tracking and Data Relay Satellite System (TDRSS). TDRSS consists of an array of five operational satellites parked in **geosynchronous orbit** over the Earth's equator. Rather than direct communications between a spacecraft and the ground, spacecraft communicate with TDRSS satellites, which in turn communicate with ground stations. As the name implies, these satellites act as a relay point for any communication between the ground and a spacecraft.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Besides forming the main communications link between the space shuttle and National Aeronautics and Space Administration (NASA) ground stations, TDRSS is used by many other NASA and government spacecraft.

The Tidbinbilla Deep Space Communication Centre in Australia is one of three communication centers in the world that provide contact with deep space probes and orbiting spacecraft.

These include the Hubble Space Telescope, the Upper Atmosphere Research Satellite, the Earth Resources Budget Satellite, Landsat, the Ocean Topography Experiment, the Earth Observing System, and the International Space Station.

Recognizing it will need more capacity in the near future, NASA has recently embarked on a TDRSS modernization program. In June 2000, NASA launched TDRS-H, the first of its new generation of communications relay satellites. By the end of 2002 it planned to have two more in place: the TDRS-I and TDRS-J. The new satellites will offer the same S-band and Ku-band communications of the original TDRSS satellites. However, the newer generation satellites will also support higher bandwidth links that are necessary for transmitting data such as high-quality video and high-resolution images.

The new generation satellites, like the older satellites, will support S-band communications, which operate at **frequencies** of between 2.0 and 2.3 GHz (gigahertz). Within the S-band communications there exists single access in which there is one back-and-forth link between the ground and spacecraft via the TDRSS satellite. This S-band single access communication channel can support data transmission rates of 300 Kbps (kilobits per second) in the forward direction (from the ground to the spacecraft via the TDRSS satellite) and up to 6 Mbps (Megabits per second) in the opposite direction. Typically, the forward transmission consists of command and control data being sent to the spacecraft, and the return transmission can include data and images.

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

TDRSS also supports another S-band mode of operation called multiple access, in which the TDRSS satellite receives data from more than one spacecraft source simultaneously and sends these data to an Earth station. In this multiple access mode of operation, a forward data rate of 10 Kbps and five return data streams of up to 100 Kbps can be supported.

For higher speed transmissions, TDRSS supports Ku-band communications, which transmits at frequencies between 13.7 and 15.0 GHz. The

The Tracking and Data Relay satellite system is a sophisticated network that has granted NASA increased communication abilities between Earth and its low-orbit spacecraft.

Ku-band communications supports forward data rates of 25 Mbps and return rates of up to 300 Mbps. To put this into perspective, this is about 50 times faster than a 56 Kbps dial-up modem, which is commonly used to connect to the Internet.

The new satellites will also support even higher transmission rates such as Ka-band transmissions, which operate at frequencies of between 22.5 and 27.5 GHz. The Ka-band systems will allow forward data transmission rates of 25 Mbps and return rates of up to 800 Mbps. The three new satellites will be phased in as replacements for the originals, some of which have been in space for over ten years.

Extending the Internet

The new generation TDRSS will handle the larger amounts of data being sent between spacecraft and researchers on Earth. Another effort will try to extend the Internet into space. The Interplanetary Internet Project (IPN), launched in 1998, began to explore the technical challenges to pushing the boundaries of the Internet into outer space. At one end of the spectrum are straightforward matters, such as the top-level domain (TLD) name extensions to be approved for use in space. On Earth, we use country TLD designations such as .uk or .ca (for the United Kingdom and Canada, respectively). In space, the naming structure might be similar including TLD designations for each planet or spacecraft. Other issues that are being investigated are how to handle the basic transmission of data. Existing Internet technology will not work in space applications, largely because of the great distances data must travel. Specifically, many of the underlying communication protocols used to carry Internet traffic, to surf the web, and to access information will not work efficiently over the vast reaches of space.

The downfall of using existing communications technology for an interplanetary Internet is the delay encountered when packets must traverse interplanetary distances. For that reason, the IPN is looking into new protocols and technologies to carry Internet traffic in space. For instance, proposed Interplanetary Gateways could serve regions of space. Combined with perhaps new Internet communications protocols, this potential technology could avoid the problems created by the long distances and transmission times in space. For example, if a person on Earth were communicating with someone on Mars, rather than sending individual communications packets and acknowledgements back and forth between the two, an Earth-based gateway would send the acknowledgement and then pass the packet between Earth and Mars to a similar Martian gateway.

Once such technologies are developed, the next thing needed would be an interplanetary Internet backbone to carry the traffic. NASA is already studying an idea for a Mars network of multiple orbiting satellites. These satellites would be launched over several years, possibly starting in 2005. This system would create high-speed connections between Mars and Earth that could be used as the basis of an interplanetary Internet backbone. SEE ALSO COMMUNICATIONS FOR HUMAN SPACEFLIGHT (VOLUME 3); GUIDANCE AND CONTROL SYSTEMS (VOLUME 3); INTERPLANETARY INTERNET (VOLUME 4); SATELLITES, FUTURE DESIGNS (VOLUME 4).

Salvatore Salamone

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Communities in Space

In 1929 Hermann Noording developed the idea of a large wheel-shaped satellite reminiscent of the **space station** in the movie *2001: A Space Odyssey* (1968). In the 1950s Wernher von Braun developed a similar plan for a refueling stop on the way to the Moon. But it was Princeton physicist Gerard K. O'Neill who saw huge orbiting communities as a means of salvation for Earth. Overcoming initial skepticism, he gained support from the National Aeronautics and Space Administration (NASA), organized a series of breakthrough workshops, and set forth detailed plans in his 1976 book *The High Frontier.* Although everyone at that time talked in terms of "space colonies," "colonies," and "colonists," these words evoke images of harsh and repressive governments. For this reason, the terms "settlements" and "settlers" are preferred instead.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

Solving Earth's Problems in Outer Space

Like most proponents of large-scale emigration to space, O'Neill believed that the world, with its rapidly growing population, was entering an era of decline. He noted the heavy consumption of fossil fuels and other resources as well as growing concern about environmental pollution and global warming. By establishing humans in space it will be possible to reduce population pressures on Earth and draw upon the immense natural resources that are available on the high frontier.

O'Neill did not see the Moon or Mars as good destinations for wholesale emigration from Earth. The Moon is small, and it is expensive and time-consuming to get to Mars. Sunlight, the source of power and life, would not be readily available during the two-week lunar night and it would be difficult to collect on Mars. Instead, he recommended human-made communities conveniently located between Earth and the Moon where people could build as many huge settlements as was needed, 500 if necessary.

Islands in the Sky

O'Neill set forth detailed, phased plans for developing a series of successively larger space settlements. The first construction crews would work out of an orbiting construction shack and at a base on the Moon where they would strip-mine building materials. A device known as a mass driver, which uses electromagnetic propulsion, would accelerate lunar material along a long track. This material, sliced into shapes reminiscent of large, thick plates, would break free of the Moon's weak gravity, and fly through space to be caught at the construction site. There the material could be used like bricks or transformed into other useful materials.

O'Neill envisioned three "islands," ranging from a sphere about 1.6 kilometers (1 mile) in circumference to a cylinder 6.4 kilometers (4 miles) in diameter and 32 kilometers (20 miles) long. These islands would house between 10,000 and tens of millions of people. A shield would protect each community from **meteors** and space debris. Windows and mirrors would fill their interiors with sunlight, and a slow spin would produce artificial gravity. These settlements would be safe from disasters, such as earthquakes and inclement weather, including storms, monsoons, droughts, heat waves, and cold snaps. Insects and other vermin would be left behind on Earth. Clean technologies could prevent pollution and minimize problems associated with environmental health. Settlers would grow their own food (primarily grains and vegetables) and earn money by collecting solar power that would be beamed to Earth.

meteors physical manifestations of a meteoroid interacting with Earth's atmosphere

O'Neill's contribution to the development of space stations involved more than an exploration of the physics and engineering involved: He moved space colony design into the realm of the possible. He attracted support from scientists in many fields and from members of the public who had never before given space settlement serious thought. This interest was sustained in later NASA Ames projects that led to many different designs, which included settlements shaped like doughnuts and paddlewheels. O'Neill's influence is evident in one of the most detailed, bold, and imaginative plans for establishing humans as citizens of the universe. This plan is set forth in Marshall Savage's 1994 book *The Millennial Project: Colonizing the Galaxy in Eight Easy Steps.*

Making Space Settlements User-Friendly

Early settlers will be a hardy lot. Traditionally, military personnel have been the first to enter new, unusual, and potentially dangerous environments. In recent times, scientists and entrepreneurs have come next. One might expect strong, restless, highly motivated people to follow—the kinds of people who stowed away on ships from Europe and Asia to build new lives in America. In the long run, to establish a permanent human presence in space, settlements will have to be accessible to everyone. Ultimately, they must be inviting communities, not just rough work camps.

Thus, designers avoid the cold, sterile, mechanical look. Some designs incorporate varied architecture, distant horizons, and the use of colors and light to open up areas. They make allowance for ornamental vegetation, including trees, shrubs, and hanging plants. To create a friendly look, buildings may be set off at angles rather than aligned with military precision. Clustering buildings, orienting entrances and exits in different ways, and developing common areas such as neighborhood parks will make it easy for residents to meet, mingle, and develop a sense of community.

The visionaries who foresee space settlements include not just scientists and engineers but social architects as well. Their goal is to establish minimal, low-profile governments that intervene as little as possible. Democracy is the preferred form of government, and "bureaucracy" is considered a bad word. And, as one might suspect, few space settlement enthusiasts propose paying taxes to authorities on Earth.

A Cloudy Crystal Ball

In their 1986 book *Pioneering Space*, James and Alcestis Oberg include a NASA artist's rendition of a huge American space station along with a photograph of a real Russian Salyut station. The flowing lines, spaciousness, and aesthetic appeal of the artist's rendition stand in stark contract to the functional, cluttered look of the real thing. Some day it may be possible to construct large, attractive settlements in space. However, people are notorious for tampering with other people's ideas. Between today's planning efforts and tomorrow's space settlements both technology and people will change. There may be many slips between today's visions and tomorrow's realities. SEE ALSO Earth—Why Leave? (volume 4); Governance (volume 4); Hotels (volume 4); Living on Other Worlds (volume 4); O'Neill Colonies (volume 4); O'Neill, Gerard P. (volume 4); Settlements (volume 4).

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Cycling Spacecraft

The furthering of humankind's expansion into space and establishing of firm footholds on other worlds could depend on a continuously moving, cycling spaceship network. These rapid-transit cycling spaceships would employ the principles of **gravity assist**, which entails taking a slingshot approach to running people and cargo from one locale to another. The motions of the planets and gravity would be used as a natural fuel.

gravity assist using the gravity of a planet during a close encounter to add energy to the motion of a spacecraft

It may be possible to establish a "recyclable space program"—a vision that is a far cry from the early days of space exploration. As an example, the Apollo Moon landing effort of the 1960s and 1970s involved tossaway technology. All of the stages of the giant Saturn V booster—except for the return capsule that brought the astronauts back to Earth—were thrown away. Even today, the idea of a fully or partially disposable space program is being perpetuated.

Opening up the space frontier, however, requires transcending reusability and recycling barriers to shape a space agenda for the twenty-first century. Putting into place a fully cycling strategy for travel in the inner solar system travel is likely to happen in phases. The first human missions to Mars will install the early segments of the network.

A champion of the cycling spaceship idea is the Apollo 11 astronaut Buzz Aldrin. Aldrin's vision is to have large cycling spaceships swinging

elliptical having an oval shape

permanently between the orbits of Earth and Mars. A cycling spacecraft in an **elliptical** orbit would transit from Earth to Mars and back again, permanently cycling between the orbits of the two planets. This approach could be used to put in place an interplanetary passenger transport system.

In an Earth-Mars scenario, transfer vehicles ferry passengers from Spaceport Earth to a cycler. At the other end of a Mars cycling trajectory is Spaceport Mars. Cyclers take advantage of the way the Earth, traveling faster on an inside orbit around the Sun, catches up to Mars about every two Earth years. Like a ship using the trade winds, a cycling spacecraft will not follow a linear route to Mars. When the planets are aligned, it will accelerate away from Earth and loop outward, swinging close to Mars five months later.

But instead of stopping, the cycler releases smaller ships that ferry people and supplies to the surface. The cycler acquires some of the planet's momentum using gravity assist and glides on, curving away and eventually back to Earth. It returns home twenty-one months after departure, but it does not stop at that point: With another boost from Earth's gravity it sails onward, and back to Mars. The vehicle becomes a permanent, human-made companion of Earth and Mars, using the free and inexhaustible fuel supply of gravity to maintain its orbit.

The cycler system would eliminate the need to accelerate and decelerate and would also discard the necessity of large and costly spacecraft hardware. Like an ocean liner on a regular route, a cycler would zip perpetually along a predictable orbit. Twin cyclers, one always en route to Mars and the other always in transit back to Earth, would greatly reduce the cost of exploring and, eventually settling, the fourth planet from the Sun: Mars. The pursuit of an economical philosophy may lead to sustainable and recyclable space transportation. Doing so would set in motion expressway traffic carrying humanity into the next great age of exploration, expansion, settlement, and multi-planetary commerce. SEE ALSO ACCESSING SPACE (VOLUME 1); ALDRIN, BUZZ (VOLUME 1); LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); ORBITS (VOLUME 2); VEHICLES (VOLUME 4).

Leonard David

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D

Domed Cities

In the Arizona desert, there is a complex of interconnected domes and glass pyramids known as the Biosphere 2 Center. This structure was originally conceived and built as a sealed environment for the purpose of determining whether a closed ecological system could be maintained and could sustain human beings for long time periods. Eight people lived in the complex for two years, from 1991 to 1992. This was followed by a shorter experiment in 1993 and 1994. However, results from these experiments were not conclusive, partly due to excessive air transfer between the outside environment and the sealed habitat.

The Biosphere✶ was a practical realization of an idea that has intrigued writers and scientists for hundreds of years—a domed city that would be completely self-sustaining. Science fiction writers have found domed cities to be a fertile ground for imaginative fiction of all types. However, domed cities or variations of domed cities are also seen by some scientists as suitable habitats for humans living on the Moon, on Mars, or in other inhospitable environments.

✶An image of this enclosed system may be seen in the Volume 3 article "Biosphere."

Science Fiction

Early science fiction stories often emphasized the use of domed cities as space colonies. Various writers placed domed cities on the Moon, Mars, and Venus. Other writers used domed or enclosed cities as metaphors exposing the ills of their own societies. In the short story "The Machine Stops" by E. M. Forster, humans live in a vast complex of rooms inside an enormous subterranean machine that provides everything they need, including vicarious experiences. These people never leave their chambers. However, the machine eventually breaks down, causing the inevitable death of the inhabitants. More recent writers began to see domed cities here on Earth as a retreat—Arthur C. Clarke's *The City and the Stars* (1956) portrayed the domed city as a modern version of Eden.

Moon and Mars Colonies

The surface of the Moon is uninhabitable. There is no air. However, there may be water locked in permafrost in some deep polar craters. Moreover, there are plenty of raw materials contained in the lunar rocks, including aluminum for structural materials and silicon dioxide for glass. This fact has led to proposals for the construction of permanent colonies on the Moon. Some designs have been suggested for glass-enclosed domed cities although the majority of proposals for lunar habitats feature extended underground bunkers to provide necessary **shielding** from **solar radiation**.

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

The Moon's surface is an ideal location for many different types of human endeavor. For instance, the Moon's low gravity might provide a suitable environment for hospitals that treat burn patients or patients with limited or painful mobility in Earth's gravity. Moreover, the farside of the Moon is shielded from all artificial radiation originating from Earth, so it would provide an ideal location for radio and optical astronomy.

There are several groups that argue Mars should be colonized. The atmosphere on Mars is so thin that a person walking on the surface of the Red Planet would need to wear a space suit similar to the ones worn by astronauts on the Moon. However, Mars, like the Moon, has ample resources to provide the raw materials for construction of artificial domes. SEE ALSO Biosphere (volume 3); Closed Ecosystems (volume 3); Dyson, Freeman John (volume 4); Dyson Spheres (volume 4); Living on Other Worlds (volume 4); Lunar Bases (volume 4); Mars Bases (volume 4); O'Neill Colonies (volume 4); O'Neill, Gerard K. (volume 4).

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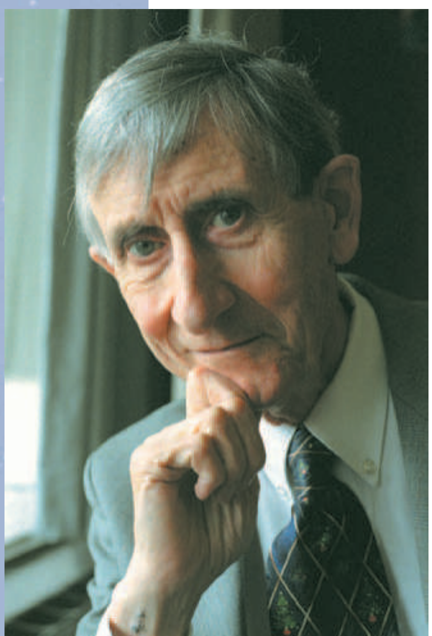
Red Colony. <http://www.redcolony.com/>.

Dyson, Freeman John

British Space Futurist
1923–



Freeman Dyson has written extensively on space, physics, weapons control, and philosophy.

Freeman John Dyson is a space futurist who has envisioned the creation of various human habitats in space. Born December 15, 1923, in Crowthorne, England, he received his bachelor of arts degree from Cambridge University in 1945. From 1943 to 1945, during World War II, he served in Operations Research with the Royal Air Force Bomber Command.

A fellow at Trinity College at Cambridge University in England and a commonwealth fellow at Cornell University, Dyson taught at Princeton University from 1947 to 1949. He was a physics professor at Cornell from 1951 to 1953 and also served as a professor at the Institute for Advanced Study at Princeton University. Since 1994 he has served as professor emeritus at Princeton. Dyson has received many honors and honorary degrees. He is a fellow of the Royal Society, London, and a member of the U.S. National Academy of Sciences and the American Physical Society.

Dyson has written and spoken widely on cosmology, nuclear physics, technology, weapons control, and philosophy. In 1959 he proposed human habitats in space that came to be known as Dyson spheres. Such habitats would surround a star harnessing light and energy to support communities of billions of people. Dyson later developed an interest in asteroids as human habitats in space. Dyson wrote a number of widely read and respected books, including *Disturbing the Universe* (1979); *Weapons and Hope* (1984); *Origins of Life* (1986); *Infinite in All Directions* (1988); *From Eros to Gaia* (1992); *Imagined Worlds* (1997); and *The Sun, the Genome, and the Internet* (1999). SEE ALSO Communities in Space (volume 4); Dyson Spheres (volume 4); Habitats (volume 3); Settlements (volume 4).

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Dyson Spheres

While the National Aeronautics and Space Administration (NASA) considers future human trips to Mars and continues to build the International Space Station, some individuals in the field have pushed for even more. They believe that the key to human expansion in space does not lie in the building of colonies on planets or even the building of small **space stations**. Scientists such as Freeman Dyson and Gerard K. O'Neill proposed building gigantic structures for humans to live in. What makes their ideas even more unconventional is the size of their proposed structures. The structures proposed by O'Neill, known as O'Neill colonies, could be a dozen miles long and a few miles wide. Freeman Dyson's structures, called Dyson Spheres or Dyson Shells, would be the size of a planet's orbit. While it would only be a few meters thick, the size of the sphere would stretch for millions of miles.

space stations large orbital outposts equipped to support human crews and designed to remain in orbit for an extended period

Dyson's Vision

In 1959 Dyson hatched the idea of building a huge sphere around a star. In his theory, a shell built at a safe distance away from the star would allow billions of people to live inside while allowing the civilization to harness a large amount of energy, in the form of radiation, from the star. While his vision is fascinating, it poses concerns.

One concern that needs to be addressed involves the materials that could be used to build such a structure. Not only would the shell need to stay together, but it would have to absorb impacts without the inertia pushing it into the star. Creating gravity would be a problem, since spinning the sphere would add more stress to the structure and force everyone to the equator of the sphere. Moreover, the amount of raw materials needed to create a space that would be one billion times bigger than the Earth is enormous. Future engineers would need to be able to deconstruct and process other planets and asteroids to create a sphere.

The Search for Dyson Spheres

Searches have been conducted using radio telescopes to see if there may be Dyson Spheres already in existence, but none have yet been found. Due to the high level of technical expertise required to build a sphere of this magnitude, some scientists question Dyson's theories. Dyson responds that advanced civilizations would have the ability to build such a device, and that we cannot be biased by our current technological level:

> One should expect that, within a few thousand years of its entering the stage of industrial development, any intelligent species should be found occupying an artificial biosphere which completely surrounds its parent star.

One type of colony Dyson suggested was the "Island Three." This design was an enormous cylinder that was twenty miles long and four miles across. The cylinder would spin to create artificial gravity, but spun slowly enough to prevent harmful **G forces**. The cylinder was designed to contain spaces for agriculture, industrial facilities, and even a place for ships to dock as they transported people from Earth. The Island Three was even designed with huge adjustable mirrors that would move to reflect the light of the Sun to create a daytime and nighttime for the inhabitants of the colony. This

G force the force an astronaut or pilot experiences when undergoing large accelerations design would be capable of holding several million colonists, but not as many as a Dyson Sphere.

Not all proposed Dyson Spheres would need to be complete enclosures. It has been proposed that a smaller series of solar energy collectors could suffice as a first step towards the building of a Dyson Sphere. The collectors would be much larger than standard solar panels, and would therefore allow for a much greater energy gain. In the future, larger solar panels will be useful for extraterrestrial colonization. SEE ALSO Dyson, Freeman John (volume 4); L-5 Colonies (volume 4); O'Neill Colonies (volume 4).

Craig Samuels

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Earth—Why Leave?

Only humans have the ability to leave their home planet and explore, settle, and even alter other worlds, and many people want to do all of these things. What is the attraction of these distant worlds that tempts humans to leave the comforts of Earth for uncertain, and probably hazardous, journeys beyond?

The history of human exploration of Earth provides a basis for understanding our motivations for exploring new places. At the same time, humankind's brief experiences with human exploration of the Moon, and the extensive robotic exploration of the solar system, show how space exploration will be different from past voyages of discovery in terms of motivation and operation.

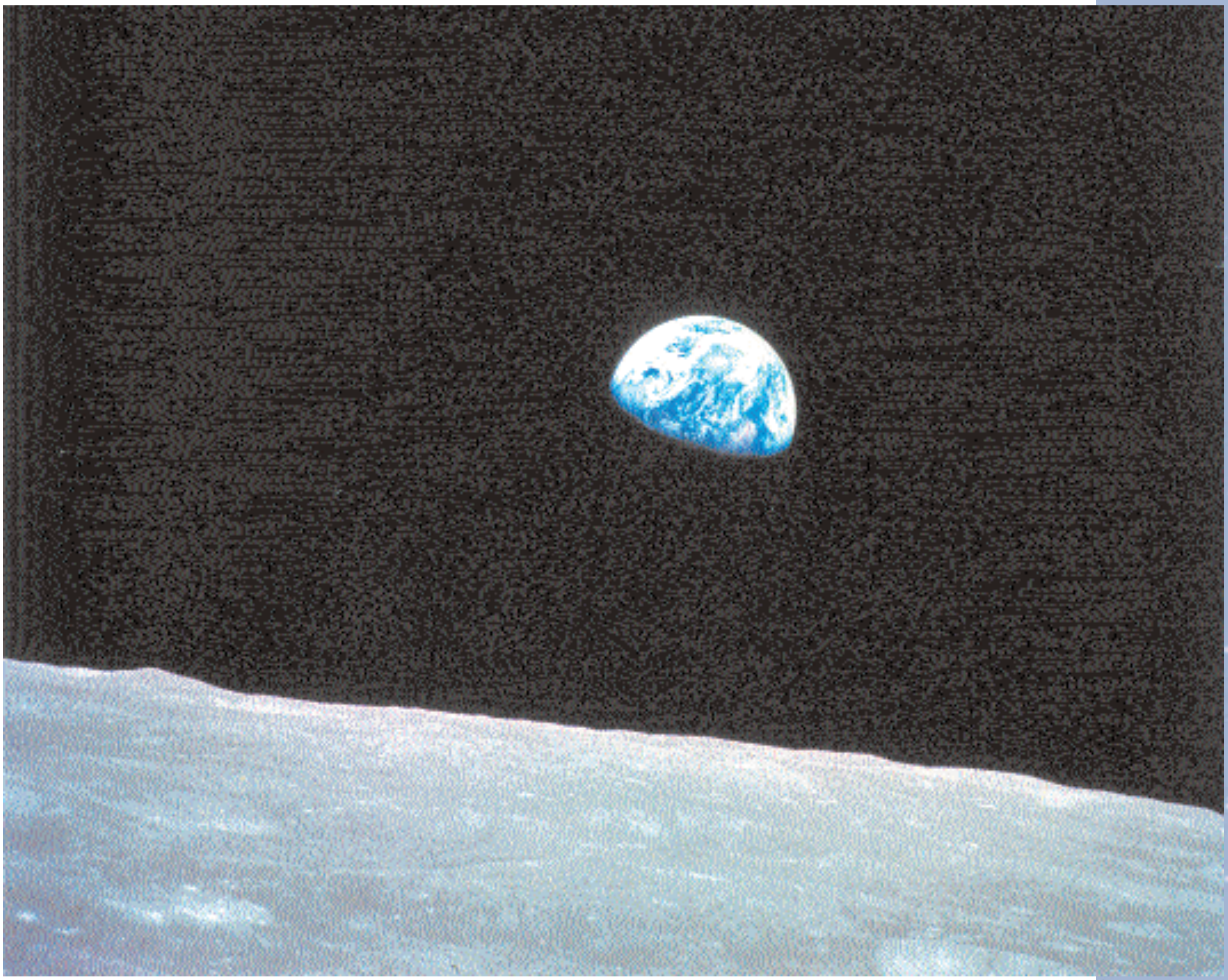
In current and near-term space missions, the search for scientific knowledge has been more prominent, sometimes exclusively so, than it was in historical voyages. Furthermore, unlike the European migrations to the New World, it is unlikely that significant fractions of the population can be transported from Earth because of the limitations and costs of **rockets**. Nonetheless, human and robotic exploration of the other worlds in the solar system might lead to the establishment of permanent human settlements on the Moon, Mars, and elsewhere and eventually to the reconstruction of a planetary-scale **biosphere** on Mars.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

biosphere the interaction of living organisms on a global scale

History and Biology Lessons

Since our ancestors ventured out of Africa, humans have explored Earth. Prehistoric peoples successfully filled every ecological niche available to them on the planet, spreading to every continent except Antarctica. Clearly, this attests to an effective and possibly biologically based drive for exploration and expansion. However, the structure and motivation of prehistoric



This famous view of Earth rising, taken during the Apollo 8 mission, gave people on the planet a new perspective of their place in the universe.

migrations are lost in the depths of time. They probably did not reflect a conscious decision to explore and expand any more than such decisions were part of the spread of the African killer bee through the Americas after its introduction to Brazil in the 1980s. Furthermore, biology is not destiny: Even if there is a biologically based drive to explore and expand, it does not necessarily follow that humans should and will explore and settle other worlds.

The drive to explore in humans can be demonstrated, by counterexample, to be nonobligatory. There are well-known examples of civilizations poised on the edge of great epochs of exploration and expansion that turned inward and developed cultural blocks to exploration and contact with foreigners. In a frequently told tale there is a striking parallel between the expansion of the Portuguese in the fifteenth century and the abortive voyages of the Chinese under the Ming emperors just a few decades before that time. After an impressive series of sea voyages far greater in scope than anything Europe could achieve, the Chinese withdrew, destroyed their seagoing vessels, and left the age of exploration to the Europeans.

There is a clear lesson in this parallel to space exploration, which shows that initial voyages of discovery do not automatically lead to subsequent exploration and expansion. If there is a biological drive to explore, it is greatly influenced, if not dominated, by cultural traditions and myths. In this regard there is general agreement that Western culture has a historical tradition and a collection of myths that inspire and reward exploration.

To Expand Scientific Knowledge

Many space scientists have argued that the fundamental motivation for a space program is the scientific understanding that it generates. In this view, the performance criterion for any mission is the scientific return compared to the cost. Certainly space missions have contributed to an understanding of Earth through studies of **greenhouse effects** on Venus, Mars, and Titan; the photochemistry of the acid clouds on Venus; the dust storms on Mars; and impact hazard assessments and prevention. Impact by an asteroid is the single most devastating natural hazard known, as testified by the extinction of the dinosaurs 65 million years ago. Through the exploration of space for scientific understanding and the development of space technologies, an asteroid on a collision course with Earth could be detected in advance and methods could be devised for deflection of the asteroid to prevent impact.

greenhouse effect process by which short wavelength energy (e.g., visible light) penetrates an object's atmosphere and is absorbed by the surface, which reradiates this energy as longer wavelength infrared (thermal) energy; this energy is blocked from escaping to space by molecules (e.g., H_2O and CO_2) in the atmosphere; and as a result, the surface warms

Perhaps the most compelling scientific motivation for space exploration is the search for a second genesis of life that has independently begun on another planet. More than being a matter of simple scientific curiosity, the question "Are we alone?" is asked by every person. The search for life is best conducted in space, whether this involves missions to search for biologically produced compounds in the subsurface of Mars, Titan's organic haze, or Europa's frozen oceans or telescopes probing the atmospheric composition of **extrasolar planets**. Space exploration, specifically the human exploration of planets and planetoids that are hospitable to life, is key in the search for life in the solar system and, by extrapolation, the universe.

extrasolar planets planets orbiting stars other than the Sun

But common sense and recent history show that space exploration is not about science alone. If science was the only important motivation for space exploration, the world's space programs would be placed within the basic science agencies and would compete directly with programs involving disciplines such as oceanography, particle physics, and geology. Yet clearly this is not the case. Space programs enjoy a special status, usually within a separate agency. This reflects a broader motivation base for space than science alone.

Beyond Science

Clearly there are significant nonscientific issues of a national and international nature that drive the current space programs of the world. At the highest levels these issues deal with national self-image, international political competition, economic competition, and national technological development. On a more direct level national space programs are perceived as having tangible benefits in terms of the level of education and the overall perception of technology as a positive force in society. For all these reasons there seems to be a consensus that a vigorous space program is in the national and international best interests.

Economics has been suggested as a possible motivation for the exploration and utilization of space. Communication satellites, the mining of helium-3 on the lunar surface and metals on asteroids, and oxygen production on the Moon have received the most attention. **Microgravity** manufacturing and space tourism also reflect economic incentives for space missions. From this list the only two that have proven profitable so far have been telecommunications satellites and space tourism. Space tourism has only three examples in its support: the flights of a Japanese reporter, a wealthy American businessman, and a South African Internet tycoon, all on Russian missions. From this humble beginning could come luxury hotels in orbit and on the Moon and possibly eco-tourism to Mars.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Reasons for Not Exploring Space

Many past migrations of human populations were driven by acute local problems such as dire economic conditions, famine, warfare, overpopulation, and environmental degradation. It is sometimes suggested that other worlds may provide similar relief when Earth becomes overpopulated or uninhabitable as a result of human actions. However, the limitation of space transport makes these motivations for settling other worlds irrelevant in the near-term. Space exploration and settlement may help solve problems on Earth by providing useful knowledge but is unlikely to provide an escape valve for mismanagement of this planet.

From Exploration to Settlement

The exploration of environments, such as the surface of Mars, that are instantly lethal to humans naturally leads to the question: Does exploration lead to settlement? Historically it has, but the historical record is based upon the exploration of the surface of Earth and, in particular, of environments in which premodern peoples with a rudimentary technology base could thrive. The only example of exploration not based on this model was the exploration of Antarctica. Although permanent scientific research bases have been established in Antarctica and some nations have made legalistic gestures toward inhabitation, there is no effective human settlement in Antarctica. Similarly, but less telling in light of the limited time spent on undersea exploration, there are no human settlements below the water. Human activity on the Moon could be expected to follow the Antarctic model, with the establishment of long-lived research stations and observatories but without a permanent population. Commuting to the Moon from Earth is not out of the question, but travel to Mars is likely to be a different case for two reasons. First, the long trip time and the intermittent nature of Earth-Mars transfer would favor more permanent, self-sufficient settlements than those on the Moon. Second, Mars may allow for the creation of a habitable environment through terraforming efforts.

From Settlement to Terraforming

The presence of humans on another planet will inevitably alter that world's environment, but this can also be done in a purposeful fashion, resulting in a planet that is capable of supporting a rich biosphere—a process called terraforming. The ultimate motivation for terraforming and for space exploration itself is enhancing the abundance and diversity of life in the universe and enriching the lives of humans. These are goals worthy of an advanced civilization. SEE ALSO COMMUNITIES IN SPACE (VOLUME 4); ENVIRONMENTAL CHANGES (VOLUME 4); HUMAN MISSIONS TO MARS (VOLUME 3); IMPACTS (VOLUME 4); LIVING ON OTHER WORLDS (VOLUME 4); LUNAR BASES (VOLUME 4); LUNAR OUTPOSTS (VOLUME 4); MARS BASES (VOLUME 4); MARS MISSIONS (VOLUME 4); SCIENTIFIC RESEARCH (VOLUME 4); SETTLEMENTS (VOLUME 4); SOCIAL ETHICS (VOLUME 4); SPACE INDUSTRIES (VOLUME 4); SPACE TOURISM, EVOLUTION OF (VOLUME 4); TERRAFORMING (VOLUME 4); TOURISM (VOLUME 1).

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Ehricke, Krafft

Aeronautical Engineer, Physicist, and Author
1917–1984

Krafft A. Ehricke was a rocket pioneer and visionary who made significant contributions to the technology and philosophical basis of space development. Ehricke was born in 1917 in Berlin, Germany. At the age of twelve he founded a rocket society, and he later studied celestial mechanics and nuclear physics at Berlin Technical University. During World War II, Ehricke became a key member of the Peenemuende rocket development team, specializing in the propulsion system for the V-2 rocket. At Peenemuende, he also worked on future space projects and developed theories on human space operations and nuclear propulsion.

After immigrating to the United States in 1947, Ehricke worked for the U.S. Army Ordnance Department, where he pursued the development of ballistic missiles and space vehicles. In the 1950s he joined the General Dynamics Astronautics Division, where he helped develop the Atlas rocket and the Centaur upper stage. Many early U.S. planetary probes were launched using the Centaur, which was the first liquid hydrogen–propelled vehicle. In the 1970s Ehricke led advanced studies at Rockwell International on the use of space for the benefit of humankind and refined ideas for interplanetary travel, manufacturing facilities in space, and mining on the Moon and the other planets. He is remembered for saying, "If God meant us to explore space, he would have given us a moon."

Ehricke died in 1984. He was survived by his wife and three daughters, who founded the nonprofit Krafft A. Ehricke Institute for Space Development in 1985. SEE ALSO Careers in Rocketry (volume 1); Moon (volume 2); Rockets (volume 3); Vehicles (volume 4); von Braun, Wernher (volume 3).

John F. Kross

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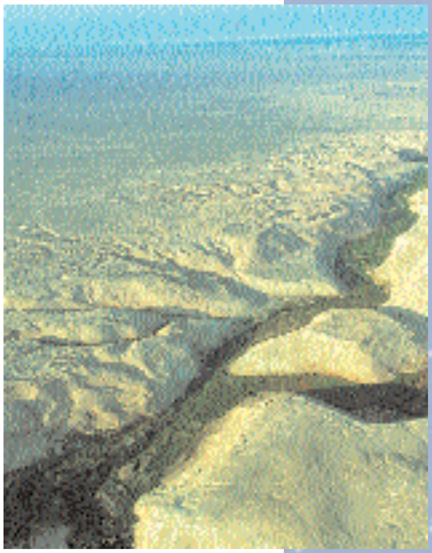
Environmental Changes

There are many causes of environmental changes on Earth. Natural events cause changes in climate. For example, large volcanic eruptions release tiny particles into the atmosphere that block sunlight, resulting in surface cooling that lasts for a few years. Variations in ocean currents such as El Niño can also change the distribution of heat and precipitation. Over longer time spans, tens to hundreds of thousands of years, natural changes in the geographical distribution of energy from the Sun and in the amounts of greenhouse gases and dust in the atmosphere have caused the climate to shift from ice ages to relatively warmer periods. On a longer timescale the presence of life on Earth has changed the environment of the planet radically, transforming a predominantly reducing atmosphere made up of methane and ammonia to today's oxygen-rich gaseous envelope.



Turning deserts into farmland via irrigation is one way humans have significantly changed Earth's environment. This strip of farmland is in the Atacama Desert in Chile.

Human activities can also change the environment. Orbiting satellites have photographed the transformation of deserts into productive agricultural areas. Conversely, satellites have tracked the advance of deserts (desertification) and the loss of forests (deforestation) as a result of human activity. One root cause of desertification and deforestation is the use of wood as the basic source of energy, with the consequent loss of trees and degradation of the soil. The most obvious impact of desertification is the degradation of rangeland and irrigated cropland and the decline in soil fertility and soil structure. Desertification affects about one-sixth of the world's population and affects 70 percent of all dry lands, amounting to 3.6 billion hectares (8.9 billion acres), or one-quarter of the total land area of the world.

The Greenhouse Phenomenon

In addition to desertification, changes caused by human activities include recent increases in the atmospheric concentrations of both greenhouse gases and sulfate particles ("aerosols"). Greenhouse gases such as carbon dioxide cover the atmosphere's "infrared window," and trap heat. Data from satellites can trace changes in the globally averaged surface temperature of Earth and can be used to predict temperature changes in the future. According to some models, if current trends continue, the amount of carbon dioxide in the atmosphere will double during the twenty-first century, and the average rate of warming of Earth's surface over the next hundred years will probably be greater than it was at any time in the last 10,000 years. The current best estimate of the expected rise of globally averaged surface temperature relative to 1990 is 1°C to 3.5°C by the year 2100, with continued increases thereafter.

Because seawater expands when heated and some glacial ice will melt, the global sea level is expected to rise a further 15 to 95 centimeters (6 to 37.5 inches) by 2100 as a result of global warming. Since 1978 satellite technology has been used to monitor the vast Arctic Sea ice cover on a routine basis. More recently, the Topex/Poseidon satellite has been instrumental in observing the global climate interaction between the sea and the atmosphere. In 2001 a joint U.S.–French oceanography mission, Jason 1, was scheduled to be launched to monitor world ocean circulation, study interactions between the oceans and the atmosphere, improve climate predictions, and observe events such as El Niño.

Ozone Depletion

Around 1985 scientists taking ozone (O_3) measurements in the Antarctic detected an alarming decrease in stratospheric ozone concentrations over the South Pole. This decline in atmospheric ozone was verified by instruments aboard the National Aeronautics and Space Administration's (NASA)'s Nimbus-7 satellite. Under usual circumstances **ultraviolet radiation** helps create and destroy ozone molecules. It is strong enough to break both ozone and oxygen molecules into individual oxygen atoms. This destruction of molecules allows the free oxygen atoms to bond with other oxygen molecules and form more ozone. However, chlorofluorocarbon (CFC) compounds such as the freon used in refrigeration systems upset this balance and destroy ozone (CFCs also are greenhouse gases). The depletion of ozone caused by CFCs results in increased ultraviolet radiation at Earth's surface that could be highly damaging to sensitive Arctic life forms. Ozone losses over the Arctic could also reduce ozone levels over the middle latitudes as a result of the mixing of air masses.

ultraviolet radiation electromagnetic radiation with a shorter wavelength and higher energy than light

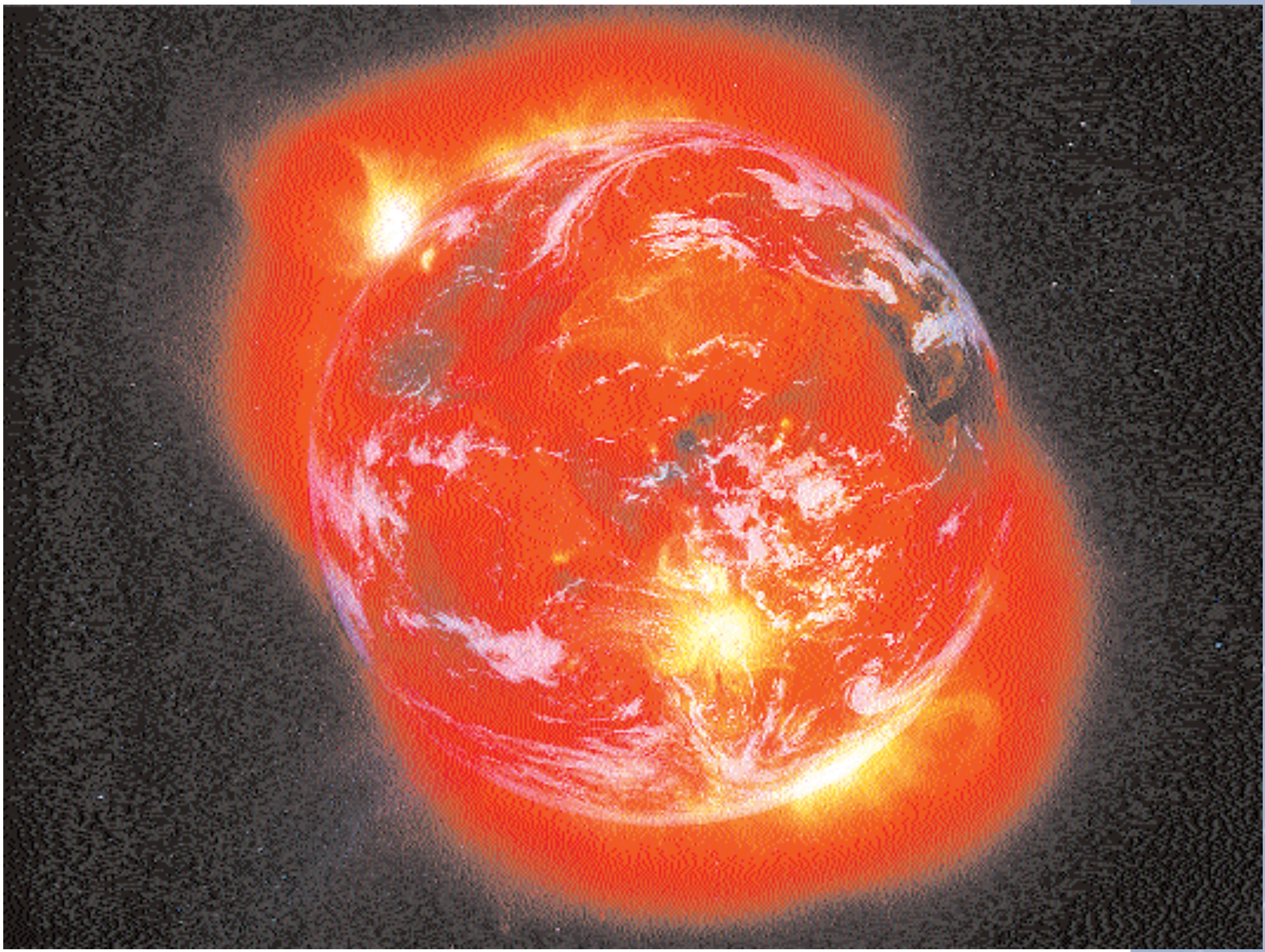
Although some forms of ozone-destroying CFCs have been banned, Arctic ozone depletion might be increased over the next few decades by further accumulations of greenhouse gases in the atmosphere. By trapping more heat near Earth's surface, these gases cause the **stratosphere** to become cooler and produce more stratospheric clouds, which have been implicated in rapid ozone loss.

stratosphere a middle portion of Earth's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

Colonization and Terraforming of Planets

Although human-induced changes to Earth's environment are increasingly apparent, humans have also altered the environment of the Moon and the neighboring planets in very small ways. The footprints left by Apollo astronauts and atmospheric gases released by their landing craft produced infinitesimal alterations in the Moon's environment. Similarly, tire tracks and shallow trenches left on the surface of Mars by landers, such as Pathfinder and Viking, have changed the environment of that planet on a minute scale. However, greater environmental changes are almost inevitable as humans venture into the solar system.

Colonization of other worlds will affect those environments, but humans may also undertake the premeditated terraforming of planets to deliberately make them more Earth-like. Making Mars habitable will in many ways restore that planet's climate of billions of years ago, creating a thick atmosphere and a warm surface with bodies of liquid water. Ironically,



Computer-enhanced image of Earth from space showing global warming "hot spots," with gas plumes at the poles.

greenhouse gases such as carbon dioxide and CFCs, which have undesirable effects on Earth, could be instrumental in terraforming Mars. Some researchers have proposed melting the southern polar ice cap on Mars to release large quantities of carbon dioxide into the atmosphere to heat up the planet. Others have suggested the use of super greenhouse gases for that purpose. Warming the atmosphere by using specially designed CFCs would be desirable and would not cause adverse affects on ozone formation.

Over time, Earth's environment has been changed for the better (e.g., transforming deserts to agricultural areas) and the worse (e.g., the ozone hole, greenhouse warming, desertification, etc.). In the future, the challenge will be to remain aware of the accompanying changes to the environment and responsibly guide and monitor those changes on the home planet and beyond. SEE ALSO Asteroid Mining (volume 4); Living on Other Worlds (volume 4); Natural Resources (volume 4); Planetary Protection (volume 4); Resource Utilization (volume 4); Settlements (volume 4); Terraforming (volume 4).

John F. Kross

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Faster-Than-Light Travel

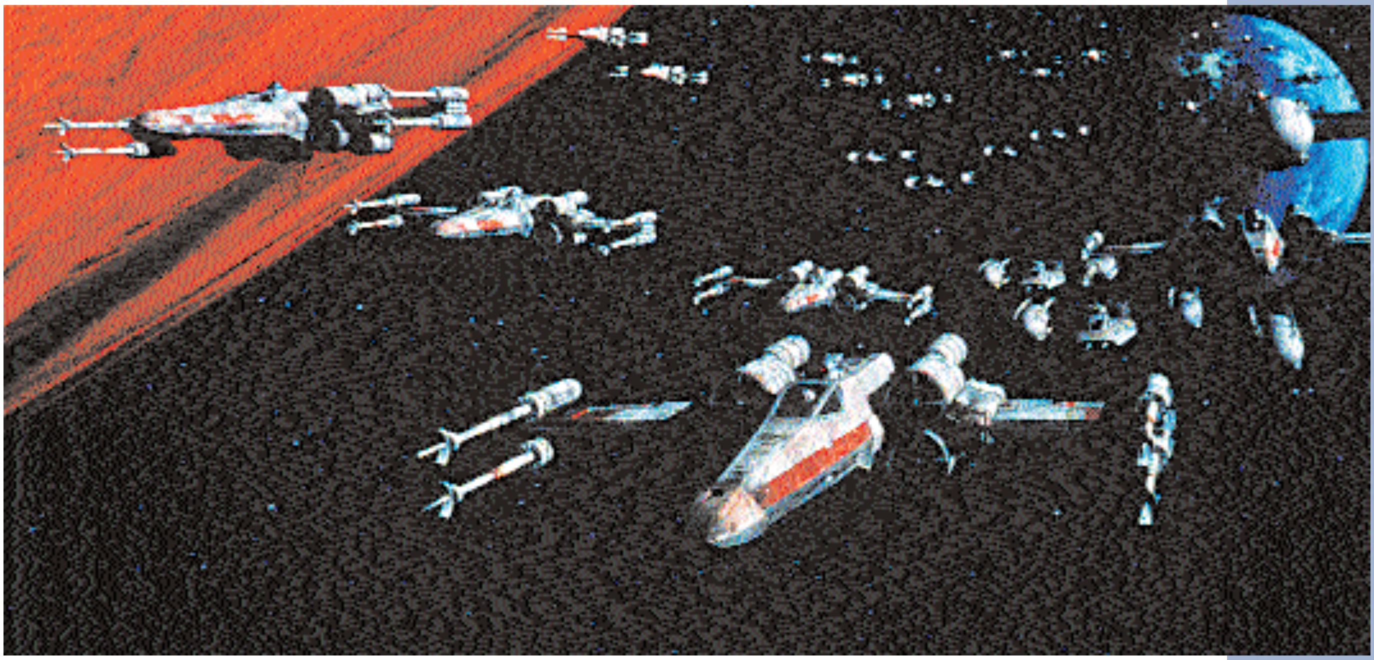
Whether science fiction novels refer to it as warp speed, hyperspeed, or lightspeed, the prospect of traveling at the speed of light or faster has enthralled humanity for decades. The possibility of traveling at speeds millions of times faster than those at which people travel today has been the focus of much debate and research. Faster-than-light travel is necessary for space journeys because of the huge distances between stars and star systems. The nearest star to Earth, not including the Sun, is 4.3 **light-years** away. This means that at the speed of light it would take 4.3 years to get there and 4.3 years to return. The Milky Way Galaxy is more than 100,000 light-years across and is only one galaxy in what is believed to be billions. No human could survive for 100,000 years with current medical techniques, and so faster-than-light propulsion would be necessary to make such a trip.

light year the distance that light in a vacuum would travel in one year (about 5.9 trillion miles [9.5 trillion kilometers])

The science of faster-than-light travel is based on the equation $E = mc^2$ determined by physicist Albert Einstein. According to this equation, energy (e) is equal to mass (m) multiplied by the speed of light (c) squared, meaning that energy and matter can be converted from one to the other. A major tenet of physics is that matter can neither be created nor destroyed. Nuclear explosions are a prime example of matter being converted into energy. Amazingly, however, atomic weapons have a very low rate of matter-to-energy conversion.

Using this equation, one can see the near impossibility of faster-than-light travel with today's technology. To travel in a ship at that speed or faster requires a great deal of energy. But according to Einstein's special theory of relativity equation, mass will increase as an object goes faster. As one approaches the speed of light, one will become so heavy that no fuel will be able to propel the ship fast enough to keep up. That rapid increase in mass prevents faster-than-light travel for humans aboard starships today, yet research is under way to determine ways to get around this limitation.

Small subatomic particles such as photons, particles of light, and hypothetical particles called tachyons—faster-than-light travelers with no mass—seem to have no problem reaching lightspeed. In fact, tachyons are widely believed to be a science fiction concept because it would take an infinite amount of energy to *slow down* a tachyon to the speed of light. Whether or not tachyons exist, the ability of particles to travel at higher speeds has not gone unnoticed by scientists. If a bubble could be created around a space-



Space travel in science fiction, like in the movie *Star Wars,* depends on the ability to move at speeds millions of times faster than possible in reality.

ship, it is hoped that the weight of the object could be lowered while its speed increased. SEE ALSO Accessing Space (volume 1); Antimatter Propulsion (volume 4); Interstellar Travel (volume 4); Laser Propulsion (volume 4); Power, Methods of Generating (volume 4); Science Fiction (volume 4); Vehicles (volume 4).

Craig Samuels

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First Contact

Over a century ago, the astronomer Percival Lowell thought that he had glimpsed artificial canals on Mars and the radio pioneer Nikola Tesla believed that he had intercepted a Martian radio broadcast. Later attempts to signal Mars by means of huge bonfires and powerful radio broadcasts proved unsuccessful. Today people realize that although remnants of microbial life

We do not know if and how we will first discover extraterrestrial intelligence, but most scientists do not expect it to happen quite like it does in the movie, *E.T. The Extra-terrestrial* (1982).

may exist within the solar system, the search for extraterrestrial intelligence (SETI) must extend to distant stars.

Search Strategies

Microwave SETI, which uses radio telescopes, was popularized in Carl Sagan's novel *Contact* (1985) and in the 1997 Jodie Foster movie of the same name. Dish antennas collect faint microwaves that are fed into receivers that scan billions of channels simultaneously. Computers flag the signals that merit a closer look. Some astronomers have employed optical SETI and use optical telescopes fitted with special devices to hunt for flashes from extraterrestrial lasers pointed toward Earth. There are other search strategies, but because these two are in widespread use, they have the greatest chance of success. Most likely, first contact will involve intercepting a faint signal from a civilization many light-years away.

Initial Reactions

So many people have become used to the idea that "we are not alone" that intercepting a signal from another solar system is unlikely to cause widespread psychological meltdown or social collapse. Indeed, when a prankster convinced the media that a microwave search had located ET, the public was not upset. An authenticated discovery would prove that humans are the product of processes that are not limited to Earth. Scientists estimate that the average extraterrestrial civilization could be about a billion years older than that on Earth. Finding such an old-timer would prove that civilizations can survive population growth, resource depletion, atomic warfare, and other threats. This would renew hope for the future of human society.

What We Might Learn

In light of the likely differences between two civilizations that are located in different parts of the galactic neighborhood, those civilizations may have trouble recognizing each other, let alone communicating. Still, an ancient civilization may have solved the problem of communicating with a civilization such as Earth's, or after years of research, humans may learn to communicate with creatures that are not from around here. Our reactions will be shaped by our impressions of the alien civilization's capabilities, intentions, and desire to travel to Earth. These reactions will depend on our expectations, whether the discovery occurs during a time of peace or war, how the media handle the story, as well as other considerations.

Most discussions of first contact are optimistic and suggest benefits for humankind. Earth's new acquaintances might share practical ways to solve energy needs, cure illnesses, and eliminate crime. Their advanced ideas could have a deep and lasting impact on our philosophy, science, religion, and the arts. Learning about their ways could transform the way people think about themselves and prompt humans to redefine their place in the universe. Of course, contact may never occur or may proceed in a less pleasant way. If generations of searches fail, people will come to grips with the reality that humans are alone. Perhaps in the very distant future, as an advanced spacefaring civilization, humankind will fill the universe with intelligent life. SEE ALSO LIFE IN THE UNIVERSE, SEARCH FOR (VOLUME 2); SETI (VOLUME 2).

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Food Production

Space explorers and settlers who are far from the farms and fields of Earth will need a reliable way to produce food. A continuous supply of nutritious, safe, and appealing food is essential for people who are living and working under unusual conditions that require peak physical condition. Food also plays an important role in the psychological welfare of crewmembers by providing familiarity and variety in the diet. The ability to continually produce food is an important element of long-term survival in space that cannot be accomplished by physical or chemical means. Food will have to be grown as quickly, reliably and efficiently as possible.

Methods of Production

Astronauts on long-duration space missions or settlers on other planets will have to maintain crops in growth chambers protected from the outside environment, but they will still need to supply adequate lighting, nutrients, and a suitable atmosphere. Natural sunlight in transparent greenhouses or artificial lights could satisfy the lighting requirement, but there are tradeoffs. On Mars, for example, sunlight is available for only half of each Martian day,

In space, plant growth requires a controlled, closed environment, and the output emissions of the light emitting diode are conducive with high rates of plant photosynthesis.

hydroponics growing plants using water and nutrients in solution instead of soil as the root medium

porous allowing the passage of a fluid or gas through holes or passages in the substance

regolith upper few meters of a body's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

and more light is required for optimal growth of many plant species. In addition, the Sun can be obscured for months by giant dust storms. Higher radiation doses and possible damage from meteoroid impacts are other dangers. On the other hand, artificial lighting systems would be costly to transport and may require a great deal of energy.

Nutrients could be provided to crops by a form of **hydroponics**, with the roots in contact with a thin film of liquid or a **porous** material such as vermiculite. Alternatively, the surface **regolith** of the Moon or Mars could be used as soil after any hypersalinity or toxic materials are washed out. Organic wastes and microbial soil communities could be added to the regolith to render it closer to the fertile soil found on Earth. On-site resources could also be processed to provide air and water for growing crops. On Mars, water can be extracted from the regolith and condensed from the atmosphere. Carbon dioxide could be taken directly from the Martian atmosphere. Atmospheric nitrogen could also be extracted and reacted with hydrogen to produce ammonia for fertilizers. Nitrogen-fixing microorganisms could be added to the soil to chemically alter this gas into a form usable by the plants.

What Kinds of Food Would Be Produced?

Foods produced in space will be carefully balanced for caloric content, nutritional quality, and palatability. Some plants may be genetically modified to alter or enhance their nutrient composition, and efforts will need to be made to optimize conditions for plant growth. Processing will also be required to convert crops into palatable, safe, and satisfying foods. In addition, processing will be needed to preserve food for storage in case of crop failure. The chosen foodstuffs will have to be versatile and capable of being converted into different types of foods. For example, soybeans can be pressed to release oils, and the remaining high-protein soybean meal can be manipulated to provide different foodstuffs. Soy milk can be used in place of cow's milk or can be used to make curd in the form of tofu or tempeh.

Adding different plant food will enhance the palatability of the diet. For example, various brassicas (similar to wild mustard) produce oils similar in quality to that of canola, and peanuts have an interesting flavor. Black-eyed peas are a good low-fat complement to oily legumes such as soybeans and peanuts. Besides being heat and drought tolerant, cowpeas are a staple crop eaten in Africa as a dry bean, snap bean, or raw salad green. In addition, their low oil content allows cowpea meal to be incorporated into formed or extruded vegetarian food products.

Rice is an excellent cereal crop to complement protein from legumes in a balanced vegetarian diet. Rice protein is tolerated by virtually all people, and it is more versatile than most other cereal grains. Wheat in the form of breads and pastas is a very important and common foodstuff in many cultures. In addition, the plants can be grown in high density, and the grain is very versatile. Potatoes, whether white or sweet, can make good and hearty additions to the diet. Much of the potato plant is edible, and the tubers are versatile and consumed throughout the world. Other crops such as tomatoes and lettuce may also be grown. Tomatoes can be used in stews, sauces, and salads, while lettuce makes good salad greens and can be grown efficiently. Spices and herbs will surely be grown to make the diet seem more varied, and hot peppers could enrich mealtime. Apples, oranges, and other fruits, however, will probably be rare because many fruits grow on bushes or trees that use space inefficiently and are comparatively nonproductive relative to the resources required for cultivation.

Other Uses for Plant Material

Despite efforts to maximize crop yields, about half of the plant material produced cannot be digested by humans. However, indigestible cellulose can be converted into sugars for use as food or as nutrients to grow yeasts, fungi, or plant **cell cultures**. Cellulose-digesting animals could also be raised on a small scale. While they would not be raised primarily for food, animals could on occasion provide high-quality protein and would make creating a balanced diet easier. At the other end of the spectrum, "microbial crops"

cell culture a means of growing mammalian (including human) cells in the research laboratory under defined experimental conditions

algae simple photosynthetic organisms, often aquatic

could be good source of single-cell protein. For example, brewer's yeast and **algae** could be used as a dietary supplement, and green algae are a good source of protein as well as essential fatty acids and vitamins. In addition, algae can help provide oxygen to the atmosphere. Although not suitable as the only source of food, algae could be grown very quickly in an emergency and provide needed sustenance for the crew. SEE ALSO BIOTECHNOLOGY (VOLUME 4); FOOD (VOLUME 3); LIVING ON OTHER WORLDS (VOLUME 4).

John F. Kross

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G

Glaser, Peter

Mechanical Engineer and Space Technology Pioneer
1923–

Peter E. Glaser conceived the solar power satellite as a means of capturing solar energy in space for transmission to Earth. In the next few decades this concept may be implemented as part of the solution to the pressing human need for more and cleaner energy.

Glaser was born September 5, 1923, in Zatec, Czechoslovakia. He moved to the United States in 1948 and went on to earn both his master's of science and doctoral degrees from Columbia University in New York City. In addition to his seminal role as inventor of the solar power satellite, Glaser has made many outstanding contributions to space technology during his illustrious career. Until retirement in 1994, Glaser led advanced technology work at Arthur D. Little, Inc. His wide-ranging interests included thermal protection systems, lunar surface properties, lunar laser ranging, and space solar power systems. He directed studies for the National Aeronautics and Space Administration (NASA) and the U.S. Department of Energy, served on several NASA task forces, and testified on numerous occasions before committees of the U.S. Congress.

Glaser has more than 150 publications, books, and patents. He served as president of the International Solar Energy Society and as editor in chief of the *Journal of Solar Energy.* He founded the Sunsat Energy Council in 1978 and was its president until 1994. He is currently the council's chairman emeritus. Glaser has been a prominent member of leading professional organizations in science, technology, and astronautics and has been the recipient of numerous awards and honors, including the Space Technology Hall of Fame in the United States Space Foundation. SEE ALSO Solar Power Systems (volume 4).

R. Bryan Erb

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Governance

The idea of governance within space, on planets, or in space stations has raised many questions. For example, would the laws of the launching country apply in settling a legal matter that occurred in outer space, or would only the laws adopted independently by the space settlement be valid? And, if more than one country sponsored the expedition, which country's laws would be binding and who would enforce these laws? Furthermore, is it realistic to expect space settlers to defer to the authority of a country that it may take months to reach by space travel? These are only a few of the questions that the concept of space governance generates.

Political Philosophies and Self-Governance

Because of Earth's problematic history with colonization it is thought that some degree of self-governance would likely be suitable for space settlements. The following political philosophies demonstrate the broad spectrum of views as related to self-governance.

Libertarian. Libertarians believe in self-governance as related to both personal and economic issues. According to libertarians, the government's only role is to provide protection from coercion and violence. Libertarians value self-responsibility and tolerance of diversity.

The Libertarian view assumes a high level of individually motivated honest behavior. There is no strong deterrence to criminal activity apart from contending with one's own conscience. But the Libertarian approach could potentially find acceptance in space settlements where populations will initially be small and the degree of self-responsibility high.

Left-Liberal. The political philosophy of Left-liberals is self-governance in personal matters accompanied by a mechanism for central government to make decisions on economic issues. Among Left-liberals, there is a strong agenda to have government provide for the needs of the disadvantaged. Left-liberals would likely allow self-governance in space to the extent that government sponsored social programs could still be financed.

Centrist. Centrists support government intervention on some issues but stress pragmatic solutions to social problems. Centrists would probably see self-governance as a practical strategy to governing small space settlements but would defer to more government intervention as the settlements grew and public problems increased.

Conservative. Right-conservatives have essentially the opposite philosophy of Left-liberals. Right-conservatives want people to exercise self-governance when it comes to economic issues, but still want the government to protect society from threats to morality.

The current fiscal situation for many space expeditions and settlements involves a hefty price tag. It takes large groups, either private or public to plan and implement projects such as the settlement of Mars. Therefore, the Right-conservative desire for self-governance in economic matters may not be compatible with the high expenditures that would accompany space colonization. At some point in the future, conservative religious groups may seek to advance their moral agenda through space settlement, as did religious groups such as the Puritans and Quakers of colonial America.

Authoritarian. Authoritarians do not see self-governance as a practical alternative, as they would prefer that the government foster advances to humankind by central planning. Left-authoritarians are also referred to as socialists, Right-authoritarians as fascists.

An authoritarian approach to space government would involve either deference to a political government on Earth (i.e., no self-governance) or the establishment of a central government power in outer space. Resource concerns would apply to the latter because a dedicated central government in space would add to the costs of the space settlement.

Free-Governance in Outer Space as Compared to Governments Used in Colonized Countries

We can look to history to learn how colonization has been handled, at what point power may have shifted from a distant sovereignty to governance by the occupants of the territory, and what the implications are for the colonization of space. At this time we do not have any indigenous, or pre-existing populations on other planets, so at least for now the topic of governance in space refers to the legal issues of persons coming from Earth. Maybe at a future time settlers from Earth will become the indigenous population of a space settlement in free space or of a planet.

Settlement Colonization. The original European colonies in the Americas were treated as the property of each respective colonizing European country (Great Britain, Spain, France). Laws were changed, as they would likewise need to be changed in space environments, to take account of special environmental conditions. Generally, however, colonists maintained whatever legal and political rights they had possessed in the colonizing country. This resulted in the colonial governments and laws differing greatly in the Americas, as they did between countries in Europe. Space governance may also differ between space settlements and levels of self-governance are likely to also vary.

Because Great Britain had a representative parliament and a monarchy with limited authority, settlement colonies adopted cabinet governments, and after 1931 became sovereign states, keeping only an allegiance to the crown. Likewise, in the realm of space governance, allegiance to original colonizing countries is likely to exist as well as a certain degree of representation in a legislative body. Perhaps a representative from a space settlement will hold a seat in a national or international legislative body on Earth and will participate in hearings remotely.

Natural conditions may modify laws in space. For example, the remoteness created by the Atlantic and consequently, the length of time it took to transmit communications, made control of Great Britain's colonies in America impractical. The setting produced a tough individualism with inhabitants making their own decisions. Government reached the frontier only gradually, and conditions of anarchy often prevailed. A rugged individualism like in the pioneer days of America could also happen in space. Technology exists to maintain communications, but there may be issues of enforcement because travel takes months to maybe years to accomplish. SEE ALSO Communications, Future Needs in (volume 4); Interplanetary Internet (volume 4); Living on Other Worlds (volume 4); Political Systems (volume 4); Social Ethics (volume 4).

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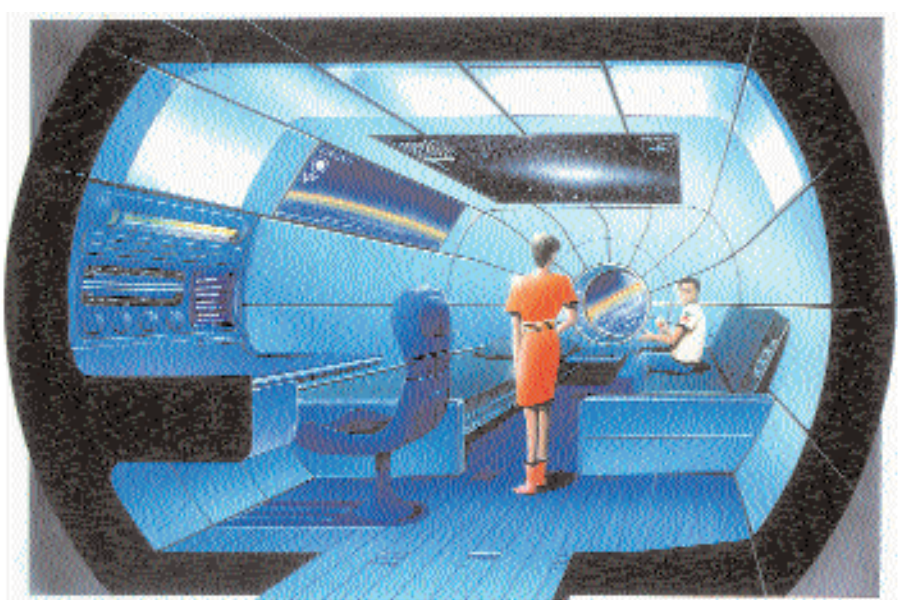
Hotels

For the general public, the concept of space tourism continues to be an exciting dream. The first stage of space tourism would consist of very simple low-Earth orbit treks: tourists would orbit Earth several times on a spaceship and then return to the planet in a one-day tour. Even these short tours would be sufficiently adventurous to attract many civilian space travelers in the near future.

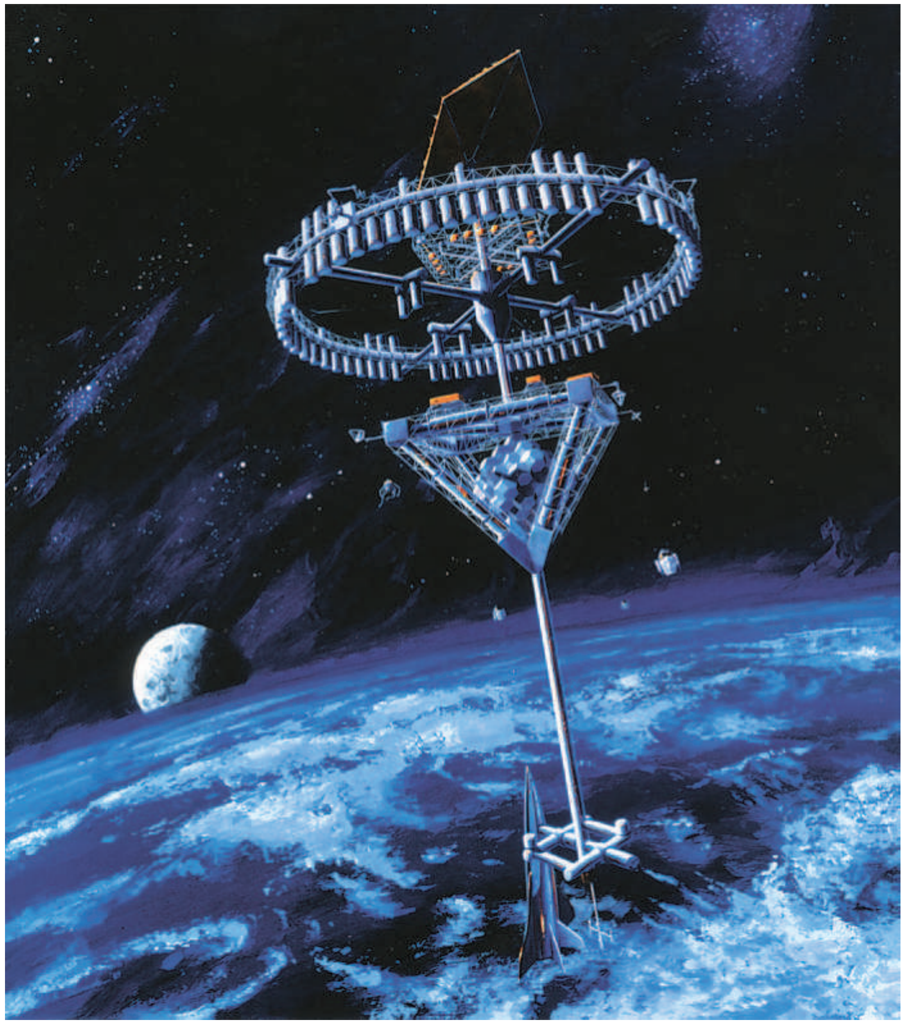
The next phase of orbital tourism would consist of "space stays" of one or two nights. If people could reside in space for two or three days, public travel above Earth would be much more enjoyable. Space tourists would then be able to watch Earth, the Moon, and the stars for long periods. It would be possible to produce many interesting materials in **microgravity**,

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface



The interior design of a proposed guest room of a space hotel.

An artist's depiction of a space hotel in low Earth orbit.



some of which would be very valuable souvenirs from space. Also, it would be possible for tourists to have many kinds of interesting physical experiences in microgravity.

For people to stay in space for two or three days, "space cottages" would be essential. Those cottages would be small but would have to have minimum habitation systems for hygiene, dining, and sleeping, among other functions. One interesting proposal is the use of the habitation module of the International Space Station to provide room for space tourists after the station's formal planned mission has ended.

Eventually larger space hotels that would have many more functions for enjoying hotel life like those found in terrestrial resorts would be constructed. The accompanying picture shows an example of a space hotel of the future designed by Shimizu Corporation more than ten years ago.

The space hotel shown above has sixty-four guest rooms and a microgravity hall. All of the guest rooms are located on a circle with a radius of 70 meters (230 feet) that rotates three times a minute to produce 0.7 G artificial gravity. Therefore, in a guest room a hotel guest could stand, walk, and sleep normally. The figure on page 51 shows the interior design of a guest room. In the microgravity hall a guest could enjoy an environment in which it is possible to eat, drink, and play. In the future, space resorts will inspire the creation of many appealing microgravity games. SEE ALSO HABITATS (VOLUME 3); LIVING IN SPACE (VOLUME 3); SPACE TOURISM, EVOLUTION OF (VOLUME 4); TOURISM (VOLUME 1).

Shinji Matsumoto

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Impacts

I

Earth's surface undergoes many kinds of environmental changes that affect human life and the evolution of all living things. Some are caused by human beings, and others result from natural processes; some evolve slowly, whereas others are sudden: "accidents" (if caused by humans) and "natural disasters." Since life can adapt to slow changes, the most disruptive changes are sudden calamities. The worst calamity occurs when a large, errant asteroid or comet collides with Earth.

Sizes of Near-Earth Objects

Fragments of asteroids and comets pervade interplanetary space. Modest cosmic impacts occur all the time. On a dark, clear night one can see a flash of light (a meteor or "shooting star") every few minutes as an interplanetary grain of dust or sand strikes Earth's upper atmosphere. More rarely, larger space rocks cause brilliant "fireballs" when they crash to Earth, perhaps leaving **meteorites** in the ground. Every few years, Earth-orbiting surveillance satellites record multi-kiloton upper atmospheric explosions when a house-size cosmic object impacts. This happened over the Yukon Territory in January 2000, lighting up the night sky ten times more brilliantly than full daylight.

meteorite any part of a meteoroid that survives passage through Earth's atmosphere

Objects 50 meters (164 feet) across strike Earth every few centuries, causing airbursts that rival the effects of large thermonuclear bombs. The last one exploded over the Tunguska region of Siberia in 1908, toppling trees over a region the size of Washington, D.C. A similar-sized object composed of solid metal rather than rock struck northern Arizona about 50,000 years ago, forming Meteor Crater.*

***An image of Meteor Crater can be found in the volume 2 article "Meteorites."**

Far larger asteroids and comets can strike Earth. About 1,000 asteroids larger than 1 kilometer (0.62 mile) in diameter approach within 45 million kilometers (28 million miles) of Earth; any one of these near-Earth asteroids (NEAs) could impact Earth in the next few million years. Most will crash into the Sun, strike another planet, or be flung by Jupiter's gravity into interstellar space. But every 100,000 years or so a kilometer-sized NEA does crash into Earth, exploding with a force approaching 100,000 megatons—more powerful than all the world's nuclear bombs together.

A few NEAs are much larger than 1 kilometer (0.62 mile). Eros, which was visited by the NEAR Shoemaker spacecraft in the year 2000, is 34 kilometers (21 miles) long. Studies of its orbital path show that Eros cannot hit Earth in the near future, but millions of years from now there is a 5 percent chance that Eros will crash into Earth; the devastation would greatly exceed the impact 65 million years ago of a 10- to-15 kilometer (6 to 9 miles)

A small asteroid hitting an ocean on Earth would cause little damage, but one measuring 200 meters across could cause cataclysmic floods.

diameter asteroid or comet that caused 70 percent of all species of plants and animals recognized in Cretaceous fossil beds to suddenly go extinct, including dinosaurs.

Even larger calamities happened early in the planet's history as life tried to gain a foothold on Earth. The circular dark patches on the full Moon are great circular impact basins formed when 100-kilometer-size (60 miles) **planetesimals** struck the Moon 3.9 to 4.2 billion years ago. Earth is a larger target than the Moon; it was surely bombarded by such projectiles during that epoch. It is unlikely but possible that Earth will be struck by such a large object again. If this were to occur, it could sterilize the world of all life. In 1997 Comet Hale-Bopp came inside Earth's orbit; its diameter was 25 to 70 kilometers (15 to 45 miles).

planetesimals objects in the early solar system that were the size of large asteroids or small moons, large enough to begin to gravitationally influence each other

Risks and Consequences

Impacts do not happen regularly. Earth is in an essentially random, cosmic shooting gallery. Kilometer-size asteroids impact every 100,000 years "on

Nearly five decades after a meteorite struck Siberia near Tunguska, Russia, in 1908, the destruction was still evident.

average." However, that means there is a 1 in 100,000 chance that one will hit "next year," or a 0.1 percent chance during the twenty-first century. A much larger, mass extinction impact is a thousand times less likely than a 1-kilometer (0.62-mile) NEA impact, but even that is not inconceivable in the very near future.

The consequences of impacts vary enormously, depending on the size and **velocity** of the impacting bodies. A Tunguska-like event, which happens somewhere on Earth every few centuries, could happen in the next fifty years. If it exploded unexpectedly over a major city, it would be a catastrophe in which hundreds of thousands might die. However, only a tiny fraction of Earth's surface has urban population densities. A sparsely populated area is a more likely target, such as Tunguska, where only one or two people may have been killed. Even more likely, the explosion would happen harmlessly over an ocean.

velocity speed and direction of a moving object; a vector quantity

A larger body, perhaps 200 meters (124 miles) in diameter, would be catastrophic no matter where it struck. It would certainly penetrate the atmosphere and strike land or water. Indeed, impact into the ocean would be devastating, generating a tsunami (tidal wave) larger than any ever recorded. Such an event might account for some flood myths from ancient times. Astronomers have discovered and tracked only a small fraction of these comparatively small asteroids, and so an impact like this (about a 1 percent chance of happening in this century) probably would occur without warning. Tsunami-warning systems most likely would be ineffective in alerting people to evacuate to high ground. Massive destruction of property along the shores of the impacted ocean would be certain, with an enormous death toll. A similar impact on land would form a crater far larger than Meteor Crater, but the death and destruction would be restricted to within a couple hundred kilometers of ground zero.

As frightening as impacts by bodies tens to hundreds of meters in size are to contemplate, more usual natural catastrophes capable of killing just as many people happen 100 times as often. During the twentieth century a dozen natural catastrophes (floods, earthquakes, and the like) each killed between 100,000 and 2 million people. Thus, these "smaller" impacts represent only about 1 percent of the danger.

Impacts by comets and asteroids over 2 kilometers (1.24 miles) in diameter have consequences that exceed those of a nuclear war. There are upper limits to the effects of earthquakes, storms, floods, and exploding volcanoes, which are restricted to localities or regions of the planet. A 2-kilometer (1.24-mile) asteroid, however, would throw enormous quantities of dust and aerosols high in the **stratosphere**, darkening the Sun, leading to the failure of global agriculture for a year or more, and resulting in mass starvation. A billion people might die, and civilization would be threatened. Such impacts are rare, having 1 chance in 10,000 of happening in this century. However, the consequences would be enormous, including possible permanent loss of the accomplishments of modern civilization, and the quantitative risk to human life ranks with other hazards (such as airline safety) that society takes seriously.

stratosphere a middle portion of Earth's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

Mitigation

The impact hazard has a hopeful feature: Human beings (unlike dinosaurs) could avert such a catastrophe if it were about to happen. Less than half of the 1- to 2-kilometer (0.62 to 1.24 miles) NEAs have been discovered, and so one could strike without warning. However, an international astronomical program (so far based mostly in the United States) called the Spaceguard Survey employs modest-size wide-field telescopes equipped with charge-coupled devices to search the skies for NEAs larger than about 1 kilometer (0.62 mile). Within less than a decade the paths of about 90 percent of these NEAs will have been charted and it will be known whether one is headed toward Earth in the next decades. A few NEAs will remain undiscovered, and comets from beyond Neptune's orbit will continue to arrive in the inner solar system with only months of advance warning. Thus, there will always be a small chance that humankind will be caught unprepared.

However, current space technology could in principle save the world from an impact catastrophe. Depending on the warning time and the size of the threatening body, several low-thrust propulsion technologies could be used to nudge the object away from its Earth-targeted trajectory. These schemes include solar sails, ion drives, mass drivers, and chemical **rockets**. If the warning time were too short or the object too large, nuclear bombs might be required. Specific engineering designs for these technologies (for example, how to couple the devices to the surface of the NEA) have not been worked out. However, there probably would be enough time to study the body and work out the engineering. Care would have to be taken to deflect the body intact rather than break it into pieces because a swarm of fragments might be more destructive than a single object.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

National and international agencies and governments are starting to listen to astronomers, who have been trying to raise the awareness of politicians and emergency management agencies to the impact hazard. However, apart from the modest ground-based Spaceguard Survey, little official action or coordination has been undertaken. Comets and small asteroids are being missed in the Spaceguard census, and the major space and military agencies have paid little attention to the impact hazard. Also, there has been no contingency planning by emergency managers to store food supplies or evacuate people from ground zero in the event of a threatening body. This lack of action represents an implicit political decision to largely ignore the unlikely threats from space in favor of dealing with more near-term issues. SEE ALSO Asteroids (Volume 2); Close Encounters (Volume 2); Comets (Volume 2); Environmental Changes (Volume 4); Meteorites (Volume 2); Movies (Volume 4).

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International Regimes *See Governance (Volume 4); Political Systems (Volume 4).*

Interplanetary Internet

Imagine a future in which human intelligence is scattered all over the solar system. That intelligence may take the form of incredibly capable robots that allow us to be "telepresent" in remote parts of the solar system without ever leaving Earth, or perhaps remote space outposts on the Moon or Mars where human beings are learning to live on other worlds. In some of these places there may be thousands or millions of intelligent systems that need to exchange information not only with other intelligence on Earth but also among themselves. How would such communication occur, and how would it differ from the information transfer across the terrestrial Internet that we know so well?

We are all familiar with the explosive growth of the Internet, and the way in which it has entered our daily lives. We log on and expect to instantly access information from all over the world. This is enabled by a vast global network of computers that exchanges information over high-speed communications links. They do this by formatting messages to each other according to highly structured rules or protocols, much the same way that humans talk to each other using highly structured language. Supporting every web page download, every electronic-mail (e-mail) message, and every piece of streaming audio are dozens of computers that are chatting back and forth with each other in the background in order to transfer messages from the source to the destination. They accomplish this by breaking the messages themselves up into little “packets” of data that are routed over the Internet. This “chatty” computer dialog is very similar to a telephone call, where two people are simultaneously online and conducting a conversation.

But what happens when we try to extend the scope of the Internet into space? On Earth, electronic signals zip around the Internet at the speed of light with negligible delay and almost no errors because the distances are short and it is easy to provide strong signals. But as one ventures farther into space the distances become large and delays and errors are introduced. It would be very difficult to conduct a phone call between Earth and the Moon, where it may take five seconds for a signal to make the round-trip. At Mars, where the delay may easily be half an hour, it would be impossible. Furthermore, a continuous connection between Earth and a remote space location is very hard to provide—the radio links are noisy and prone to errors, spacecraft disappear behind the Sun for days on end, planets rotate, and spacecraft on and around them can only occasionally see Earth. The whole nature of communications changes—no longer chatty, with lots of instant feedback, but far more like the letter writing days of the Victorian era in the nineteenth century.

So will we ever be able to talk to other planets using the Internet? The answer is yes, and a small team of engineers at the California Institute of Technology’s Jet Propulsion Laboratory in Pasadena, California—the National Aeronautics and Space Administration’s lead center for deep-space exploration—is making it happen. New communications protocols are under development that form messages into autonomous “bundles” of information—much like letters or e-mail—that will allow human or robotic users all over the solar system to exchange information across the vast and hostile distances of space even though they may never be simultaneously connected. Deployment of these new capabilities will begin during the period of intensive Mars exploration in the early twenty-first century. The Interplanetary Internet is just around the corner. SEE ALSO Communications, Future Needs in (volume 4); Living on Other Worlds (volume 4); O’Neill Colonies (volume 4); Settlements (volume 4); Space Stations of the Future (volume 4); Telepresence (volume 4).

Adrian J. Hooke

Internet Resources

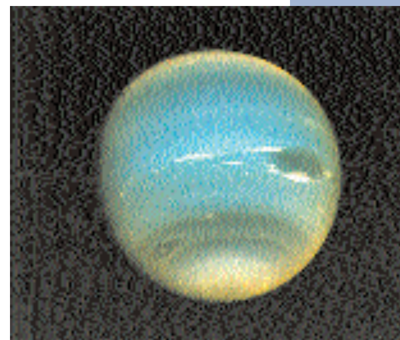
InterPlaNet. <http://www.ipnsig.org>.

Interstellar Travel

Fast, routine travel from one star to another has long been a staple of science fiction. However, interstellar travel would be extremely difficult with current technologies because of the tremendous distances to even the nearest stars, the amount of energy required, and the constraints imposed by the laws of physics. Although there are no specific plans in place for interstellar missions, and there are only a few spacecraft that are heading into interstellar space, a number of concepts for human and robotic spacecraft that could travel from this solar system to another star have been developed.

Challenges

The greatest challenge of interstellar travel is the enormous distances between stars. Proxima Centauri, the nearest star to the Sun, is about 4.2 **light-years** away, more than 9,000 times the distance between Earth and Neptune. Voyager 2 took twelve years to travel to Neptune, but at the same speed it would take a spacecraft over 100,000 years to reach Proxima Centauri. However, accelerating spacecraft to speeds that would allow them to reach the stars in decades, let alone years, requires energy levels far beyond the capabilities of chemical propulsion systems today.



It took Voyager 2 twelve years to travel from Earth to Neptune (pictured). Current technology does not allow for the speeds needed for travel to other stars and galaxies.

light year distance that light in a vacuum would travel in one year (about 5.9 trillion miles [9.5 trillion kilometers])

kinetic energy the energy an object has due to its motion

Travel at high speeds presents several challenges. At extremely high velocities even tiny objects have large amounts of **kinetic energy**. A collision with a speck of dust could be powerful enough to destroy a spacecraft traveling at a significant fraction of the speed of light if the spacecraft is not properly shielded. Relativistic effects also become significant as a spacecraft approaches the speed of light, causing time dilation as well as increasing the mass of the spacecraft.

Regardless of the energy available to accelerate a spacecraft, the speed of light remains the ultimate speed limit that no spacecraft can surpass, according to modern physics. Barring major innovations in physics, it will require years, if not decades, to travel from one star to another. This requires that interstellar spacecraft be able to work for long periods of time, far longer than the short-duration missions common for spacecraft today. Human interstellar missions may require suspended animation or the development of "generation ships," in which the descendants of the original crew members will arrive at the destination.

Interstellar Propulsion Technologies

Because current chemical propulsion systems are inadequate, scientists have turned their attention to a number of other means to propel spacecraft at the speeds necessary for interstellar travel. Although the technologies needed to make these spacecraft a reality do not exist yet, they are based on well-known laws of physics.

One of the first realistic designs for an interstellar spacecraft was Orion, whose design dates back to the 1950s. Orion would work by ejecting nuclear bombs out the rear of the spacecraft at a rate of five bombs per second. The bombs would explode and push against a shock plate attached to the rear of the spacecraft, accelerating the vehicle. Orion was originally designed as an interplanetary spacecraft for missions to the Moon or Mars, but the design was adapted for interstellar travel. However, the use of such a spacecraft would violate existing treaties that forbid nuclear explosions in space.

The British Interplanetary Society revisited the Orion concept and refined it, creating an interstellar spacecraft design called Daedalus. Daedalus would generate thrust through small **fusion** explosions, using hydrogen scooped up from Jupiter's atmosphere before leaving the solar system. The force of the explosions would be channeled out of the spacecraft through the use of magnetic fields. The spacecraft would be able to reach Barnard's Star, about 6 light-years away, in fifty years.

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

Both Orion and Daedalus require the spacecraft to carry all the fuel needed to cross interstellar distances, a significant fraction of the mass of the vehicle. An alternative proposal, the Bussard Interstellar Ramjet, would circumvent this problem by using the trace amounts of hydrogen in interstellar space. A laser on the front of the spacecraft would fire ahead to ionize hydrogen atoms, which would be scooped into the spacecraft by means of magnetic fields. The hydrogen would then be used in the vehicle's fusion engine to generate thrust. The spacecraft would have to go at least 6 percent of the speed of light for the ramjet to work; to reach this speed, the spacecraft would have to carry some hydrogen of its own. There are a number of potential problems with this concept, including how effectively the ramjet could scoop up hydrogen without slowing down the spacecraft as a result of magnetic field drag. Another major problem is the fact that there are currently no fusion engines.

Another alternative is the use of lasers to propel spacecraft. An interstellar laser sail proposed by scientist Robert Forward would shine an Earth-based laser on a sail attached to a spacecraft, accelerating the craft out of the solar system and towards another star. Forward's original proposal would use a 10-million-gigawatt laser shining on a 1,000-kilometer (62,000 miles) sail attached to a 1,000-ton spacecraft, sending the craft to Alpha Centauri in just ten years. However, the laser would be thousands of times stronger than all of the power used on Earth today, and so Forward revised the concept to use a 10-gigawatt laser on a 16-gram (0.57-ounce), 1-kilometer (0.62-mile) sail embedded with sensors to make observations as it flew by another star.

The best systems for interstellar travel, however, may come from aspects of physics that are not yet known. The National Aeronautics and Space Administration has funded a small project called Breakthrough Propulsion Physics that supports researchers looking into new concepts that could lead to effective interstellar propulsion systems. Research in this area features a number of esoteric topics, from **quantum vacuum** energy to antigravity.

quantum vacuum consistent with the Heisenberg uncertainty principle, vacuum is not empty but is filled with zero-point energy and particle-antiparticle pairs constantly being created and then mutually annihilating each other

Destinations

Where the first interstellar missions will go is an open question. The most likely destinations are the stars closest to Earth, such as Alpha Centauri and Proxima Centauri, Tau Ceti, and Epsilon Eridani. Scientists will probably be most interested in stars that appear to have Earth-like planets, and thus would be likely to have life. Although no Earth-like planets have been discovered, astronomical techniques are improving to the point where such discoveries should be possible within the next few decades. It is quite likely that future interstellar explorers will have a wide range of new worlds to explore. SEE ALSO Antimatter Propulsion (volume 4); Faster-Than-Light Travel (volume 4); Laser Propulsion (volume 4); Power, Methods of Generating (volume 4); Science Fiction (volume 4); Vehicles (volume 4).

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Ion Propulsion

Ion propulsion is a method of propulsion that uses electrical rather than chemical forces to generate thrust for a spacecraft. Although less powerful than chemical engines, ion propulsion engines are more efficient and can be used continuously for long periods, making them ideal for deep space missions. The concept of ion propulsion has existed for many years, but only recently have ion engine–driven spacecraft been flown.

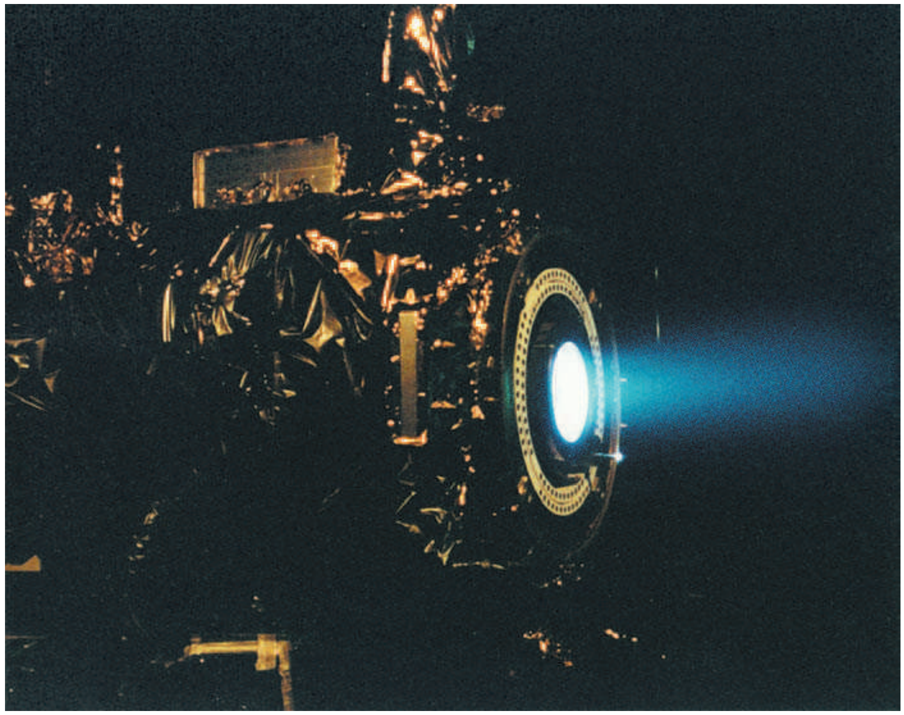
Ion propulsion works by taking advantage of the very strong repulsive force between two objects with the same electric charge. A cathode emits a stream of **electrons** that collides with neutral atoms of xenon, a gaseous element, in a chamber. The collisions strip the xenon atoms of one or more electrons, converting these atoms into positively charged ions. The xenon ions drift toward a pair of grids, one positively charged and one negatively charged, in back of the chamber. Once the ions are between the grids, the repulsive force from the positively charged grid accelerates them out the back of the chamber at speeds of up to 30 kilometers (18.6 miles) per second. Once the xenon ions are free of the engine, another cathode fires electrons at them to neutralize them and prevent them from being attracted back to the engine. A variation of this design referred to as the “Hall effect thruster,” uses a combination of electric and magnetic fields to accelerate ions.

electrons negatively charged subatomic particles

A key advantage of ion propulsion is efficiency. The exhaust from an ion engine travels up to 10 times faster than does the exhaust from a chemical engine, generating far more thrust per pound of propellant. However, the thrust from an ion engine is very weak and cannot support the weight of the engine, let alone the rest of the spacecraft. This makes ion propulsion unsuitable for lifting spacecraft off the surface of Earth. In space, however, ion engines can run continuously for weeks, compared to minutes for chemical engines. These engines can build up significant thrust over time.

The American **rocket** pioneer Robert H. Goddard first proposed ion propulsion in 1906. Research started in earnest in the 1950s, and the first suborbital flight tests of ion engines took place in 1964. Although American interest in ion propulsion waned in the late 1960s, the Soviet Union continued to work in this area, flying Hall effect thrusters on a number of spacecraft in Earth orbit. These thrusters allowed the spacecraft to modify their orbits with less propellant than is the case with chemical engines. In the 1990s the American satellite manufacturer Hughes began to include ion thrusters on communications satellites, allowing them to stay in the proper orbit.

rocket vehicle (or device) especially designed to travel through space, propelled by one or more engines



Charged atoms emit a faint blue glow from a xenon ion engine tested at NASA's Jet Propulsion Laboratory. Ion propulsion is being researched as an alternative to chemically produced power during space travel.

The most important test of ion propulsion in space has been the National Aeronautics and Space Administration's (NASA) Deep Space One (DS1) spacecraft. DS1 was launched in October 1998 to test a number of advanced technologies, including ion propulsion. A month after launch, and after some initial problems had been overcome, DS1 fired up its ion engine. Working for months at a time, the engine propelled DS1 past the asteroid Braille in July 1999 and the comet Borrelly in September 2001. The engine operated for over 15,000 hours, well over a year, during the mission. SEE ALSO ACCESSING SPACE (VOLUME 1); MARS MISSIONS (VOLUME 4); POWER, METHODS OF GENERATING (VOLUME 4); ROCKET ENGINES (VOLUME 1).

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L

L-5 Colonies

A concept to build giant stations in space far from Earth and the Moon, L-5 colonies would be cities in space, located in a gravitational node in the Earth-Moon system. These colonies would be home to tens of thousands of people each, and serve as bases for building solar power satellites to generate electricity for Earth. L-5 colonies were extensively studied in the 1970s, but the high costs of building them prohibited their construction and they have been largely ignored since.

L-5 is the designation given to one of five Lagrangian points that exist in the Earth-Moon system. These points, also known as libration points, exist where the gravity of Earth and the Moon partially cancel each other out. The first three points, L-1, L-2, and L-3, exist on a line connecting Earth and the Moon. These three libration points are considered unstable: An object placed near them will quickly drift away. The other two points, L-4 and L-5, are in the orbit of the Moon, 60 degrees ahead and behind the Moon. Unlike the other three Lagrangian points, L-4 and L-5 are relatively stable: An object in orbit around either point will remain there.

The first person to propose L-5 colonies was Princeton University physicist Gerard K. O'Neill. Concerned in the early 1970s about both the effects of industrialization on Earth's environment and the energy crisis, he proposed developing giant space stations capable of hosting up to 10,000 people. These space colonies, as O'Neill called them, would be used to support the construction and operation of large solar power satellites that would convert sunlight into microwave energy to be beamed to Earth and converted into electricity.

Many concepts for space colonies✶ were developed in the 1970s, but most shared key characteristics. They had spherical, cylindrical, or wheel shapes, a kilometer (0.6 miles) or more in diameter, and rotated to generate artificial gravity. The interiors were designed to resemble small towns, complete with houses, parks, and farms. O'Neill estimated that one basic design, called Island One, would cost about $100 billion in 1978 dollars (about $275 billion today.)

✶In the mid-1970s, the U.S. State Department prohibited the use of the term "space colony" because colonialism is a system that denies human equality.

Placing colonies at L-5, rather than on the Moon or in a closer Earth orbit, had a number of advantages. At L-5 the colonies would have continuous sunlight and would be free of the gravity of both Earth and the Moon. The L-5 location would also make it easy to transport building materials from the Moon. At L-5, colonies could be built to support whatever level of gravity was desired, from normal Earth gravity to weightlessness.

The concept of L-5 colonies attracted the attention of the National Aeronautics and Space Administration (NASA), which funded several studies of them and solar power satellites in the 1970s. Interest in such colonies among the general public also led to the creation of the L-5 Society, a precursor to the present-day National Space Society. However, by 1980, NASA's interest in space colonies and space solar power waned and it stopped funding additional studies. Also around this time, supporters discovered that the shuttle would not offer the low launch costs needed to make colonies feasible. There has been only sporadic interest in L-5 colonies since then. SEE ALSO Domed Cities (volume 4); Dyson Spheres (volume 4); O'Neill Colonies (volume 4); O'Neill, Gerard (volume 4); Settlements (volume 4).

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Land Grants

Possession of property in outer space is an area of space law that is complex and controversial. There exists a tension between the desire to encourage scientific exploration that will benefit all humankind and the economic reality that no one wants to invest billions of dollars in a space endeavor that has to be shared with others who have not contributed financially.

Consequently, the question remains: How does one clarify who owns what in space, or, what is called in law, "property rights"? How can an infinite area be divided up? Or should it belong to everyone? If so, how are decisions to be made that involve everyone on Earth? Since the beginning of space exploration nations have been struggling with these questions.

Treaties

Many countries, through the United Nations General Assembly, have entered into international agreements, international conventions, or charters, which are usually called treaties. A treaty is similar to a law in that it is officially written and is binding, but it is binding only on the states that have signed it.

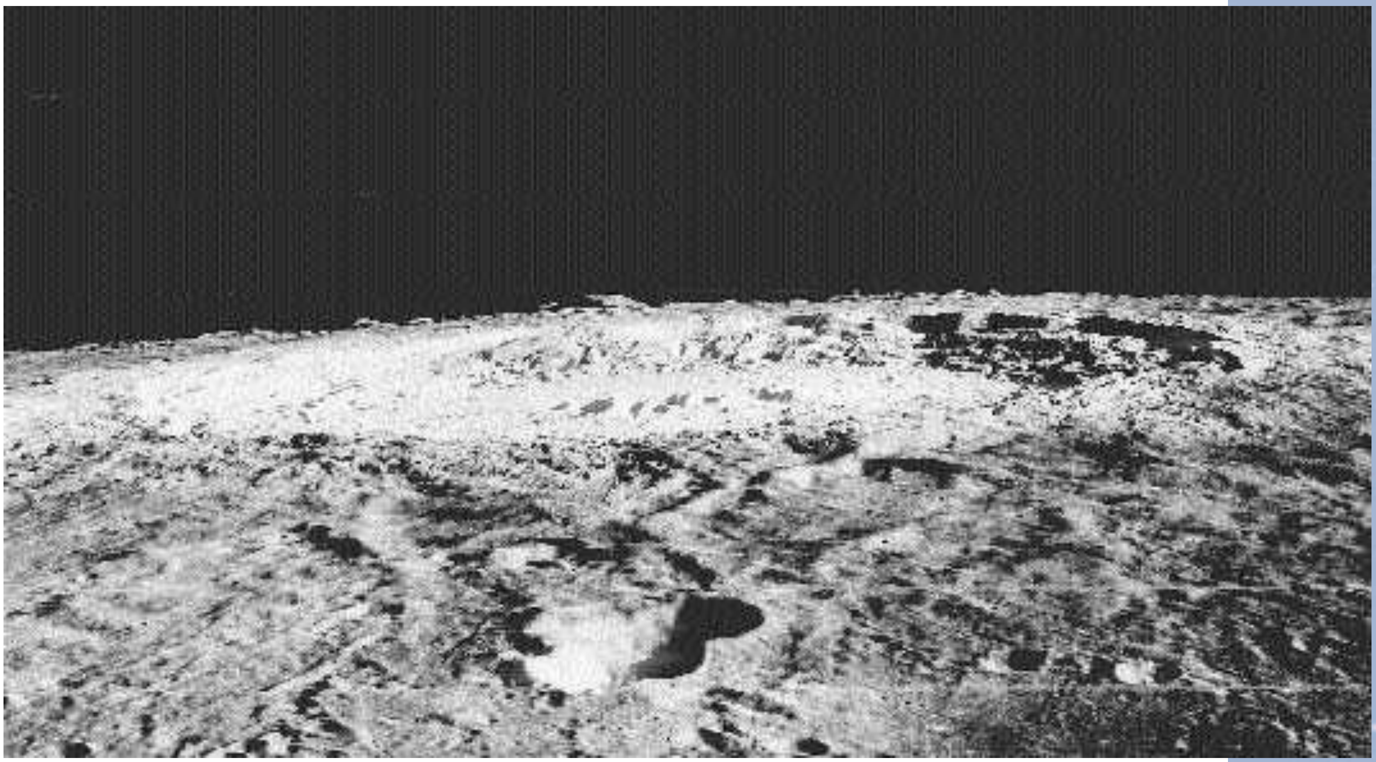
The Outer Space Treaty. The United Nations facilitated the enactment of one of the first treaties that addressed this issue, the 1967 Outer Space Treaty. Operating under the philosophy that "there is a close interrelationship between the prosperity of the developed countries and the growth and development of the developing countries," the treaty holds that space is the heritage of all humankind.

Land grants inherently convey the idea of private property rather than communal or public property. The concepts of community and property have developed over time within most societies. In the majority of societies, possessing land or property is thought of as a natural right that must be protected from intrusion by those who would violate it. However, outer space, which requires enormous financial outlays to even enter, falls between the notions of communal property and private property.

Often, ownership of the high seas is used as an analogy for ownership of space and planets, which are sometimes referred to as "celestial bodies." Maritime law is involved in definitions of and concerns about the utilization and conservation of resources such as fish and oil beneath the seabed. National defense is also a concern in regard to the appropriation of the high seas and outer space.

Resources in outer space could sustain Earth once a growing population has exhausted the planet's natural resources. The Outer Space Treaty addresses the goals of resource management in Article 11 (7):

1. The orderly and safe development of the natural resources of the Moon;
2. The rational management of these resources;



3. The expansion of opportunities in the use of these resources;
4. An equitable sharing by all States Parties in the benefits derived from these resources, whereby the interests and needs of those countries which have contributed either directly or indirectly to the exploration of the Moon, shall be given special consideration.

The Outer Space Treaty prohibits any single country from colonizing outer space but does allow the use of space resources.

Who owns the Moon? Possible governmental and commercial uses of resources from the Moon and other planets make this a compelling question.

The Moon Treaty. The 1979 Moon Treaty forbids ownership of the natural resources found on the Moon or other celestial bodies. The purpose of this treaty is to ensure that the wealth of outer space is shared among all nations. Only seven countries have ratified this treaty. Neither the United States nor Russia has agreed with its strict guidelines and thus neither has signed the treaty.

Comparison of Outer Space and New World Land Grants

Land grants in outer space may seem as alien as the colonization of the New World to us, but some of the concerns are the same. A trip to the New World was costly and required the financial backing of a sovereign nation. Initially, the New World was seen as a source of resources for countries such as Spain and England. With colonization, different groups, such as the Puritans in New England, founded settlements that relied on a philosophy of communal property.

In colonial America an emphasis on agriculture shifted to an emphasis on more commercial endeavors, and so communal rights gave way to speculative land policies that the colonial governments endorsed. Speculators were granted large tracts of land that they then sold to emigrants who had recently come to the country. The promise of plentiful, cheap land drew groups of colonists from the Old World. A family generally owned its own farm. Land was plentiful, but laborers were lacking.

With the fishing industry came commercialization because many more fish were caught than could be consumed. The fishing industry quickly led to trade for commodities such as molasses, ginger, and sugar, which were sold in the West Indies and Europe. Therefore, it seems possible that as in the initial colonization of the New World, where the backing of countries with large financial resources and a vested interest in lining their coffers with newfound riches derived from resource acquisition, space exploration may require incentives for financial investment.

The history of the western expansion of the United States may parallel the promise of space exploration. During the western expansion speculators were able to purchase for practically nothing vast expanses of land that they soon resold to settlers. But acquisition of a land title was often a dispensable technicality for those too poor to purchase one, or who were not inclined to do so because of the vastness of the land.

Only in the future will it be possible to discover what strategies for granting land ownership in outer space to individuals or groups representing private or national interests will best benefit humankind. Perhaps, as in with the move to the New World, the emphasis will shift from communal property interests to private interests. There is some evidence that the pendulum is swinging in that direction. Space is no longer the exclusive preserve of government programs. Commercial companies launch and operate communications satellites, and other commercial ventures will follow. SEE ALSO GOVERNANCE (VOLUME 4); LAW (VOLUME 4); LAW OF SPACE (VOLUME 1); PROPERTY RIGHTS (VOLUME 4).

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Laser Propulsion

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

The performance of conventional **rockets** is limited by the amount of chemical energy in their fuel. One way to improve the performance of rocket engines is to separate the energy source from the rocket. This can be accomplished by using a laser beam to transfer energy from a stationary source to the rocket. In laser propulsion, the rocket carries a tank of reaction mass, but a stationary laser supplies the energy. The laser can either be located on the ground, and beamed upward at the rocket, or in orbit, and beamed downward.

There are two approaches to laser propulsion to launch from the surface of Earth into space. In laser-thermal propulsion, a laser beam is used to heat a gas, which expands through a rocket nozzle to provide a thrust system. The laser beam is focused on a thermal receiver, consisting of a chamber with pipes through which the reaction fluid can flow. This thermal receiver then heats a fluid to vaporize it into a gas, and the hot gas expands through a conventional rocket nozzle to produce thrust. The advantage of the laser thermal system is that the fluid used for reaction gas can be an extremely light fluid-weight, such as liquid hydrogen, to result in very high performance.

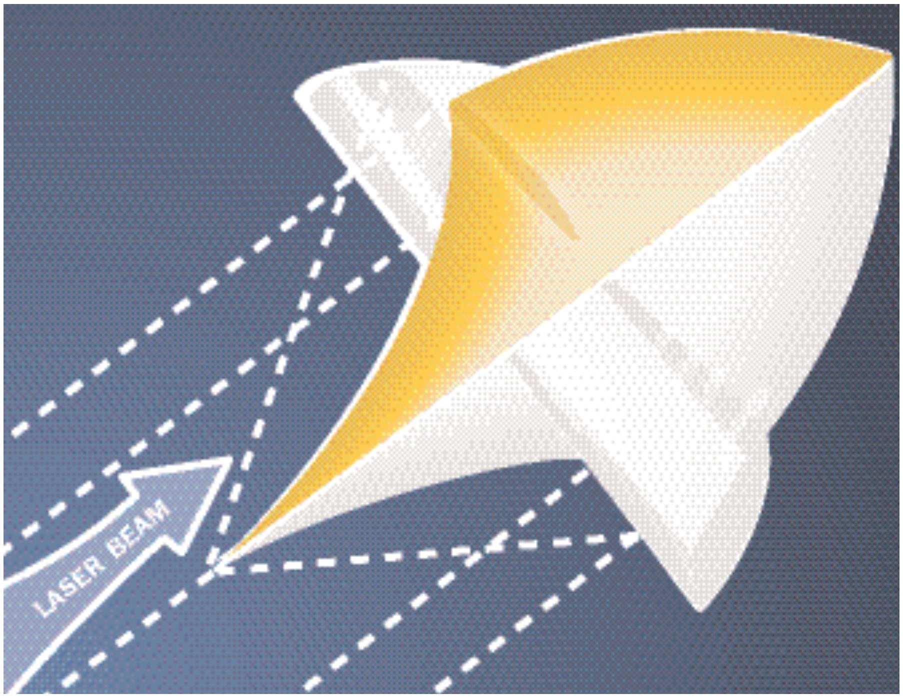
A laser-propelled vehicle is tested in this image.

A second approach to laser propulsion for launch is laser-supported detonation. In laser-supported detonation, a repetitively pulsed laser is utilized. Either liquid or solid reaction mass can be used. The reaction mass is vaporized by a pulse of the laser, and then a second laser pulse causes the reaction mass to explode into a high-energy plasma, a gas heated to the point where the **electrons** are stripped from the gas molecules, behind the rocket. The explosion pushes the rocket forward. An advanced laser propulsion system might use air as the reaction mass for the initial portion of the flight, when the rocket is still in the atmosphere.✶

electrons negatively charged subatomic particles

✶**Low-altitude flight of laser rocket vehicles have been demonstrated by Leik Myrabo at the White Sands Proving Grounds in New Mexico.**

Laser propulsion systems require a high-power laser, a tracking system to follow the motion of the rocket, a mirror (or "beam director") to aim the laser at the rocket, and a lens or focusing mirror to focus the laser light onto the receiver. The difficulty of laser propulsion is that the system requires a



This is a schematic of a "LightCraft" laser-propelled launch vehicle. The propulsive energy is provided by a pulsed laser beam from a ground-based source. The optical rear surface of the lightcraft is used to focus the laser beam into the engine, creating a laser-supported detonation that expands out the rear of the vehicle, producing the thrust that propels the lightcraft into the sky.

laser with higher power than is available in currently existing laser systems. Laser propulsion can also continue to be used once the rocket is in space, to raise the vehicle to a higher orbit, or to boost it to a transfer orbit.

Another propulsion system is laser-electric propulsion, the use of a laser to illuminate a solar array to power an electric thruster. In laser-electric propulsion, a stationary laser (either based on Earth or in orbit) sends a beam of light to a photovoltaic array, which converts the beam into electrical power. This electrical power is then used as the power source for an electric thruster, such as an ion engine.

Further in the future, a laser might also be used to push a lightsail. This propulsion concept could be used as the engine for an interstellar probe. SEE ALSO Accessing Space (Volume 1); Ion Propulsion (Volume 4); Lightsails (Volume 4); Power, Methods of Generating (Volume 4).

Geoffrey A. Landis

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Lasers in Space

The word "laser" is an acronym for "light amplification by the stimulated emission of radiation." The laser is a unique device that produces a very pure color of light that is concentrated into a pencil-thin beam that stays concentrated, or focused, as it travels.

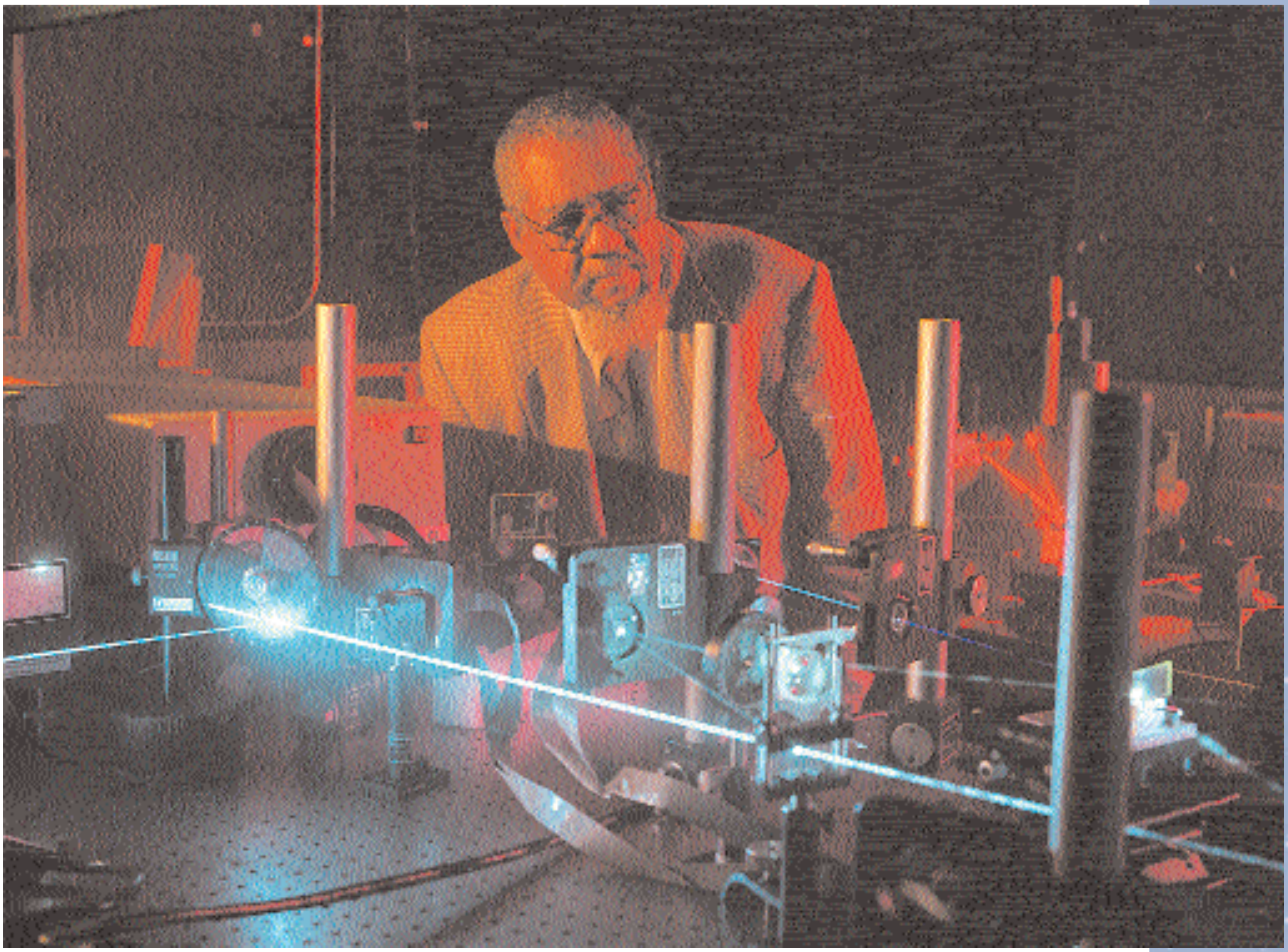
Lasers are commonly seen in several ordinary commercial applications, such as bar code scanners, laser pointers, CD players, CD-ROMs, videodiscs, laser surgery, and laser-light shows. However, lasers have many other applications as well. For instance, lasers enable us to communicate and transfer massive amounts of information, monitor our environments, provide protection from aggressive military attacks, and probe the deepest reaches of space and understand the origins of the universe. Lasers will have a myriad of applications in space, the following of which will be highlighted: (1) laser communications, (2) lasers for environmental and remote sensing, (3) space-based laser defense systems, and (4) lasers for astronomical applications in gravity wave detectors.

Laser Communications

The use of lasers as a tool to transmit information, such as telephone conversations, television programs, and data, is well known. As the **information age** continues to advance, the use of lasers in space as a communication tool will become critical. During the first decade of the twenty-first century, most of the lasers used in communication applications will be associated with optical fiber connections. The growth of the Internet, however, will eventually clog up today's **fiber-optic cables**. This will occur because many people will use computers that send information back and forth to

information age the era of our time when many businesses and persons are involved in creating, transmitting, sharing, using, and selling information, particularly through the use of computers

fiber-optic cable a thin strand of ultrapure glass that carries information in the form of light, with the light turned on and off rapidly to represent the information sent



each other through fiber-optic phone lines (or fiber-optic cables). This clogging up of the phone lines and cables by computer usage is similar to the clogging up of the phone lines on major holidays, such as Mother's Day.

One way to avoid this problem is to place lasers on satellites in space. In this way, data can be collected from multiple locations that are geographically close to one another and beamed up to a satellite by either a laser or **microwave link**. The satellite can then collect the data and retransmit the information from one satellite on an ultrahigh-capacity optical data link using lasers.

The importance of using lasers in space for communications is that since light is traveling in space (a **vacuum**) the light signals are not corrupted as much as they would be traveling through optical fiber. In addition, instead of using one color of a laser to transmit information, a satellite could have many different lasers, each transmitting information on a different color. This method of using different colors to increase the amount of information to be transmitted is called "wavelength division multiplexing" and is similar to how conventional radio signals are broadcast on different radio frequencies. With this type of laser technology, optical communication links

Optical films formed with lasers have the potential to replace electronic circuits and wires in optical computers of the future. A space shuttle science team was able to form these films in a purer state than those made on Earth.

microwave link a connection between two radio towers that each transmit and receive microwave (radio) signals as a method of carrying information (similar to radio communications)

vacuum an environment where air and all other molecules and atoms of matter have been removed

in space could easily handle many tens of trillions of bits of information being sent every second.

Environmental and Remote Sensing

One of the most common uses of lasers in space is for environmental and remote sensing. In this application, a laser stationed on a satellite can orbit Earth (or other heavenly bodies such as the Moon or Mars) and direct a sequence of short optical pulses onto the surface. These pulses are then reflected from the surface, and the reflected pulses are detected by the satellite that contains the laser. Since the speed of light is known accurately, the time it takes for the light pulses to leave the laser/satellite, travel to the surface, and return can be measured, as can the distance from the satellite to the surface. By repeatedly sending sequences of pulses from the satellite to Earth's surface, a three-dimensional topological map can be generated.

The truly amazing feature of using lasers for this type of geographical mapping is that a distance resolution of a few millimeters can easily be achieved. More importantly, different types of lasers emit different colors of light, and these different colors reflect in particular ways, depending on the type of surface the laser light reflects from. In this way, one can use different types of lasers that not only will map out the geographical terrain but also will be able to measure the composition of clouds and perhaps detect water, **minerals**, and other natural resources underneath the surface.

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

Laser Defense Systems in Space

The prospect of using lasers in space, as part of an overall strategic defense plan of the United States, was gaining significant support in the early twenty-first century. In this scenario, lasers would not be a source of directed energy in an offensive attack, but the lasers would primarily be used in a defensive mode to target, track, and identify potentially hazardous threats that may come in the form of intercontinental ballistic nuclear missiles. The types of lasers used would vary widely, depending on the functions to be performed by the laser. For example, small low-powered lasers would be used to realize **optical radar** functions and to determine the location and **velocity** of moving targets in space. More powerful solid-state or chemical lasers could then be used as a source of directed energy to disable rogue missile attacks. Several plans have been proposed to incorporate lasers in space as part of a unified missile defense plan, including ground-based lasers and orbiting reflectors to assist in tracking and directing the laser radiation. Owing to the harsh environment of space, novel engineering approaches would need to be employed to make these laser systems robust and reliable. In addition, the need for generating power to operate the lasers may easily be accomplished by a combination of solar cells or direct solar-pumped lasers.

optical radar a method of determining the speed of moving bodies by sending a pulse of light and measuring how long it takes for the reflected light to return to the sender

velocity speed and direction of a moving object; a vector quantity

optical interferometry a branch of optical physics that uses the wavelength of visible light to measure very small changes within the environment

gravity waves waves that propagate through space and are caused by the movement of large massive bodies, such as black holes and exploding stars

Gravity Wave Detection in Astronomy

Lasers in space are also used in astronomy. Researchers use ground-based lasers and **optical interferometry** to detect **gravity waves**. Optical interferometry is a technique that splits a laser beam into two beams by using a partially silvered mirror. Each beam travels in a different direction (or arm of the interferometer) and is then reflected back to the silvered mirror. The two beams are recombined and the resulting combined beam can provide information about the differences between the two paths that each beam traversed.

This method is being used on Earth to detect the presence of gravity waves that could have been produced from exploding stars or colliding galaxies. Currently, the limitation in the ground-based approaches is that the sensitivity provided is not sufficient for detecting gravity waves. It should be noted that the lengths of the arms of the interferometer on ground-based gravity wave detectors are on the order of 1 kilometer (0.6 miles). By placing the laser and interferometer in space, the sensitivity can be improved by increasing the lengths of the arms of the interferometer to thousands of kilometers and by removing any disruptions caused by Earth-related effects. The detection of gravity waves would be an incredibly important finding in science, because it would serve as another verification of German-born American physicist Albert Einstein's theory of **general relativity**.

general relativity a branch of science first described by Albert Einstein showing the relationship between gravity and acceleration

Outlook Towards the Future

This brief description of the potential applications of using lasers in space shows that these light sources are truly unique and can provide unprecedented performance in specific applications. Scientists and engineers worldwide are researching these and other applications of lasers in space, not only to consider and test the feasibility of specific uses but also to continue to develop state-of-the-art laser systems so that these applications will flourish. What will the newest applications of lasers in space bring? How will these applications change the way humans live their lives? No one can be completely sure, but the new uses that will be discovered will be limited only by the human imagination. SEE ALSO Communications, Future Needs in (volume 4); Laser Propulsion (volume 4); Military Space Uses of Space (volume 4); Mining (volume 4); Power, Methods of Generating (volume 4); Scientific Research (volume 4); Space Industries (volume 4).

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Launch Facilities

In years past, ships about to sail gathered in port to be fitted and take on their crew and provisions for voyages of exploration or commerce. Today's spaceports have facilities to perform many of these same functions. Of course, launch facilities include the platform from which a rocket is launched, but the most sophisticated facilities also allow state-of-the-art **payload** processing,

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

A space shuttle slowly moves from the Vehicle Assembly Building on its crawler transporter toward its launch site at the Kennedy Space Center.

encapsulation enclosing within a capsule

including fueling and **encapsulation** of satellites and integrating a payload with a launch vehicle. Launch facilities can serve civil, scientific, commercial, and/or military functions.

Facilities in the United States

The United States has a number of launch sites and associated facilities, located primarily on the East and West Coasts. Perhaps the best known is the National Aeronautics and Space Administration's (NASA) Kennedy Space Center (KSC), where the space shuttle is processed and launched. At KSC are Launch Complex 39's Pad A and Pad B, which were originally built to support Apollo missions but which have been modified for space shuttle launches. Major changes since Apollo include the additions of a Fixed Service Structure (FSS) and a Rotating Service Structure (RSS). Pads A and B are virtually identical and stand almost 106 meters (348 feet) high. At their base are flame trenches, 13 meters (43 feet) deep and 137 meters (449 feet) long, to carry away the flames and exhaust of the shuttle at liftoff.

Because the shuttle stands upright on the launch pad, the RSS is mounted on a semicircular track, which rotates through an arc of 120 degrees and allows payloads to be loaded vertically. The RSS pivots from a hinge on the FSS until the spacecraft changeout room on the RSS fits flush with the orbiter's cargo bay. This room allows payloads to be installed or serviced under contamination-free or "clean room" conditions. A separate Orbiter Access Arm swings out to the orbiter crew hatch. At the end of the arm is the environmentally controlled "White Room" where the ground crew assists astronauts entering the orbiter.

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

Fuel, **oxidizer**, high-pressure gas, electrical, and pneumatic lines connecting the shuttle with ground-support equipment are routed through the

RSS and FSS. There are approximately 400,000 meters (1.3 million feet) of tubing and piping at Launch Complex 39, enough to reach from Orlando to Miami. Not far from Pads A and B are large ball-shaped liquid oxygen and liquid hydrogen storage tanks used to store supercold propellants for the shuttle's external tank.

The shuttle is transported to Launch Complex 39 aboard the Mobile Launcher Platform (MLP), a giant crawler with eight tracks—each 2 meters (6.5 feet) by 13 meters (43 feet)—with cleats that weigh a ton each. Mounted on these eight tracks is a platform, bigger than a baseball diamond, on which the shuttle rides to the launch pad at 1.6 kilometers per hour (1 mile per hour). Once there, six permanent and four extensible pedestals are used to provide support. The MLP starts its trek to Launch Complex 39 from the giant cube-shaped Vehicle Assembly Building (VAB), where the shuttle is mated with its external tank and twin solid rocket boosters (SRB). The VAB was originally built for assembly of Apollo/Saturn vehicles and is one of the largest buildings in the world, enclosing 3.6 million cubic meters (4.7 million cubic yards) of space.

Inside the VAB, integrated SRB segments are hoisted onto the MLP and mated together to form two complete SRBs. The external tank is inspected, checked out, and attached to the SRBs already in place. Next, the orbiter, which is refurbished inside the Orbiter Processing Facility, is towed to the VAB where it is raised to a vertical position, lowered onto the MLP, and mated to the rest of the stack. When assembly and checkout is complete, the crawler-transporter picks up the platform and the shuttle and carries them to the pad.

Adjacent to the VAB is the Launch Control Center, a four-story building that acts as the "brain" of Launch Complex 39. Here are housed four "firing rooms," in addition to telemetry and tracking equipment, plus computers of the Launch Processing System (LPS), a highly automated, computer-controlled system that oversees the entire checkout and launch process. The LPS continually monitors the space shuttle and its ground components, including its environmental controls and propellant loading equipment.

While KSC is widely recognized for its shuttle connection, launch facilities for **expendable launch vehicles** (ELVs) are located at the Cape Canaveral Air Station, south of Launch Complex 39, and at Vandenberg Air Force Base in California. The Cape Canaveral Air Station contains NASA, U.S. Air Force, and contractor facilities for processing ELV hardware and payloads. In addition, Launch Complex 36 is used to launch Atlas II vehicles. This complex has two launch pads (Pads A and B), a blockhouse, and a launch support building and equipment needed to prepare, service, and launch the Atlas vehicles. Pad 36A is used for military launches, and Pad 36B is for commercial launches. Just south of these facilities is Launch Complex 17, which is designed to support Delta II and Delta III launch vehicles.

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

The primary missions of launch facilities on Vandenberg Air Force Base include military and scientific launchings, and the conducting of missile test flights. There are facilities to support Delta launch vehicles and the Titan rocket, America's largest ELV. The United States also maintains smaller launch facilities, such as the Wallops Flight Facility in Virginia, which typically support scientific research and orbital and suborbital payloads.

The Baikonur cosmodrome has been the launch site of all of the Russian piloted spaceflights, including Sputnik 1 and this Soyuz-TM rocket.

Major Launch Facilities outside of the United States

The Guiana Space Center, located on the French Guiana coastline, services and launches the European-built Ariane family of rockets. This spaceport was deliberately situated close to the equator to support flights to **geostationary orbit**, the destination of many commercial satellites. The spaceport's ELA-2 Launch Complex supports the Ariane 4 vehicle and has been used for more ninety launches. More recently, Arianespace's ELA-3 Launch Complex was built specifically to serve the new Ariane 5 heavy-lift vehicle. Ariane 5 starts its assembly process at the 58-meter-tall (190-foot-tall) Launcher Integration Building where the main **cryogenic** stage is positioned over Ariane 5's mobile launch table. The Ariane 5 is then transferred to the Final Assembly Building. In this facility, the payload with its **fairing** is mated to the launcher, the attitude control system is loaded with fuel, and the launcher's upper stage is filled with storable propellant. After leaving ELA-3's Final Assembly Building, the completed Ariane 5 arrives at the launch zone, where it is positioned over a concrete foundation and readied for launch.

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis

cryogenic related to extremely low temperatures; the temperature of liquid nitrogen or lower

fairing a structure designed to provide low aerodynamic drag for an aircraft or spacecraft in flight

The Chinese have several launch facilities—Jiuquan, Taiyuan, and Xichang—but the Xichang Satellite Launch Center, which is located within a military installation, supports all **geostationary** missions from its location in southern China. Two separate launch pads support flight operations, and a command and control center is located several kilometers from the launch site. Other facilities include communication systems to provide telephone and data communications.

geostationary remaining above a fixed point above Earth

The Tanegashima Space Center is Japan's largest launch facility. Located on an island 115 kilometers (71 miles) south of Kyushu, this 8.6-square-kilometer (3.3-square-mile) complex plays a central role in prelaunch countdown and postlaunch tracking operations. On-site facilities include the Osaki Range, tracking and communication stations, several **radar** stations, and optical observation facilities. There are also related developmental facilities for firing of liquid- and solid-fuel rocket engines.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Russia launches all of its crewed missions as well as all geostationary, lunar, and planetary missions from the Baikonur Cosmodrome. Baikonur is the launch complex where Sputnik 1, Earth's first artificial satellite, was launched in 1957. It is the only Russian launch site capable of launching the Proton launch vehicle and was used for several International Space Station missions. The Plesetsk Military Cosmodrome, Russia's northernmost launch complex, is used to launch satellites into high-inclination, polar, and highly **elliptical** orbits.

elliptical having an oval shape

Unique among the world's launch facilities is the floating Sea Launch facility managed by the Boeing Company. Two unique ships form the marine **infrastructure** of the Sea Launch system. The first is a custom-built Assembly and Command Ship (ACS), and the second is the Launch Platform (LP), a semisubmersible vessel that is one of the world's largest ocean-going launch platforms. Both vessels are equipped with spacecraft handling and launch support systems.

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

The LP—a former North Sea oil-drilling platform—is equipped with a large, environmentally controlled hangar for storage of the Sea Launch rocket during transit, and with mobile transporter/erector equipment that is used to erect the rocket in launch position prior to fueling and launch. Special facilities onboard enable the storage of rocket fuels. Floating nearby is the ACS that serves as a floating rocket assembly factory while in port and also houses mission control facilities for launches at sea. Launch operations begin at home port in Long Beach, California, where satellites are fueled and encapsulated in a payload processing facility and then transferred to the ACS for integration with the launch vehicle.

Commercial Spaceports

Around the world, steps have been taken to develop commercial spaceports, some at sites of established launch facilities and others unrelated to existing facilities. For example, the Spaceport Florida Authority has created a commercial spaceport where missiles were once launched from the Cape Canaveral Air Station. Launch Complex 46 has been modified to accommodate Lockheed Martin Corporation's LMLV family of launch vehicles and Orbital Sciences Corporation's Taurus launcher.

California's Western Commercial Space Center is planned for Vandenberg Air Force Base. Thousands of kilometers up the coast, the Alaska

Aerospace Development Corporation has built a commercial spaceport at Narrow Cape on Kodiak Island, about 400 kilometers (250 miles) south of Anchorage. The Kodiak Launch Complex is a state-of-the-art launch facility containing all-weather processing adaptable to all current small launch vehicles, and it is the only commercial launch range in the United States not co-located with a federal facility. Other commercial launch facilities have been proposed at various locations around the world, including Australia and the Caribbean. SEE ALSO Launch Management (volume 3); Launch Sites (volume 3); Space Centers (volume 3); Space Industries (volume 4); Space Shuttle (volume 3); Traffic Control (volume 4).

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Law

The birth of the Space Age in the late 1950s opened a new frontier for exploration. It also opened a new arena for law, since existing international laws and treaties did not cover launches or other activities in space. Given the backdrop of the Cold War, there was a concern by some that space could become a new battlefield between the United States and the Soviet Union. In 1959, in an effort to keep space free of conflict, the United Nations established the Committee on the Peaceful Uses of Outer Space (COPUOS), which was charged with, among other things, considering the legal problems that could stem from space travel. COPUOS, through its legal subcommittee, led to the development of several space treaties.

The first international treaty that included specific provisions related to space was a nuclear test ban treaty in 1963. That accord specifically prohibited countries from detonating nuclear weapons in space. The first treaty devoted exclusively to space, though, was the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, more commonly known as the Outer Space Treaty. This 1967 agreement prevents nations from making territorial claims in space or placing weapons of mass destruction there. The treaty does allow nations to maintain sovereignty over satellites and other vehicles they launch, and requires nations to be responsible for any damage or loss caused by spacecraft launched from their territory, regardless of whether the spacecraft belonged to the government or another organization or company. The Outer Space Treaty also requires nations to treat astronauts as "envoys of mankind" and render them any necessary assistance.

The Outer Space Treaty was seen at the time as a major achievement toward the goal of peaceful exploration of space, at a time when the two major nations involved in space exploration, the United States and Soviet Union, were locked in struggle against each other. By preventing countries from laying claim to the Moon or other bodies, prohibiting the placement of nuclear weapons, and preventing countries from establishing military bases in space, the treaty largely succeeded in its goal of keeping space from being turned into a new battleground. While the militaries of the United States and former Soviet Union, as well as other nations, make extensive use of space, it is for the purposes of **reconnaissance**, navigation, and communication.

reconnaissance a survey or preliminary exploration of a region of interest

Some provisions of the Outer Space Treaty were followed up by additional agreements over the next several years. The section of the treaty regarding astronauts was expanded upon with a separate agreement in 1968, the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, regarding the rescue and return of astronauts and objects. This agreement requires countries to assist astronauts who land on their territory and return them to their home country as soon as possible. Another agreement in 1972, the Convention on International Liability for Damage Caused by Space Objects, expanded the section of the Outer Space Treaty that governs the liability a country has for damage that a spacecraft could cause to another country. A 1975 agreement, the Convention on Registration of Objects Launched into Outer Space, requires countries to give the United Nations basic details about each spacecraft it launches.

The last, and most controversial, space treaty was the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, completed in 1979. This accord, popularly known as the Moon Treaty, requires nations to use the Moon and other bodies for peaceful, scientific purposes and not to damage its environment. The treaty also requires nations to treat the Moon and its natural resources as the "common heritage of mankind"—they do not belong to a single country, organization, or company. Any benefits gained from those resources, according to the treaty, are to be shared with all countries that signed the agreement through an international organization.

The language in the Moon Treaty regarding the use of the Moon's natural resources generated considerable controversy in the United States and other nations, since it would prevent private enterprise from developing in space. The United States did not sign the treaty, in part because lobbying by space activists opposed to the agreement led the Senate to opt against signing it. Only nine nations have ratified the treaty, none of which are major spacefaring nations. While enough nations have ratified the treaty for it to go into effect, the lack of support from major nations means that the treaty has little real power.

The United Nations has developed no additional space treaties since the Moon Treaty. However, there have been a number of minor declarations that COPUOS has approved since then. These declarations cover issues such as the use of television broadcasting and remote sensing satellites as well as the use of nuclear power sources in spacecraft. In recent years there have been discussions about either renegotiating the Outer Space Treaty or developing a new treaty to expressly forbid weapons of any kind in space, including those that might be used in a missile defense system. This effort has been opposed in particular by representatives of the United States, who note that there is no "arms race" in space as of 2002, and no evidence of one for the foreseeable future.

The field of space law is not limited to international treaties. A number of nations, including the United States, have written their own laws governing the use of space by their citizens. Many of these laws are a direct outgrowth of the international treaties, fulfilling some of the provisions in them. For example, in the United States, companies that wish to launch a satellite are required by law to obtain a license from the Federal Aviation Administration to ensure that the launch will be conducted in a safe manner. This law is in place because the Outer Space Treaty makes the U.S. government responsible for all launches from its territory, including those by private parties. SEE ALSO Governance (volume 4); Law of Space (volume 1); Political Systems (volume 4).

Jeff Foust

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Willy Ley was a tireless supporter of the idea of rocket travel.

Ley, Willy

Scientist, Engineer, and Science Writer
1909–1969

Willy Ley was born in Berlin, Germany, in 1909. Educated as a paleontologist, Ley chose a career in rocketry and became a tireless advocate of the concept of rocket travel. He founded the German Society for Space Travel in 1927 and attempted to establish that organization as the world's most important society for spaceflight. Among the members he recruited was Wernher von Braun, who later moved to the United States and designed the Saturn series of rockets that carried astronauts to the Moon and space stations into Earth orbit.

Ley emigrated to the United States in 1934 when the German government chose to use rockets as military weapons, a decision he opposed. In the United States he became a popular writer on scientific subjects, including spaceflight, rocketry, and astronomy. He advised filmmakers, including Fritz Lang and Walt Disney, and helped Disney design a theme park attraction about travel to the planets and a documentary television series. Ley worked with *Collier's* magazine in its special 1947 series about space travel, written by von Braun. The magazine articles and books that followed were a major force in popularizing the idea of spaceflight in the period after World War II. Ley wrote more than nineteen books, including *The Conquest of Space* (1959), *Rockets and Space Travel* (1948), *Kant's Cosmogeny* (1968), and *Rockets, Missiles, and Space Travel* (1961–1969). He died in 1969, a few weeks before the launch of Apollo 11 and the first landing of astronauts on the Moon. SEE ALSO ROCKETS (VOLUME 3); VON BRAUN, WERNHER (VOLUME 3).

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Lightsails

A beam of light carries both energy and momentum. The momentum of light results in a slight pressure on a surface exposed to sunlight that is known as photon pressure. When light reflects off a mirror, it pushes the mirror slightly. A spacecraft that uses this effect for propulsion is called a lightsail. One that specifically uses light from the Sun to push the sail is called a solar sail spacecraft.

Photon pressure is very weak. At the distance of Earth from the Sun, the pressure produced by sunlight on a mirror with an area of 1 square kilometer (247 acres, or about a third of a square mile) is slightly under 10 Newtons. This pressure would cause an acceleration of about a tenth of a centimeter per second per second on a spacecraft with a mass of 10,000 kilograms (roughly 10 tons). This is not a very high rate of acceleration, but because the mirror does not use up any fuel, the acceleration can be continuous, and speed will build up slowly. In an hour (3,600 seconds) the speed will build up to 3 meters per second (about 10 feet/second); in a day (86,400 seconds) the speed will build up to almost 80 meters per second (260 feet/second); and in a year the speed will build up to 28 kilometers per second—over 96,000 kilometers (60,000 miles) per hour.

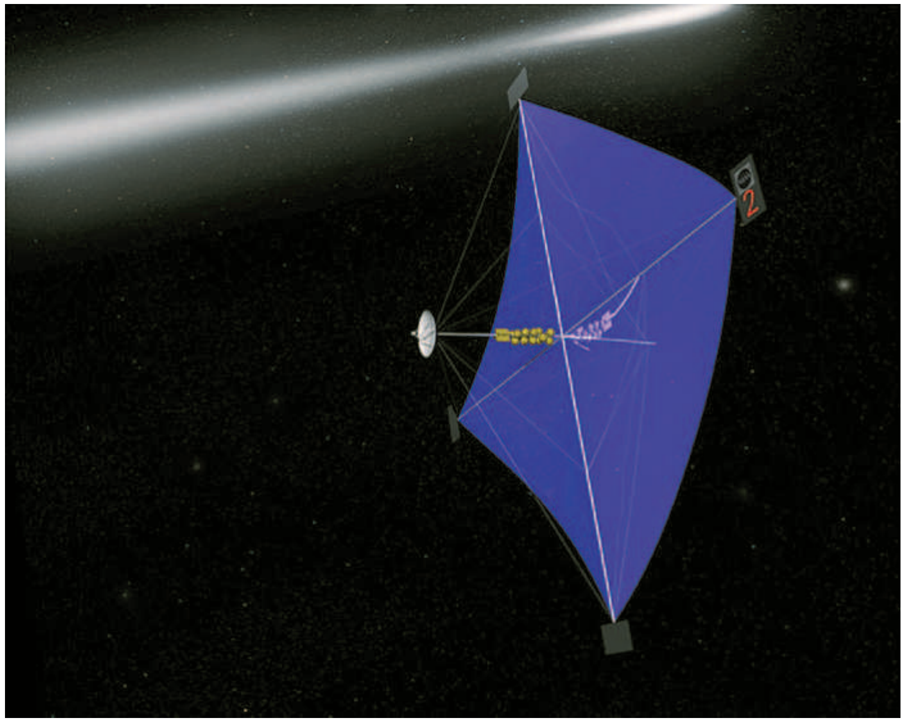
Solar Lightsails

The characteristics of a solar sail spacecraft are extremely light weight, a very large sail area, and low but constant acceleration. Designs for a solar sail spacecraft use a sail that is made out of thin plastic (often Mylar or Kapton), with a thin coating of aluminum to make it reflective. The total sail thickness might be as little as 5 micrometers (1/4000th of an inch). A square meter of this type of sail will weigh only 7 grams (a quarter of an ounce). To keep the thin sail spread, a solar sail spacecraft will use lightweight spars, or else the sail will rotate so that **centrifugal** force keeps it extended.

centrifugal directed away from the center through spinning

The light pressure force on a sail, F, can be calculated from the Einstein relation:

$$F = 2P/c$$



A solar sail spaceship uses the Sun's energy to propel it through space.

The force produced is equal to two times the power of light reflected, divided by the speed of light. (The factor of two assumes a perfectly reflecting mirror and is derived from the fact that the reflected light is reversed in direction, thus giving the sail a momentum of twice the photon momentum.)

The force of a solar sail need not be directly outward from the Sun. If the sail is tilted, a sideways force can be produced to increase or decrease the **orbital velocity**. If the orbital velocity is increased, the orbit moves outward from the Sun; if the velocity is decreased, the orbit moves inward toward the Sun.

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

Lightsails have been proposed as a propulsion system for missions to other stars because the fact that a lightsail does not need a fuel tank means that it can continue to accelerate for the extremely long period required to achieve a significant fraction of the speed of light. Since a mission to the stars would move through interstellar space far from the Sun, this type of lightsail-propelled starship would require a large laser to beam the light to push the sail. To make the lightest possible sail (and thus create the highest level of acceleration), proposed laser-pushed lightsails would be designed without the plastic sheet and would have only the thin reflective layer of the sail.

Solar Wind

The pressure produced by light from the Sun should not be confused with the solar wind. The solar wind consists of a stream of charged particles (mostly **protons**) emitted by the Sun. The solar wind also has a pressure, although because the density of the solar wind is very low, the pressure is also low. Solar-wind pressure is about one-tenth as strong as light pressure.

protons positively charged subatomic particles

The use of magnetic fields to sail on this solar wind pressure has been proposed. This is called "magnetic sail" propulsion or "minimagnetospheric plasma propulsion." SEE ALSO Power, Methods of Generating (volume 4); Solar Power Systems (volume 4).

Geoffrey A. Landis

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Living on Other Worlds

Many things about Mars would remind a settler of Earth, but some things are quite different. Except for the lack of any vegetation, the sandy, rock-strewn landscape looks much like an earthly desert. Dust devils and blowing dust storms are often seen. A day on Mars is 24.6 hours, similar to Earth's day, so the **circadian rhythm** of a settler would not be upset. Mars's rotation axis is tilted at 25 degrees compared to Earth's 23.5 degrees, so Mars also has seasons. However, its year is nearly two Earth-years long because Mars is one and a half times farther from the Sun. Therefore, the seasons on Mars are much longer than Earth seasons. Martian gravity is only about four-tenths as great as gravity on Earth. A person weighing 60 kilograms (132 pounds) on Earth would weigh about 24 kilograms (53 pounds) on Mars.

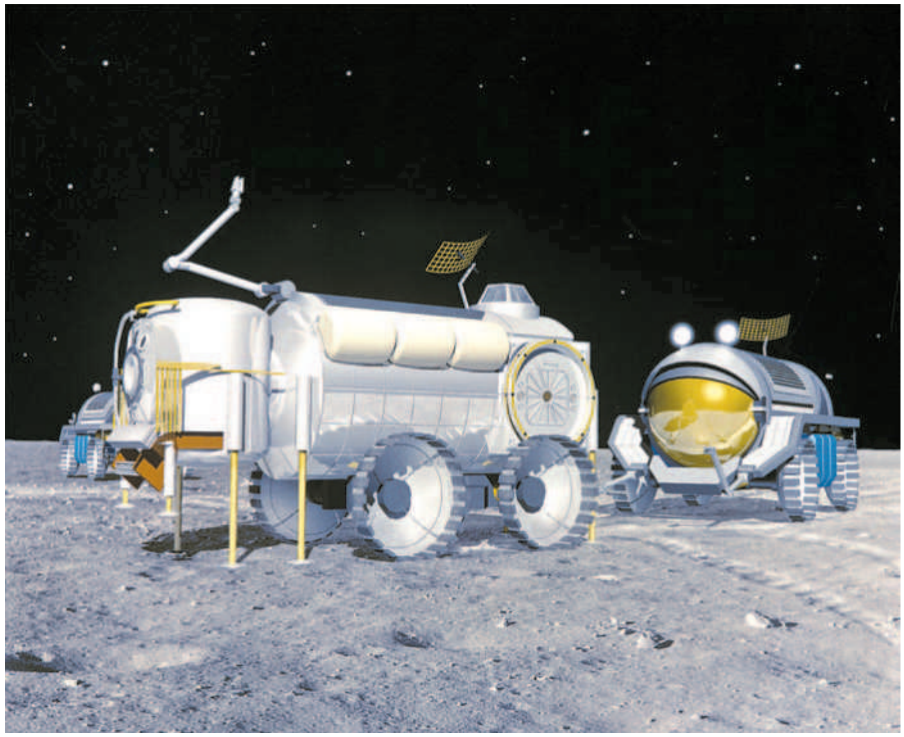
circadian rhythm the activities and bodily functions that recur every 24 hours, such as sleeping and eating

The Moon, on the other hand, is extremely different from Earth. It rotates once on its axis in the same time it goes once around Earth. Consequently, the Moon's day is about twenty-seven and one-third days long—two weeks of sunshine followed by two weeks of darkness. Also, the same side of the Moon always faces Earth. To someone standing on the visible side of the Moon and looking up, Earth is always at the same spot in the sky. Although it has phases like the Moon does, it never sets. Gravity on the Moon is only one-sixth of Earth gravity. A person weighing 60 kilograms (132 pounds) on Earth would weigh about 10 kilograms (22 pounds) on the Moon.

In considering how people might live in a settlement on another world, one needs to examine both the necessities of life and the quality of life. The basic necessities are oxygen, water, food, and protection from radiation. Quality of life includes pleasant surroundings, having something worthwhile to do, good health, a general feeling of well-being.

The Basic Necessities

Oxygen is certainly the most important of human necessities. Humans can live for days without food or water but only minutes without oxygen. Earth is the only known place that has a breathable atmosphere. The Moon has no atmosphere, and the Martian atmosphere is 95 percent carbon dioxide at a pressure only one-hundredth that of Earth's atmosphere.



The housing and equipment needed for settling other worlds would incorporate adaptations made to suit alien environments.

Airtight habitats are necessary. They come in various sizes, ranging from a large dome enclosing an entire settlement to a small space suit enclosing an individual. Inside the habitat, the temperature, pressure, and oxygen content would be controlled. Pressure must be sufficient that lungs operate efficiently and oxygen is absorbed into the bloodstream. On Earth, sea-level pressure is 14.7 pounds per square inch (psi), but people live comfortably in mountain towns where the pressure is less than 10 psi. Pressure in the habitats would probably be less than 10 psi. Lower pressure means less stress on the structure of the habitat and less leakage. Settlers would have to wear a space suit whenever they left the habitat on foot, but rover vehicles for exploration could be pressurized with a breathable atmosphere.

In the list of essentials, water is second only to oxygen. Water was recently detected in sheltered craters in the polar regions of the Moon where the Sun never shines. There is evidence in the images of Mars that water once flowed on the Red Planet. Although the surface of the planet is extremely dry, much of the water may still be frozen in the ground similar to the permafrost in Earth's arctic regions. Dormant volcanoes exist on Mars, and there are probably warm spots underground where liquid water may exist.

An initial supply of food would have to be brought from Earth. A lunar settlement could continue to be supplied from Earth; it is only a three-day trip from Earth to the Moon. A permanent settlement on Mars would construct greenhouses in which to grow its own food supply using the resources of the planet. Plants need carbon dioxide and Mars's atmosphere has plenty. As a by-product, plants produce oxygen.

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

Carbon dioxide and noxious gases would be cleansed from the habitat air. Fresh oxygen extracted from Martian **minerals**, water, and atmospheric carbon dioxide would be added to the habitat's air as needed. Lunar settlers could extract oxygen from the minerals ilmenite ($FeTiO_3$) and anorthite ($CaAl_2Si_2O_8$). Everything would be recycled—air and water, in particular. Solid waste would be recycled into fertilizer and other usable products.

Settlers would need protection against the high-energy particles in space, mostly **protons** and **electrons** from the Sun and cosmic rays from beyond the solar system. On Earth humans are protected from these hazardous particles by Earth's magnetic field, which deflects them away, and by the atmosphere, which absorbs them before they get to the ground. The Moon, without a magnetic field or atmosphere, affords no protection against them. Mars also has no current magnetic field. The thin atmosphere of Mars absorbs some of the particles, and a settlement's walls would reduce them to a tolerable level, no greater than living on a mountaintop on Earth. Occasionally **solar flares** on the Sun spew out very-high-speed particles in great number and intensity. For protection during such a storm, settlers would have underground "storm cellars," much as storm cellars are used for protection against tornadoes in the Great Plains of the United States.

protons positively charged subatomic particles

electrons negatively charged subatomic particles

solar flares explosions on the Sun that release bursts of electromagnetic radiation, such as light, ultraviolet waves, and X rays, along with high speed protons and other particles

From the above it is obvious that Mars is a more desirable place than the Moon to establish a new branch of human civilization.

A City in a Dome

The enclosure for the settlement would be an inflated sphere with the bottom half buried underground. A simple dome would be difficult to anchor down because the pressure of the air inside would tend to force the dome off its foundation. With a sphere, however, the downward air pressure and the weight of the dirt in the bottom half would hold the upper half in place. The dirt-filled lower half would contain tunnels for rapid transit and chambers for life-support equipment and storage.

To reduce the stress of being on an alien world, the homes should look like terrestrial homes, especially the interiors. Construction material from Earth would be at a premium, so buildings inside the spherical shell would be square. Using the same amount of material, a square building has more floor space than a rectangular building. The citizens of this strange new world would quickly learn to use indigenous materials. They would develop their own ideas of what a Martian home should look like and how to make it comfortable.

Obviously the city in the sphere would have a circular layout. The center of activity would be located in the center of the settlement with a circular street running around the perimeter and linear streets radiating outward from the center. With such a layout, everyone would have about the same distance to walk to reach the center.

Energy Sources

No oxygen-consuming or polluting fuels would be allowed; only electric energy would be used in the dome. Legs, bicycles, and electric carts would be the primary means of transportation.

Nuclear generators located outside the habitat some distance away would be a primary source of electric power. In addition, electricity could be generated by solar panels during the day when the Sun is shining. Sunlight, however, is only half as intense at Mars than at Earth because Mars is one and a half times farther from the Sun, so the solar panels would have to be twice as large to produce the same electricity. On the Moon, night is two weeks long during which time the Sun could not be a source of electric power.

Once the settlement is well established, indigenous fuels would be used. Methane could be manufactured from the carbon dioxide in the Martian atmosphere. Water can be electrolyzed into hydrogen and oxygen simply by running an electric current through it.

Communications within the settlement would be by cell phone and videophone. Mars and the Moon are both much smaller in diameter than Earth so the horizon is much nearer and line-of-sight television and cell phones would work only for much shorter distances. Low-frequency shortwave radio would work over longer distances on Mars because it has an **ionosphere** to reflect the radio waves beyond the horizon.

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

Communicating with Earth from Mars involves a time delay because of the distance the radio waves must travel. This means that a Martian settler talking to someone on Earth using a radiophone would have to wait for their response, ten minutes to half an hour, depending on how far apart Mars and Earth are in their orbits. The best way to communicate would be by e-mail.

The Workforce

From the above description of the settlement one can see the wide variety of jobs that must be done. The atmosphere control equipment, the water pumps and distribution system, the electrical generating and distributing system, the structure of the habitat, the vehicles, and the greenhouses, all require people who can do more than just repair the machinery. Members of the settlement would need to thoroughly understand how the entire system works so they could modify or redesign it to improve its operation. Besides keeping the habitat functioning, scientists and engineers would need to explore the planet to look for resources that can be mined, processed, and fabricated into useful products to build additional habitats for future immigrants.

In the beginning, with only a few settlers, there would be a labor shortage. A person who is expert in several trades and professions would be given the first chance to go. Construction engineers, mechanical engineers, agricultural engineers, and at least one medical doctor would likely be among the first settlers.

Eventually, the settlers would find products that can be manufactured on the Moon and Mars better and cheaper than on Earth, and they would have a surplus to sell to Earth in exchange for equipment that cannot easily be manufactured on other worlds. As the population grows, the settlement would become more self-sufficient, eventually establishing its own political system and declaring its independence from Earth. SEE ALSO Communities in Space (volume 4); Earth—Why Leave? (volume 4); Food Production (volume 4); Governance (volume 4); Habitats (volume 3); Human Missions to Mars (volume 3); Interplanetary Internet (volume 4); Land Grants (volume 4); Lunar Bases (volume 4); Lunar Outposts (volume 4); Mars (volume 2); Mars Bases (volume 4); Mars

MISSIONS (VOLUME 4); MICROGRAVITY (VOLUME 2); MOON (VOLUME 2); POLITICAL SYSTEMS (VOLUME 4); PROPERTY RIGHTS (VOLUME 4); RELIGION (VOLUME 4); SETTLEMENTS (VOLUME 4); SOCIAL ETHICS (VOLUME 4).

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Lunar Bases

When humans return to Earth's Moon, they will probably first live for short periods of time in lunar outposts. Eventually, they will establish lunar bases where they can live for longer periods—months or even years. These bases may result from the growth of lunar outposts, or they may be designed as lunar bases from the outset.

Any successful lunar base must accomplish a few goals. First, it must protect and satisfy the needs of those who live there. Second, it must enable the inhabitants to get some useful work done. Finally, it must minimize the cost of operating it. Sending anything from Earth to the Moon is very expensive, so a high priority for any lunar base will be to minimize the need for resupply from Earth.

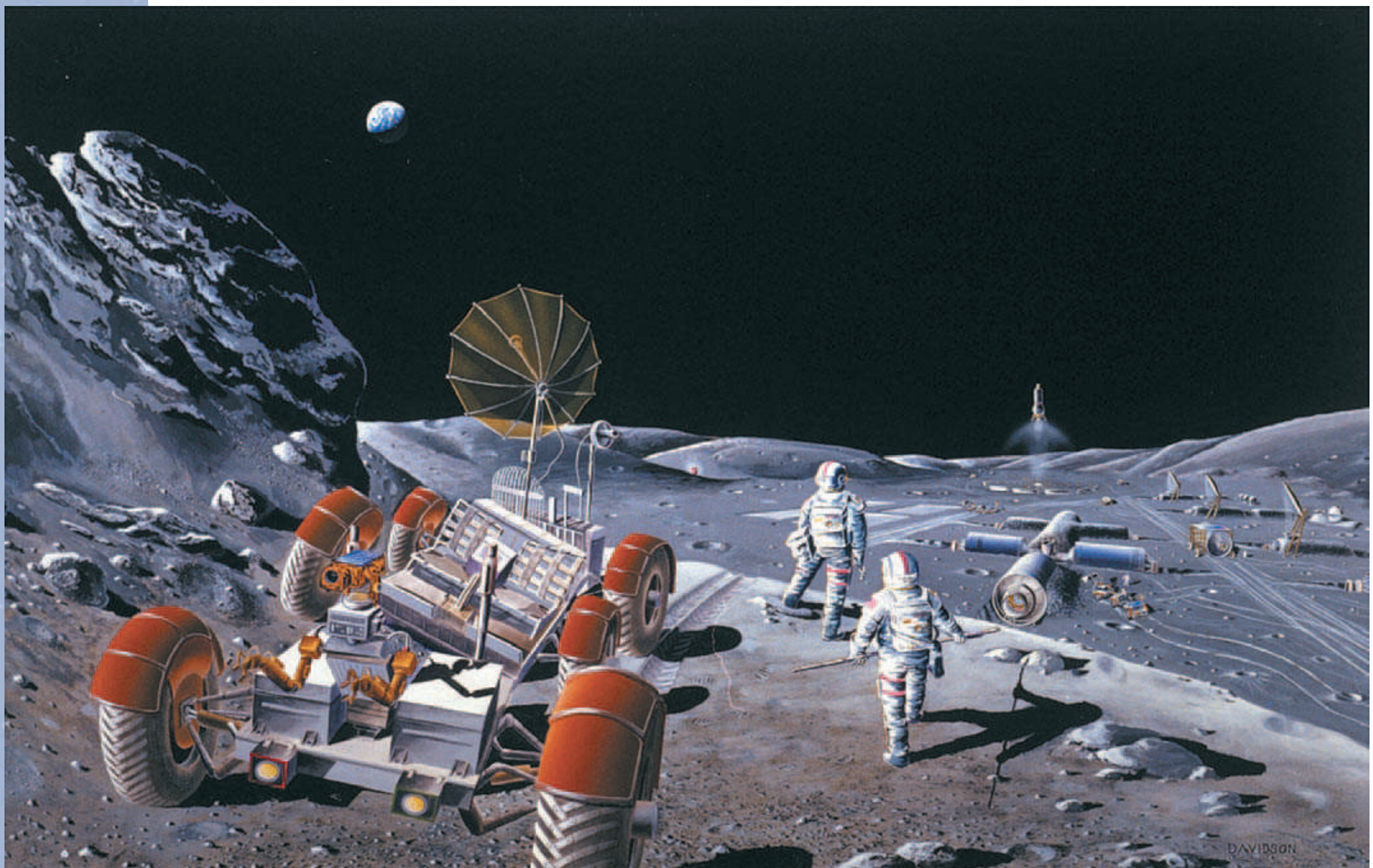
An ideal place to meet all these goals might be the Aristarchus Plateau. Located at about 25° north latitude, 50° west longitude, the Aristarchus Plateau is relatively easy to spot from Earth. Aristarchus crater, at the plateau's southeast edge, is the brightest feature on the full Moon. Aristarchus Plateau is covered by fine-grained **pyroclastic** glass beads formed when volcanoes erupted there more than a billion years ago. This material is a good resource, and the area is very interesting to geologists.

pyroclastic pertaining to clastic (broken) rock material expelled from a volcanic vent

Protection of the Inhabitants

The most critically important function of a lunar base is to protect its inhabitants. The Moon has no atmosphere, so a lunar base must be airtight and provide breathable air. Earth's atmosphere is good for more than breathing, though. It protects humans from harmful radiation from space. A lunar base must shield those inside from radiation, and pyroclastic material can do that. From **radar** studies, scientists have found that the pyroclastic deposits on the Aristarchus Plateau are loose and deep enough to be easily

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects



While NASA has no formal plans for a human expedition to the Moon or Mars as of 2002, this conception of a lunar base and extra-base activity captures and presents the various theories and possibilities that have developed over the years.

dug up and moved around. It would be relatively easy to scoop out a trench, place a habitation module in it, and cover it with several feet of pyroclastic material. That would be enough to protect those inside.

Another way to protect a lunar base from radiation is to put it underground in a lava tube. Photographs of the Aristarchus region show many interrupted channels. These may be lava tubes that have collapsed in places. The interruptions may be places where the lava tubes are still intact. Future lunar explorers might find suitably large, intact lava tube sections that could be turned into next-generation lunar bases.

Resources to Sustain the Base

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

Pyroclastic deposits are good for more than just radiation **shielding**. The Sun produces the solar wind—gases that are blown away from the Sun. Earth's atmosphere stops the solar wind before it can reach the planet's surface, but because the Moon has no atmosphere, the solar wind impacts the lunar surface directly. These gases, mostly hydrogen with some helium and other trace components, are sometimes trapped when they hit the surface of the Moon. Because the pyroclastic deposits are fine-grained, they provide a lot of surface area. It would be possible to drive off and collect the solar wind gases from this material by heating it to a few hundred degrees.

The most abundant of the gases, hydrogen, would be very valuable. If the pyroclastic material or other lunar rocks were heated to higher temperatures, the hydrogen could be combined with oxygen to form water vapor. The water vapor could be collected and condensed into liquid water.

Water is necessary to sustain life, of course, but it could also be used as part of the energy system in a lunar base. The Sun is in the Moon's sky for about two weeks, then there is a two-week-long night. During the lunar day, **photovoltaic** panels could convert sunlight into electricity, but storing power for two weeks would require a lot of batteries. A better method would be to use electric power during the day to break water apart into hydrogen and oxygen. During the lunar night, the hydrogen and oxygen could be recombined in a fuel cell to produce water and power.

photovoltaic pertaining to the direct generation of electricity from electromagnetic radiation (light)

People living at a lunar base will want to grow as much of their own food as possible. Greenhouses could be built with sufficient radiation shielding, or plants could be grown indoors with artificial lighting. Perhaps plants could be genetically engineered to withstand the intense lunar sunlight. There will be a strong economic incentive to recycle materials as efficiently and completely as possible on the Moon, and plants will play an important role. The goal will be to recycle all human wastes (solid, liquid, and gas) completely through the greenhouses, both to reduce the need for resupply from Earth and to reduce the amount of waste disposal on the Moon. People on Earth might benefit by applying the recycling techniques developed on the Moon.

Lunar base inhabitants will also experiment with other technologies that can reduce the need for bringing materials from Earth. For example, they might be able to produce building materials simply by melting lunar soils and cooling them quickly to form molded glass. Lunar surface gravity is only one-sixth that on Earth, so materials of a given strength could support much more massive structures.

Science and Exploration from Lunar Bases

One reason to build lunar bases is to study the Moon. The Aristarchus Plateau is very interesting to geologists. The plateau itself may have been raised up by the impact that formed the nearby Imbrium basin, but this is not certain. The volcanic eruptions that produced the pyroclastic material brought material to the surface from deep in the lunar interior. Scientists can learn much by studying the geology near Aristarchus.

Of course, there are many other suitable sites for lunar bases. Many other pyroclastic deposits exist in other parts of the Moon, and scientists would like to have samples from all of them. Other locations that might provide resources for lunar bases include the lunar poles. Because the Moon's polar axis is nearly perpendicular to its orbit around the Sun, sunlight never reaches the bottom of some craters near each pole. If water molecules were deposited there, for example, when a comet hit the Moon, they might remain frozen. The Lunar Prospector spacecraft had an instrument to detect hydrogen, and it did find evidence of more hydrogen near the lunar poles. The instrument could not determine whether the hydrogen was contained in water molecules, but that is the likely explanation. If abundant water is found, a lunar base at one of the poles could get its power from photovoltaic panels located on the rim of a crater at a high point that is always in sunlight, and it could get water from the permanently shadowed bottom of the same crater.

Lunar colonists will handle medical and other emergencies with new technologies and procedures. In this rendering, the crew responds to a colleague who has broken his leg.

Another place that would be interesting for geologists to study is the South Pole-Aitken basin, a giant crater located (mostly) on the lunar farside. This basin is so big that its bottom is about 8 kilometers (5 miles) lower than the average lunar surface. Scientists would like to sample rocks from that deep in the crust.

There are other reasons to establish a lunar base besides studying the Moon. The lack of an atmosphere makes the Moon a very good place to do astronomy. Earth's atmosphere distorts the light that comes through it and even prevents much light from reaching the surface at all. (That is how it protects humans from radiation.) A telescope on the Moon would produce a clear image and could gather light of any wavelength. Because the Moon turns so slowly on its axis, a telescope anywhere on the Moon could observe its target continuously for days at a time, so even a small telescope could do useful work. With no atmosphere to scatter sunlight, observing in the daytime would be possible as well. Radio astronomers on Earth are encountering increasing problems with noise, but the farside of the Moon is the only place in the solar system that is always shielded from the radio noise from Earth. Because of the Moon's lower gravity, telescopes could eventually be built far larger on the Moon than on Earth.

The Moon could also be a good platform for observing Earth and its neighborhood in the solar system. Earth is always in the sky on the lunar nearside (although Earth turns and goes through its phases as it seems to hang in one spot). Because the Moon orbits Earth, and because Earth's magnetic field is affected and distorted by the solar wind, the Moon samples different regions of Earth's **magnetosphere** as it circles Earth every month.

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

Finally, the Moon can serve as a stepping-stone on humanity's journeys beyond Earth. It took the Apollo astronauts only about three days to travel between the Moon and Earth. A trip to Mars takes at least six months one-way with today's technology. It might be wise to test the abilities of humans to live for an extended period on the Moon before trying to live on Mars. It would be possible to make an emergency return from the Moon in a few days if necessary, but that would be difficult or impossible from Mars. Also, hydrogen and oxygen make excellent rocket fuel, so if there is abundant water at the lunar poles, the Moon may turn out to be the "last chance for gas" on the way to Mars and beyond. SEE ALSO Communities in Space (volume 4); Domed Cities (volume 4); Food Production (volume 4); Governance (volume 4); Habitats (volume 3); Living on Other Worlds (volume 4); Lunar Outposts (volume 4); Moon (volume 2); Political Systems (volume 4); Power, Methods of Generating (volume 4); Scientific Research (volume 4); Settlements (volume 4); Social Ethics (volume 4); Solar Wind (volume 2).

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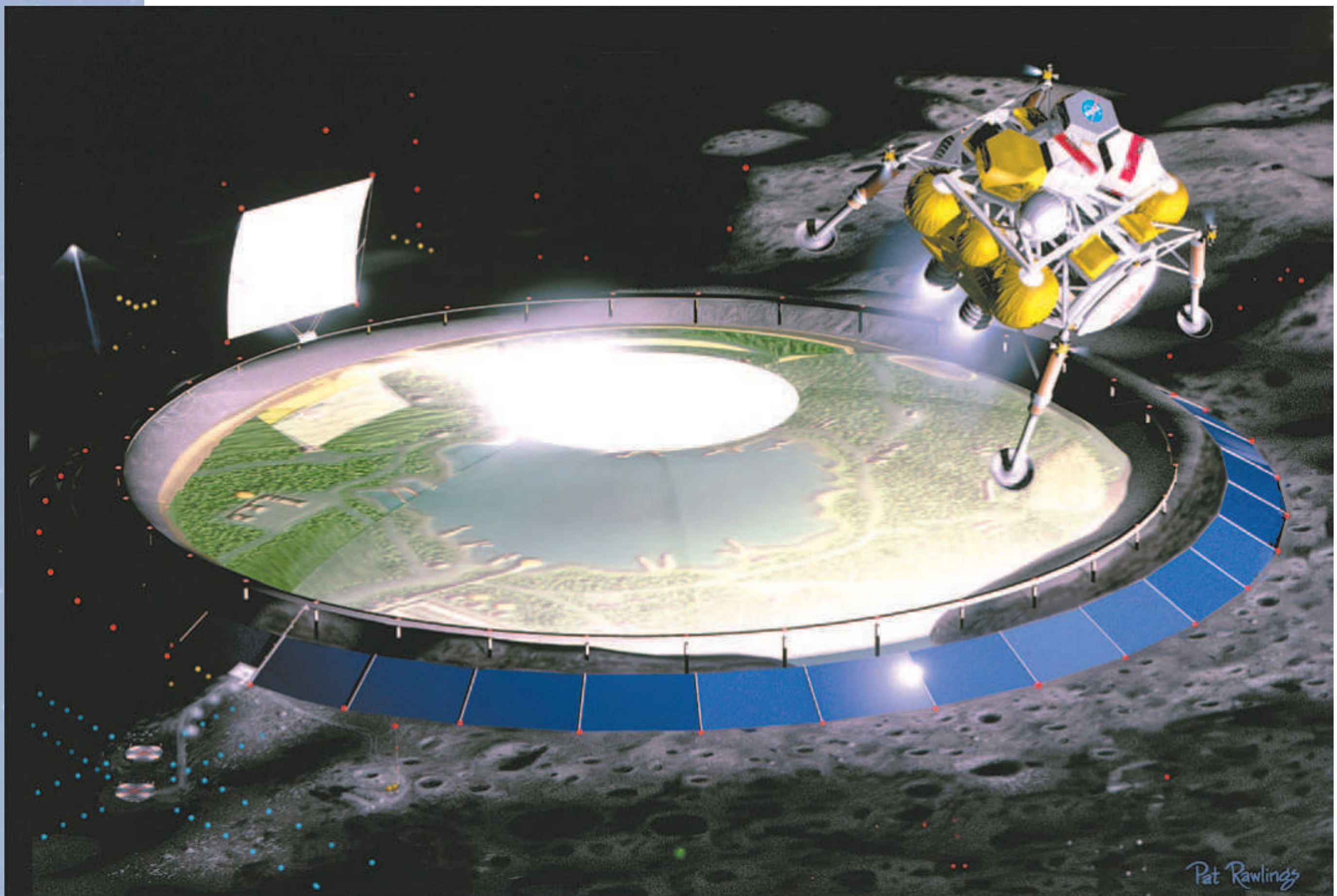
Lunar Outposts

Someday humans will live on Earth's Moon. However, before permanent settlements are established, people will probably occupy a series of lunar outposts. Each outpost will be visited one or more times for a few days to as long as a few months so that specific tasks can be performed; when the jobs are finished, the occupants will leave. Visitors to a lunar outpost will have to take with them almost everything they will need there, including the food they will eat and the air they will breathe.



Lunar outposts have potential scientific, commercial, and military uses.

The Apollo Outposts

The Apollo program of the National Aeronautics and Space Administration (NASA) placed six lunar outposts on the Moon between July 1969 and December 1972. Each one was part of a lunar landing mission during which two American astronauts landed a spacecraft on the surface of the Moon. The astronauts traveled on the surface of the Moon to place scientific instruments and gather geologic samples and then returned to orbit to rejoin the main spacecraft, in which another astronaut had been orbiting the Moon. Part of the landing craft remained on the Moon to be used as a launch platform; the rest was used to carry the astronauts back to lunar orbit. After the astronauts transferred everything necessary back to the main spacecraft, the landing craft was crashed onto the Moon. One reason for crashing the landers was to provide signals for the seismometers the astronauts had placed on the surface to study moonquakes.

Future Outposts

The Apollo missions were designed as brief visits to a variety of locations, and so there was no reason to establish reusable outposts. In the future, lunar outposts may be designed differently. Scientists have studied the rocks and soil returned from the Moon by the Apollo astronauts and have used telescopic and spacecraft observations to learn a great deal about the lunar environment. It is likely that future outposts will be located in areas that scientists want to study in more detail and will be more permanent facilities that can be visited more than once.

All future lunar outposts will have some features in common. The primary function of each outpost will be to keep the people who visit it alive. This includes protecting them from danger and providing what they need to remain healthy. Dangers in the lunar environment include radiation, extreme temperatures, and the **vacuum** of space. The Moon has almost no atmosphere, so the Apollo astronauts had to wear space suits when they left the landing craft. Any future lunar outpost will need to be airtight so that its visitors will be able to remove their space suits after they enter. An airlock would help reduce the amount of air lost to space each time someone entered or left the outpost.

vacuum an environment where air and all other molecules and atoms of matter have been removed

Earth's atmosphere protects people from much of the harmful radiation produced by the Sun and moderates the temperatures on the planet's surface. The Moon lacks this natural protection, and so lunar outposts must protect their visitors. The longer people stay on the Moon, the more protection from radiation the outpost must provide, because the effects are cumulative. One way to protect against radiation is to shield the outpost with rock or soil. The surface of the Moon is covered by a soil layer called regolith, which has been produced by meteorite impact. This layer can be moved relatively easily to cover the outposts. A layer a few meters thick would protect the people inside from radiation. It also would help insulate the outpost and make it easier to maintain a comfortable temperature inside.

People need to eat food, drink water, and breathe air, and all these things must be taken along with them to a lunar outpost. These materials are all cycled through the body and turned into waste products, and so there must be toilets and air purification equipment to maintain a healthy environment.

The Purpose of Future Outposts

Other features of lunar outposts will depend on the tasks to be performed. Some activities of the Apollo astronauts will probably be repeated at future lunar outposts. Scientific instrument packages will be put in place, maintained, and serviced in order to provide information on the lunar environment, surface, and interior. Geologic fieldwork will be performed; samples of rock and soil will be gathered for this purpose. Some human exploration will be done, although robotic explorers, perhaps controlled remotely by people at the outpost, probably will also be used.

One scientific endeavor for which the Moon is well suited is astronomy. Although the lack of an atmosphere is a problem in terms of life support, it makes the Moon an almost ideal platform for astronomy. Because the Moon turns on its axis only once a month, targets may be observed continuously for many days. Light is not lost or distorted by traveling through air, and so even a small telescope can make useful observations. The farside of the Moon is the only place in the solar system that is always shielded from radio waves coming from Earth, and so it is a perfect place for radioastronomy. The Moon's weaker gravity, only one-sixth that of Earth, will make it possible to build bigger telescopes on the Moon than can be built on Earth.

Some outposts will probably be utilized to test technologies that will be used later in more permanently occupied bases. Some of these technologies will relate to maintenance of the bases, such as automated greenhouses to grow food and recycle carbon dioxide. Other technologies to be tested will include the extraction of hydrogen, oxygen, and other gases from lunar rocks and soil. The hydrogen and oxygen can be used for fuel, water, and breathing. Helium eventually may be used in **fusion** reactors to produce power.

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

The next lunar outposts could be constructed by NASA, a cooperating group of nations, a government-industry partnership, or even private for-profit companies. Lunar outposts have been built before, and more can be built in the future. SEE ALSO Asteroid Mining (volume 4); Closed Ecosystems (volume 3); Habitats (volume 3); Living on Other Worlds (volume 4); Lunar Bases (volume 4); Moon (volume 2); Power, Methods of Generating (volume 4); Resource Utilization (volume 4); Scientific Research (volume 4); Settlements (volume 4); Space Industries (volume 4).

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Mars Bases

A Mars base could be the key to making Mars part of humanity's future. Explorers at a base could explore Mars for years or even decades. This is significant because while Mars has only half Earth's diameter, it has as much surface area to explore as Earth has land area. A Mars base might also serve as a stepping-stone to a permanent Mars settlement. Mars is a desirable settlement target because it is the planet in the solar system most like Earth.

Types of Bases

The form that the first Mars base will take will depend on its ultimate purpose. If established only for brief use with specific objectives in mind, it might resemble a temporary base camp set up to scale Mt. Everest. Alternatively, it might be established for long-term scientific exploration, like McMurdo Base in Antarctica. A base might also be intended as a nucleus around which permanent Mars settlement could grow, much as Jamestown, Virginia, was for the English who settled North America in the early seventeenth century.

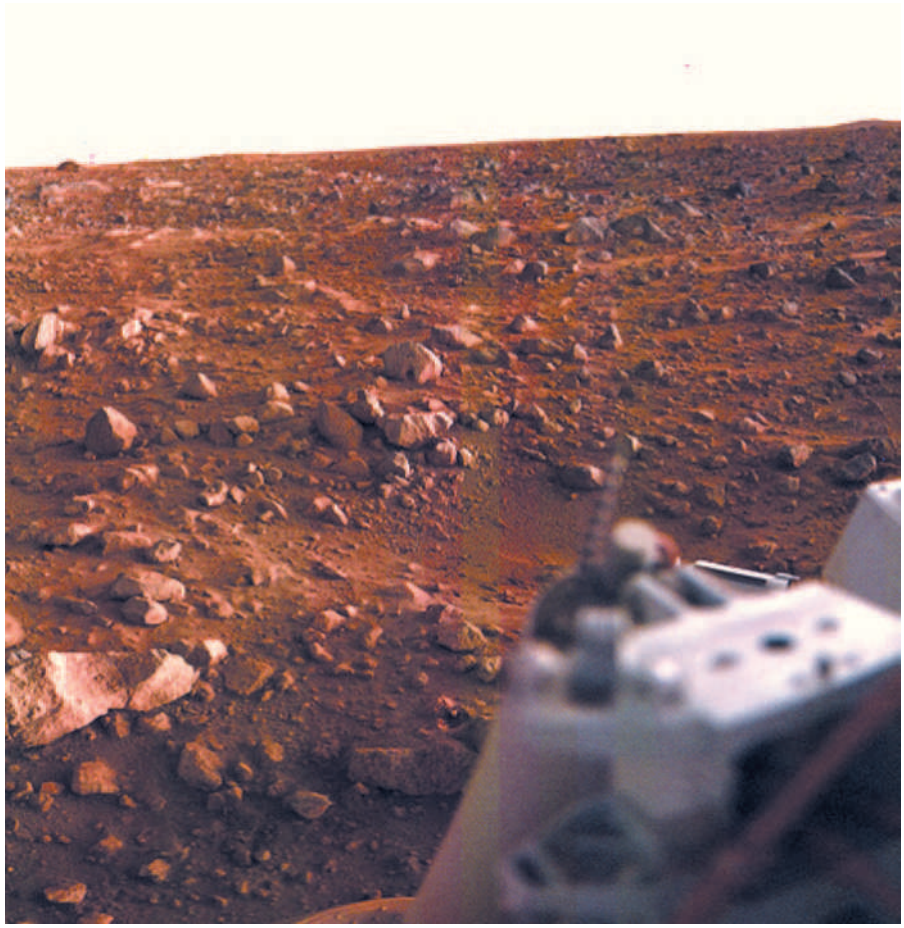
In old Mars plans, piloted landing missions, each lasting less than a month, started human exploration of Mars, and any form of base came only later. The Mars exploration plan favored today by the National Aeronau-

Although interplanetary settlement is many years away, Mars is the likely candidate for first settlement since its environment is most like Earth's.

tics and Space Administration (NASA), however, encourages establishment of a temporary base camp on Mars on the first expedition. In NASA's plan, spacecraft use a six-month, low-energy path to travel to Mars. The explorers must then wait at Mars for about 500 days while Earth and Mars move into position so the explorers' spacecraft can follow a six-month, low-energy path home to Earth. This strategy slashes the amount of **rocket** propellant needed, which saves money—less propellant means fewer expensive rockets are needed to launch the Mars mission into space. If NASA's Mars plan becomes the basis for future Mars expeditions, the astronauts are likely to spend most of their time at Mars on the surface, where they can dig in for protection from radiation and explore as much as possible.

rocket vehicle or device especially designed to travel through space, propelled by one or more engines

If settlement is the ultimate goal, the base will serve as a "kindergarten" where humanity can learn about settling another planet. Researchers at the base will test human reactions to long exposure to Mars conditions. It is not known, for example, whether humans can survive indefinitely in Mars



This image, taken by Viking Lander 1 just before sunset, shows a landscape dotted with rocks, exposed bedrock, and small depressions.

gravity, which is only one-third as strong as Earth gravity. The base will also develop settlement technologies. For a Mars settlement to be truly permanent, it will need to use Martian resources to sustain itself and grow. The base might, for instance, experiment with processing Mars dirt so it can be used to grow food plants in pressurized greenhouses. Researchers will also experiment with making fuel for surface and air vehicles and with manufacturing building materials.

Building a Mars Base

Setting up the base will be a step-by-step process. The first step will be to gather data about Mars so that a base site can be selected. Current robotic missions are providing initial data that might eventually be used for base site selection. At minimum, the site must be accessible by spacecraft, with flat places to land, and scientifically interesting sites should be located nearby. If meant for a long-term base or a permanent settlement, the site should be near useful resources, such as underground water or ice, geothermal heat sources, wind for windmills, and latitudes where solar energy can be used year-round. The base should be in a relatively warm area, not prone to dust devils (small whirlwinds of dust) or seasonal dust storms. It might be established on Mars' northern plains or in the southern hemispheric Hellas basin, both places where low altitude means that air pressure is relatively high (though even in such low-lying places it is still barely

1 percent of Earth sea-level pressure). High air pressure means that spacecraft can make fuel-saving parachute-assisted landings and that industrial processes using Martian air as a resource can be more efficient.

The next step will be to build the base. To start, modules built on Earth might land at the chosen site to form a start-up base. In 1965 German-born American rocket pioneer Wernher von Braun described a plan for a "little village" on Mars made up of crew and cargo landers based on Apollo program technology. The second Case for Mars conference, in 1984, envisioned a similar start-up strategy—cargo landers based on space shuttle and **space station** technology would be tipped on their sides to serve as living space.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

A temporary base camp might not progress beyond this stage. If, however, the base is meant for the long term or as a settlement nucleus, the astronauts will eventually need to build large, complex structures to supplement modules shipped from Earth. At first, they will probably use prefabricated parts made on Earth. A Mars blimp hangar, for example, would be too large to ship from Earth in one piece, so it would have to be shipped in pieces and assembled on Mars. As new construction equipment arrives from Earth and experience with living on Mars increases, the explorers might begin building using Martian materials. As the Mars explorers become Mars settlers, they might dig tunnels into cliff faces, then progress to erecting clear plastic "tents" over craters and valleys, turning them into huge greenhouses.

Will We Build a Base on Mars?

These plans assume that we will send people to Mars, and that we will decide to establish a Mars base. History shows that, just because a new world awaits us, it does not follow that we will explore it. Apollo was not followed by a lunar base, even though much remains to be explored on the Moon. If there is life on Mars, we might not build a base—or, indeed, land humans—because to do so would contaminate the planet and possibly destroy its unique biota. We might instead settle worlds without life, such as Earth's Moon or the asteroids. Alternatively, if Mars is lifeless, a base could become life's first foothold on the planet. In time, Mars settlers might begin experiments aimed at remaking Mars' environment—a process called terraforming—so it can support plants and animals from Earth. SEE ALSO Earth—Why Leave? (volume 4); Food Production (volume 4); Habitats (volume 3); Human Missions to Mars (volume 3); Living on Other Worlds (volume 4); Lunar Bases (volume 4); Mars (volume 2); Mars Direct (volume 4); Mars Missions (volume 4); Power, Methods of Generating (volume 4); Resource Utilization (volume 4); Scientific Research (volume 4); Settlements (volume 4); Space Industries (volume 4); Terraforming (volume 4).

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Mars Direct

The Mars Direct concept for a human mission to Mars has been vigorously championed since 1990 by engineer Robert Zubrin, who developed it with fellow Martin Marietta Corporation engineer David Baker. The National Aeronautics and Space Administration (NASA) estimated in 1993 that its plan for Mars exploration, which is called the Design Reference Mission and drew heavily on the Mars Direct approach, could make human footsteps on Mars possible by as early as 2009.

A Clever Synthesis

Mars Direct originated in a Martin Marietta–sponsored effort to develop plans for U.S. President George H. W. Bush's Space Exploration Initiative (1989–1993), which aimed to return humans to the Moon and land the first astronauts on Mars by 2019. Bush's initiative failed because of excessive cost and lack of political support, but it provided an opportunity to revive many old Moon and Mars exploration ideas. Mars Direct, for example, is a cost-saving synthesis of concepts dating back to the 1950s.

Old concepts in Mars Direct include manufacturing propellants on Mars for the trip home to Earth; splitting the expedition between cargo and crew spacecraft; and a 500-day stay on Mars for the first expedition. The last idea allows the crew to wait for Mars and Earth to move into positions in their orbits around the Sun and enable a propellant-saving low-energy voyage back to Earth. In 1989 NASA's Space Exploration Initiative Mars plan was expected to cost about $400 billion. According to Zubrin's 1990 estimate, Mars Direct might cost a quarter as much.

The Mars Direct Plan

In their earliest Mars Direct papers, Zubrin and Baker described a Mars expedition kicking off in December 1996. A giant Ares rocket consisting of a space shuttle external tank with four attached space shuttle main engines and two shuttle advanced solid rocket boosters would lift off from Kennedy Space Center in Florida. Atop the external tank would sit a rocket stage and a 40-ton automated cargo lander covered by a streamlined shroud. The cargo lander would include an **aerobrake** heat shield, a descent stage, an Earth-return vehicle (ERV), a propellant factory, 5.8 tons of liquid hydrogen, and a nuclear reactor on a robot truck. The Ares rocket would launch the cargo lander onto a direct course to Mars without assembly in Earth orbit—hence the name Mars Direct.

aerobrake technique of using a planet's atmosphere to slow down an incoming spacecraft. Its use requires the spacecraft to have a heat shield, because the friction that slows the craft is turned into intense heat

The 1996-launched cargo lander would land on Mars, then the robot truck would trundle away to safely position the nuclear reactor in a crater. The reactor would then activate to generate electrical power for compressors. These would draw in Martian air to manufacture propellant for the ERV.

The propellant factory would use the Sabatier Process first proposed for use on Mars in 1978 by engineers Robert Ash, William Dowler, and Giulio Varsi at NASA's Jet Propulsion Laboratory. Liquid hydrogen **feedstock** would be exposed to Martian atmospheric carbon dioxide in the presence of a **catalyst**, producing liquid methane and water. The methane would be stored and the water split using electricity to yield oxygen and more hydrogen. The oxygen would be stored and the hydrogen recycled to manufacture more water and methane. In a year this process would manufacture 107 tons of methane and oxygen propellants.

feedstock the raw materials introduced into an industrial process from which a finished product is made

catalyst a chemical compound that accelerates a chemical reaction without itself being used up

In January 1999 two more Ares rockets would lift off. One would carry a cargo lander identical to the one already on Mars; the other, a drum-shaped, 38-ton piloted spacecraft 8.4 meters (27.5 feet) wide and 4.9 meters (16 feet) tall. Its top floor would house the four-person crew, while its bottom floor would carry cargo, including a Mars rover. The Ares rockets would launch the two spacecraft directly onto six-month transfer paths to Mars.

The 1999-piloted spacecraft would land near the cargo lander launched in 1996. The 1999 cargo lander, meanwhile, would land 800 kilometers (500 miles) from the 1996 cargo lander and begin making fuel for the second crew, which would leave Earth in 2001.

Eleven of the 107 tons of propellants manufactured by the 1996 cargo lander's propellant factory would fuel the rover. The explorers would undertake long traverses, thoroughly studying and recording the characteristics of the region around their landing site. The rover might traverse a total of 16,000 kilometers (10,000 miles) during the explorers' 500-day Mars surface stay.

As Earth and Mars move into position, the 1999 expedition crew would board the 1996 ERV. Rocket engines burning the methane and oxygen propellants manufactured from the Martian atmosphere would place it on direct course for Earth. After six months in the ERV, the crew would reenter Earth's atmosphere and perform a parachute landing.

The most significant difference between Mars Direct and NASA's 1993 Design Reference Mission was the division of ERV functions between two vehicles. In the judgment of many, the Mars Direct ERV was too small to house four astronauts during a six-month return from Mars. It provided about as much room as a phone booth for each crew member. In NASA's plan, therefore, the crew would use a small Mars ascent vehicle to reach Mars orbit. Once there, they would dock with an orbiting ERV.

Martian Towns

The 2001 expedition crew would land near the 1999 cargo lander, and the 2001 cargo lander would land 800 kilometers (500 miles) away and make propellants for the 2003 expedition. The 2003 crew would land by the 2001 cargo lander; meanwhile the 2003 cargo lander would touch down 500 miles away and make propellants for the 2005 crew; and so on. After several expeditions, a network of Mars bases would be established. “Just as towns in the western U.S. grew up around forts and outposts,” wrote Zubrin and Baker, “future Martian towns would spread out from some of these bases. As information returns about each site, future missions might return to the more hospitable ones and larger bases would begin to form.” (Zubrin and Baker 1990, p. 41). SEE ALSO Human Missions to Mars (volume 3); Living on Other Worlds (volume 4); Mars Bases (volume 4); Mars Missions (volume 4); Natural Resources (volume 4); Power, Methods of Generating (volume 4); Resource Utilization (volume 4); Zubrin, Robert (volume 4).

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Mars Missions

Mars has attracted human interest throughout history. *The War of the Worlds* (1898) by H. G. Wells, about an advanced Martian civilization that came to attack Earth, was inspired by the work of the Italian astronomer Giovanni Schiaparelli, who observed *canali* (channels) on Mars. (The Italian word *canali* was mistranslated as “canals.”) This led to interest in the possibility of intelligent life on Mars.

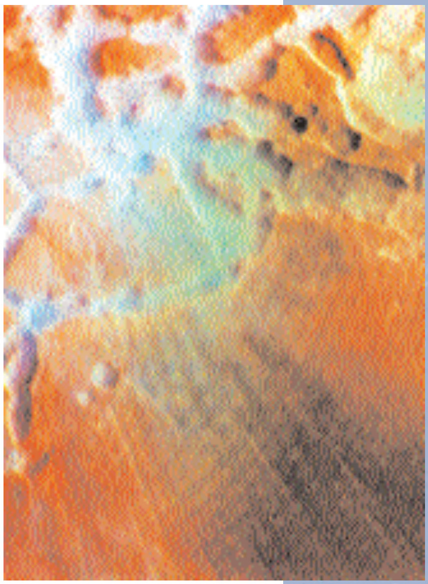
Although it is now known that there is no intelligent life on Mars, planning for exploration of the Red Planet is at an all-time high. The question of whether simple life ever arose on Mars is a strong motivation for exploration. Other questions include how the Martian climate evolved and how it differs from that on Earth and how the surface and interior of Mars evolved.

Proposed Missions

With the long-term goal of human exploration, many preliminary missions are needed to address these questions and engineering issues. Water is the link between these goals, and the plan of the National Aeronautics and Space

Administration (NASA) is to "follow the water." The strategy will be to sample the Martian environment through **in situ** experiments and by bringing pieces of the planet back to Earth.

The proposed mission plans for the next decade include one or more spacecraft launches every two years. These spacecraft will be designed to address the primary scientific questions and conduct the experiments necessary to prepare for the launching of astronauts to Mars. The vehicles will probably alternate between orbiter and lander spacecraft. Beginning in 2007, there will be less expensive spacecraft, termed "scouts," which will supplement the program by addressing objectives not targeted by the other missions.



Viking Orbiter I captured this sunrise over tributary canyons in a high plateau region of Mars. The bright white areas are clouds of water ice, which appear starkly set against the rust-colored Martian desert.

in situ in the natural or original location

Life and Water on Mars

Life on Earth contains organic carbon and needs water and energy to exist. Searching for carbon in the soil and ice on Mars and understanding how the amount of carbon has changed during that planet's history are primary goals of future Mars missions. It is important to understand where water (ice, liquid, and vapor) exists on Mars today, how much there is, and how it is transported around the planet. There may have been much more liquid water on Mars in the distant past. Flowing water may have deposited sand and silt in the bottoms of lakebeds or oceans. If standing water once existed, these areas will be a primary place to search for fossilized life.

The Mars Odyssey orbiter spacecraft, launched in April 2001, is designed to detect evidence of ancient water on Mars and possible locations of current water in the subsurface. The two rovers that will be sent to land on Mars in 2003 will study rocks and soils to determine whether water was ever present at those sites.

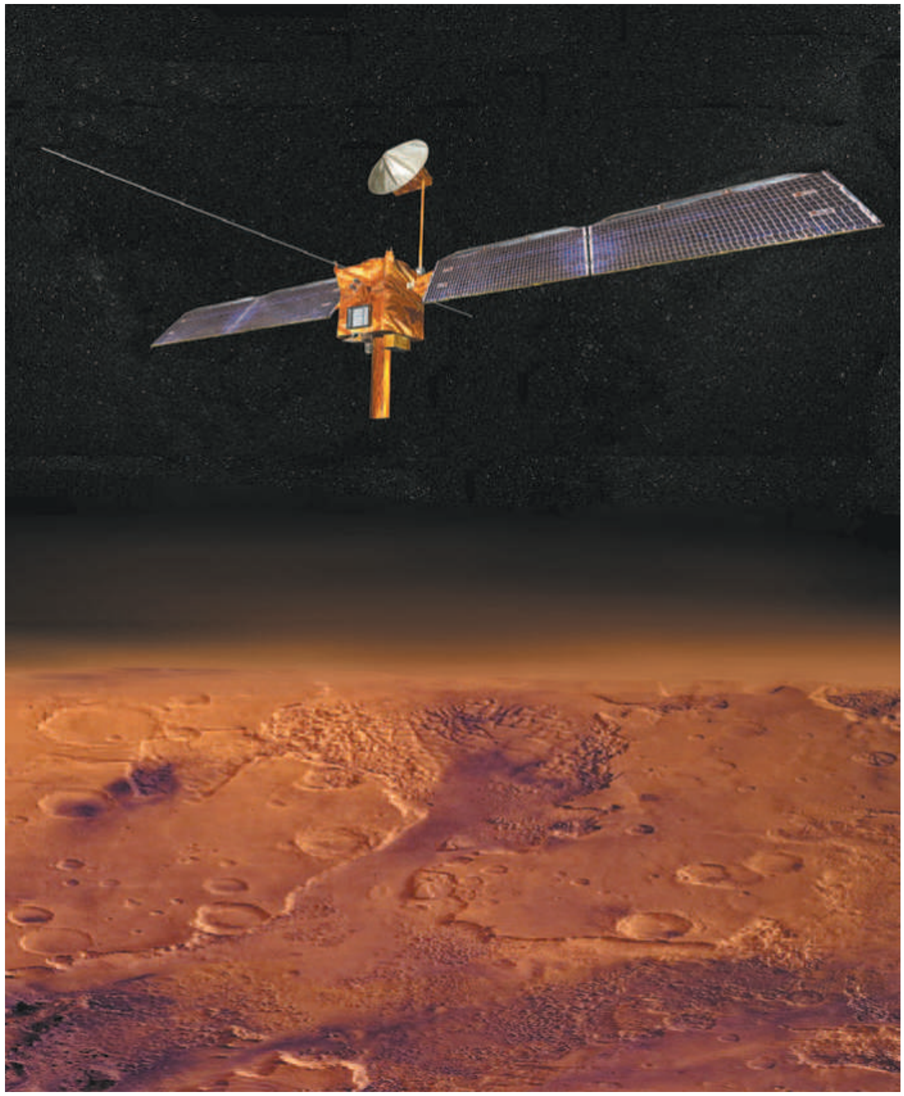
The Mars Reconnaissance Orbiter, planned to be launched in 2005, will have cameras that can see beachball-size rocks on the surface. This will allow scientists to compare surface to orbiter observations and may indicate which parts of the surface were created by volcanic flows and which were created by sand and silt deposited in water.

Scientists would also like to know how the Martian climate has changed since the ancient past. The atmosphere of Mars contains mostly carbon dioxide, with very little water. This means that there are only very thin clouds that occur rarely. Because it is very cold on Mars and the atmosphere is thin, there is no rain. Mars also has severe dust storms during the southern hemisphere summer.

However, if liquid water flowed on Mars in the distant past, the climate might have been very different from what it is today. To understand those changes, it is necessary to understand the present-day climate. The Mars Odyssey spacecraft will gain insight into the climate, but the Mars Reconnaissance orbiter will contain instruments specifically designed to address these issues.

Astronauts on Mars

Landing astronauts on Mars will not be easy. A spacecraft with humans onboard will be much heavier than any previous spacecraft and thus will enter



The Mars Reconnaissance Orbiter is expected to launch in 2005. Its main purpose will be to study the Martian surface using a high-resolution camera.

the Martian atmosphere at a very high speed. It therefore will need a new type of aeroshell and a strong parachute to slow it down.

With humans onboard, a safe landing becomes more critical—for instance, it will be important to avoid large rocks or cliff walls. To do that, instruments and software are being developed to view the ground below the spacecraft just before landing and automatically select the safest touchdown spot. The plan is to have the Mars 2007 spacecraft demonstrate these capabilities.

While on the surface, the astronauts will need to have continuous communication with Earth. This will require a network of communication satellites around Mars to provide the connection at all times of the Martian day and night. Most future science orbiters will be designed to continue in use as communications satellites. There is also a plan to have an Italian Space Agency communications satellite at Mars in 2007. Since it is difficult to bring much to Mars, rocket fuel to return to Earth probably will have to be made on the surface.

It will be very difficult for humans to survive on Mars. One of the main concerns is the radiation level on the surface of the planet. The Mars radiation environment experiment, named MARIE, is flying on the Mars Odyssey spacecraft and will help investigate the level of radiation above the atmosphere.

Understanding how much water is present and where it is located will be crucial for human survival. If water is found in deep reservoirs, instruments such as drills will be designed and tested to bring it to the surface. There also may be very small amounts of water in the soil that instruments can separate out.

If enough water and oxygen are not brought to Mars, instruments will be needed to create them on the surface. Bringing enough food will also pose a challenge. It is vital to learn enough about the soil on Mars to determine whether it is safe and can be used for growing plants for food. In addition, the soil may corrode the spacecraft or the space suits. The survival of the astronauts also will depend on having enough power to operate all the necessary machinery.

With more sophisticated instruments on Earth, scientists are certain to learn a great deal from returned Martian rock and soil samples. In the second decade of the proposed Mars plan, NASA intends to return the first sample in 2014 and the second in 2016. SEE ALSO Astrobiology (Volume 4); Human Missions to Mars (Volume 3); Living on Other Worlds (Volume 4); Mars (Volume 2); Mars Bases (Volume 4); Mars Direct (Volume 4); Natural Resources (Volume 4); Planetary Protection (Volume 4); Power, Methods of Generating (Volume 4); Resource Utilization (Volume 4); Scientific Research (Volume 4); Telepresence (Volume 4); Terraforming (Volume 4).

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Migration *See Living on Other Worlds (Volume 4).*

Military Uses of Space

During human history, the exploration of space has been based on more than just scientific potential. People may like to believe that we are exploring the cosmos purely for academic purposes, but the truth is that space plays a huge role in both offensive and defensive military planning. In fact, much of the exploration that humans have already achieved would not have come to pass if it had not been for the military motives that underpin most space missions. Long before satellites orbited Earth for cell phone calls, **global positioning systems**, or picture taking, the military was interested in space. Commercial interest would not come until years later.

global positioning system a system of satellites and receivers that provide direct determination of the geographical location of the receiver

The U.S. Department of Defense uses satellite images to monitor foreign military installations and troop movements. This image shows the damage caused to the Baghdad Directorate of Military Intelligence Headquarters by a U.S. missile attack.

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

While many countries now have space agencies and conduct missions into space, it was the United States and Russia who first began the competition to reach the stars. In 1957, more than a decade after World War II, and after the Cold War had been in bloom for years, the "space race" began. The Cold War—a war of spies and threats, of moves and countermoves—had reached a new plateau. Nuclear power had been demonstrated by both superpowers and as **rockets** began slowly to become more advanced, space weaponry became the new battleground. Not only could weapons be placed in space, but powerful cameras could be used for spying on the enemy. The potential uses for space during the Cold War were numerous and clearly visible.

Each side believed that having weapons in orbit could mean their success in this war and the destruction of their enemies. Test planes were designed to fly in space, while rockets became more than just short range missiles. Satellites would soon be designed and the launches would lead to panic and confusion.

In 1952 branches of the U.S. military, including the air force and the navy, along with private companies began trying to design planes for space travel. During a time when all planes flew with propellers, these ideas were unheard of. When the experimental X-15 debuted in 1958, the craft was far ahead of other planes. For nine years, these three hypersonic, or faster than sound, planes made more than 200 trips with twelve different pilots. They continued their trips during the Mercury, Gemini, and Apollo missions. These craft would lead designers to create a reusable spacecraft that later became the space shuttle. Amazingly, these planes made it into space and landed back on Earth decades before the space shuttle ever flew.

Ironically, the role these weapons played would become more defensive than offensive. As each superpower increased its stockpile of nuclear arms and continued its space program, it was obvious that an attack and destruction of one would lead to the mutual destruction of the other. Great efforts were made by both sides to keep the mutual destruction from happening while secretly trying to gain the advantage.

In January 1954, U.S. Secretary of State John Foster Dulles announced the new "Massive Retaliation" policy. If the Soviet Union attacked, the United States would return the attack with its huge nuclear arsenal. Despite this, the Cold War would continue to grow in scope, and while no nuclear weapons were fired, there were plenty of times when this Cold War almost became a hot one.

Russia Takes the Lead

Three years later, in 1957, America went through one of its biggest nuclear scares. On October 4, the Soviet Union launched Sputnik, the world's first artificial satellite. Even though it was only the size of a basketball, many believed that a nuclear warhead was onboard and that this was a Russian attack. During the 98 minutes that it circled Earth, the 83 kilogram (183-pound) ball showed that the space race was no longer theoretical, or even solely missile based.

In reality, the Soviets had simply beaten the United States to the first satellite launch. No nuclear warhead was onboard and the only thing given off by Sputnik was a radio transmitter's beep, proving that the satellite was functioning properly.

The Soviet Union would improve its lead, as it would soon send up Sputnik II, containing a small dog in its cargo. This was still before any U.S. satellite had been launched. The seriousness of the situation led Congress to pass the National Aeronautics and Space Act in July 1958. This act created NASA, the National Aeronautics and Space Administration, on October 1 of that year.

The United States would launch satellites of its own, but for years Russia maintained the lead in the space race. Russia beat the Americans to records for the first person in space, Yuri Gagarin; the first space walk, Alexei Leonov; and the first woman in space, Valentina Tereshkova.

As time went on, the Cold War would continue to visit new levels. A mere year after U.S. President John F. Kennedy had told Americans to begin building bomb shelters in a letter to *Life* magazine, the Cuban missile crisis in 1962 brought the world to the brink of nuclear disaster for two weeks.

Going to the Moon

It was only the year before when President Kennedy set the bar for the United States—going to the Moon. He said:

> I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish.

Great skepticism existed as to whether the United States would be able to perform this task in the time frame that Kennedy had determined. If Americans got there before the Soviets, it would mean the end of the race and a U.S. victory; if Americans did not get to the Moon before the Soviets did, the United States would have lost according to Kennedy. The next year, he further explained his decision, saying: "We have a long way to go in the space race. We started late. But this is the new ocean, and I believe the United States must sail on it and be in a position second to none." Kennedy also uttered this now-famous line: "We choose to go to the Moon. We choose to go to the Moon in this decade and do the other things, not only because they are easy, but because they are hard."

Seven years later, on July 20, 1969, U.S. astronauts Neil Armstrong and Edwin "Buzz" Aldrin would be the first men to land on the Moon, and Armstrong would say the now immortal line: "That's one small step for man, one giant leap for mankind." The United States had successfully sent men to the Moon and back before the Soviets. Despite all the setbacks—President Kennedy's assassination, astronauts who had died in previous Apollo mishaps, and the United States' start from the underdog position—Americans had won. The country rejoiced, thinking it had won the space race. But then a new race began.

President Ronald Reagan introduced a new defense program, "Star Wars," on March 23, 1983. The program was meant to protect U.S. soil from potential Soviet missile attacks.

The New Race

No longer was the race about who could get their citizens to what location. Instead, the war became about technology. Defenses against offensive systems, imaging for early warning systems, and weapon ships for ensuring military victory. The Russians would build Mir, and the United States would build its Skylab. When the space shuttle was built, the hope was to have numerous shuttles, keeping one above Earth at all times, and possibly armed with nuclear weapons. Both sides launched satellites for spying, photography, and communication interception.

As the years went on, each division of the military would begin to form its own agenda for space defense and offense. Plans continued to become more complex, until on March 23, 1983, U.S. President Ronald Reagan introduced a plan for a new defense system, nicknamed Star Wars. In his speech, the president spoke of the continuing threat of Soviet attack and raised the question, "What if free people could live secure in the knowledge . . . that we could intercept and destroy strategic ballistic missiles before they reached our own soil. . . ?" The controversy began.

The underlying technology was very new and untested. The idea that the required accuracy to destroy a missile either with a laser or by colliding another missile with it was too advanced. The concept was ahead of its time and was never successfully developed during President Reagan's days in office. Ironically, the animations of this shown on television during that time were created by the television networks and not by NASA or the government.

During U.S. President Bill Clinton's administration, tests were conducted to try and shoot down a test missile by hitting it with another. Every test failed. The proposed Missile Defense System or Missile Defense Shield did not look promising. During the office of U.S. President George W. Bush, the Missile Defense Shield again became a priority; despite massive cost overruns and failures, the tests continued.

It was during this time that the Missile Defense Shield had its biggest success and failure. For the first time, the test worked and the missile was successfully destroyed. However, the proposed Missile Defense System is in violation of the 1972 Anti-Ballistic Missile Treaty that the United States and Russia both signed. The treaty was one of many between the 1960s and the present designed to continue moving away from the prospect of nuclear holocaust. President Bush has stated that he believes the treaty is outdated, and will continue tests in spite of it. Russian President Vladimir Putin has not agreed to abandon the treaty and is a strong critic of the plan. As of this writing, each side claims they are willing to make compromises to the treaty, but the exact form those compromises will take has yet to be seen.

Another controversial event occurred during President Clinton's term in office when the armed forces were given the right to attack another spacecraft, whether it be government owned or privately owned, should it "attempt to hinder the ability of U.S. spacecraft to operate freely in space." Any such attempted hindrance is now considered to be an attack on the United States itself. At first, this piece of legislation was destroyed using the line item veto but, on appeal, the U.S. Supreme Court found the line item veto unconstitutional and this new policy replaces the one put in place by President Reagan in 1987.

Ever since the fall of the Soviet Union, Russia has been struggling to try and keep its space program afloat. From the costs of upkeep on the Mir space station to the new International Space Station, the Russian Space Agency has undergone many challenges. In 2001 the organization was restructured again as Russia continued to cut back on its military space program. Between cost concerns for the International Space Station and political feelings about Missile Defense Systems, experts predict that Russia's space program will either undergo a vast transformation in the coming years or a terrible collapse. Russia and the United States are not the only countries, however, with space programs.

Today, many different space agencies exist in numerous countries. France has its agency, the Direction Générale de l'Armement or DGA, while Japan has its own space agency, called NASDA, or the National Space Development Agency, founded in 1969. Even countries without large space agencies still have launch sites for military and commercial satellites. Brazil has prime real estate, near the equator, for launches. (Being closer to the equator means the rocket can leave Earth having used less fuel.) Many countries are joining together and launching satellites and rockets by combining

USING SATELLITES TO FIGHT

The military's use of space continues to grow with each passing campaign. In January 2002, the final Milstar satellite was launched into orbit. This series of satellites provide more secure data transmission, as well as faster relaying of mission critical data. The system is capable of cutting the transmission time from dozens of hours to a mere few when transmitting photographs taken from orbit. The same imaging sensors are used to help aid precision bomb attacks over enemy targets.

their money and resources. It is in this fashion that the International Space Station is being built. Ironically though, as countries come together to build this station, many still develop and launch satellites designed for defense against other countries. It indicates that space exploration may always include a defensive submotive, at least as long as there is disagreement here on Earth.

Now, many military officers carry specially modified computer laptops that rely on satellite-guided data to ensure the positions of themselves, their allies, and their targets. The accuracy available is so remarkable, it puts the revolutionary GPS to shame. Military satellites with these abilities can map areas on Earth down to the last inch, and possibly even smaller areas. Full information on military space capabilities is not made available to the public. SEE ALSO Global Positioning System (volume 1); Launch Facilities (volume 4); Military Customers (volume 1); Space Industries (volume 4).

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Miniaturization

Space exploration is an expensive and risky business. All too often, probes malfunction once they leave the ground; launching a satellite costs many millions of dollars at a minimum, and prices increase with **payload** weight. Designers feel constant pressure to keep spacecraft as efficient and cost-effective as possible.

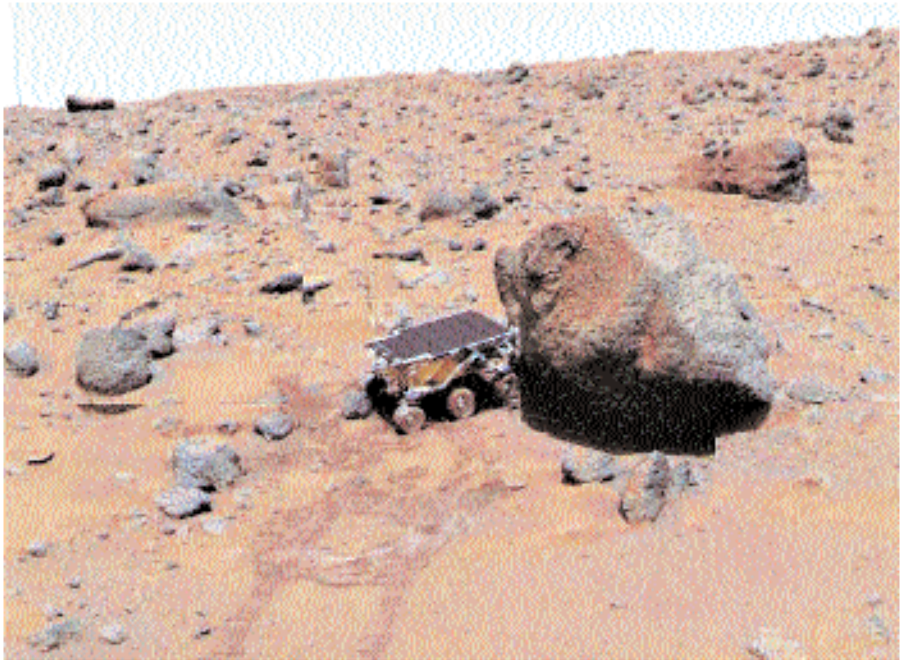
payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

To solve these problems, engineers are finding new ways to miniaturize spacecraft components, often pursuing branches of science that are still in their infancy. But the potential benefits for both the space program and private industry are driving a concerted effort toward smaller, more advanced technology.

Nanotechnology

The capability to construct nanometer-sized materials promises to have tremendous impact on space exploration and industry. Scientists are still learning to manipulate nanomaterials, but one promising creation is a form of carbon called a nanotube. These cylinder-shaped molecules are not only unusually strong, but also have potential as **semiconductors**, which could

semiconductors elements with properties intermediate between the metals and nonmetals



Advances in nanotechnology at NASA are important in the miniaturization of equipment such as the Sojourner rover. By helping reduce payload weight and size, launch costs can be cut dramatically.

make them ideal candidates for both the next generation of spacecraft hull and the computers inside them. Composite materials that incorporate nanotubes could dramatically reduce the weight of launch vehicles and commercial aircraft, cutting fuel requirements by 25 percent or more. NASA is also trying to develop sensors based on nanoscale devices. These would potentially be sensitive enough to detect a single molecule of a substance, while still being microscopically small.

In the long term, scientists may be able to exploit the characteristics of biological systems to create materials that actually assemble themselves—without need for manufacture. Such materials would also have the ability to "heal themselves" after being damaged, increasing the durability of the aircraft or spacecraft.

Computer Microsystems

It is predicted that within ten years, the silicon switches on chips will be made of single molecules, at which point silicon will reach its physical limits as a semiconductor. While other materials such as nanotubes could help augment silicon, other innovations in computer design can help shrink systems as well.

Systems on a chip will replace circuit boards with many discrete components, leading to much smaller and lower-power systems with higher reliability. A current example is a digital camera on a chip that includes the imager, all control electronics, and an analog-to-digital converter—all on the same silicon chip. Navigation systems built around this technology can guide spacecraft, and also can help soldiers and firefighters position themselves.

Micro Power Sources

Powering a spacecraft under the extremes of heat, cold, and radiation levels encountered on a mission has always been challenging, but it is even more so when the power source has a size limitation. The only miniaturized power sources currently available are electrochemical batteries (which have a limited lifespan) and solar cells (which lose their effectiveness when far from the Sun or in a planet's shadow).

kinetic energy the energy an object has due to its motion

Two potential solutions are thermoelectric power, which converts heat energy into electricity; and alpha-voltaic power, which converts the **kinetic energy** of alpha particles emitted from a radioactive isotope. While still under development, these methods could produce chip-sized, solid-state power supplies that could have applications on Earth whenever battery lifetime and environmental limitations play a role. SEE ALSO Communications, Future Needs in (volume 4); Mars Missions (volume 4); Nanotechnology (volume 4); Scientific Research (volume 4); Space Industries (volume 4); Vehicles (volume 4).

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Mining ***See Asteroid Mining (Volume 4); Natural Resources (Volume 4); Resource Utilization (Volume 4); Space Resources (Volume 4).***

Movies

In 1997 astronomer Jim Scotti discovered the asteroid 1997 XF11. Initial calculations predicted that the asteroid would make an extremely close approach to Earth in 2028. A collision would result in a global catastrophe, killing hundreds of millions of people. More accurate calculations of the orbit of the asteroid, however, determined that its probability of colliding with Earth is zero. Nonetheless, Hollywood films such as *Deep Impact* and *Armageddon*, both released in 1998, illustrated the global crisis that a comet or asteroid heading toward Earth would generate. Together with the alarming news about 1997 XF11, these movies heightened public awareness of the threat from an asteroid impact. As a result, the National Aeronautics and Space Administration (NASA) doubled its funding to $3 million a year for searching for near-Earth objects (NEOs). In addition, NASA initiated the Spaceguard Survey, intended to find 90 percent of all NEOs larger than 1 kilometer (0.62 mile) in diameter by 2008. Ultimately, the Torino scale, developed by astronomer Richard Binzel, was released in 1999 as a means of categorizing the likelihood of an asteroid or comet colliding with Earth.

Deep Impact and *Armaggedon* are two of over a hundred science fiction films about space that have generated interest in space exploration. For instance, *2001: A Space Odyssey* (1968) illustrated what space travel may have been like in the year 2001. In addition to its artistic use of visual and sound effects, that film introduced fascinating ideas for new technologies. The *Star Wars* trilogy and the *Star Trek* movie franchise also offered ideas for advanced technological devices. Other science fiction films, such as *E.T. The Extra-Terrestrial* (1982) and *Contact* (1997) in which humans make contact with intelligent extraterrestrial life have sparked the imagination and curiosity of viewers, generating excitement about exploring the depths of space.

A year before humans walked on the Moon, *2001: A Space Odyssey* opened in theaters. This movie has had such a great impact on society that a NASA spacecraft en route to Mars was named after it: the 2001 Mars Odyssey. Adapted from the novel by Arthur C. Clarke and directed by Stanley Kubrick, *2001: A Space Odyssey* foresaw a colonized Moon and a piloted mission to Jupiter in the year 2001. While the Moon has not yet been colonized, scientists are looking closely at Mars, where settlement may be easier because of the possible presence of water. Perhaps the enthusiasm generated by the piloted trip to Jupiter shown in the movie will be caused by the first human mission to Mars.

Extraterrestrials emerge from their spacecraft to warn humans of impending nuclear disaster in a scene from the 1951 film *The Day the Earth Stood Still.*

Settling Mars, however, will probably require a process known as terraforming. The atmosphere of Mars is composed of carbon dioxide, which may be converted to breathable air by this process. As an example, the movie *Red Planet* (2000) suggests one possible way of terraforming Mars—using **algae** to create a **greenhouse effect** that would allow life to thrive there. Some ideas for new technologies introduced by *2001: A Space Odyssey* exist today. For example, videoconferencing as shown in the movie is feasible via the Internet along with an inexpensive video camera. However, an intelligent computer such as HAL 9000 is still science fiction, although advances in artificial intelligence have produced expert systems that help professionals make decisions.

algae simple photosynthetic organisms, often aquatic

greenhouse effect process by which short wavelength energy (e.g., visible light) penetrates an object's atmophere and is absorbed by the surface, which reradiates this energy as longer wavelength infrared (thermal) energy; this energy is blocked from escaping to space by molecules (e.g., H_2O and CO_2) in the atmosphere; and as a result, the surface warms

Technology

George Lucas's *Star Wars* trilogy generated another wave of enthusiasm for space travel. The technology of *Star Wars* is highly advanced, although the ideas behind it have caused people to ponder their possibilities. The lightsaber, a powerful energy-based sword, is one example. Today researchers can use lasers to cut through some materials, but there is nothing like the lightsaber. Another interesting concept in those films is the hyperdrive, which can transport a starship at a speed faster than that of light. Scientists are just beginning to ask directed questions about the possibility of lightspeed travel. Similarly advanced is the idea of antigravity. Researchers have been able to simulate antigravity under extremely cold temperatures for small objects, but true antigravity is only a theoretical concept. Other technologies, such as the holocam, the proton torpedo, the blasters, and the electrobinoculars, are high-technology devices that with human ingenuity may become realities.

The *Star Trek* television series and movies offer a myriad of advanced technologies, the most prominent being the transporter and the holodeck. The transporter can convert every atom of an object into a stream of matter and send it to its destination to be reconstructed there. By taking advantage of the properties of quantum mechanics, scientists have been able to "teleport" a photon, or light particle, a promising achievement. The holodeck can produce a holographic environment that feels as real as

The crew of the starship Enterprise in a scene from the 1986 film *Star Trek IV: The Voyage Home.* Fans of the series *Star Trek* successfully petitioned the White House to name the first space shuttle orbiter "Enterprise."

reality. Researchers at the Massachusetts Institute of Technology have been able to make small holographic imaging devices with force-feedback, but holodeck-type rooms are technologies of the future. Like the high-technology devices in *Star Wars*, the tricorder, the warp drive, and the phaser in *Star Trek* remain to be explored.

Extraterrestrial Life

The discovery of extraterrestrial life would be one of the greatest achievements in human history. As a result, many movies that depict an alien encounter have generated enthusiasm for space exploration. Steven Spielberg's *E.T. The Extra-Terrestrial* touched many viewers' hearts through its depiction of the love of an alien, giving people a motivation to explore outer worlds. Similarly, *Contact*, based on scientist Carl Sagan's novel, motivated space exploration through the words of an advanced alien being. However, the central theme of *Contact* was the process of decoding a message that described how to build a machine with an unknown function. *Contact* illustrated how the message united people around the world for the common goal of building a machine that might reveal the purpose of humanity. Other films, such as *Cocoon*, *The Abyss*, and *Mission to Mars*, have given humans a motive to explore space: the possibility of an encounter with an alien civilization and the rewarding consequences it might have.

Science fiction movies express ideas that may become realities and provide reasons to examine the depths of space more closely. SEE ALSO Domed

Cities (volume 4); Faster-Than-Light Travel (volume 4); First Contact (volume 4); Interstellar Travel (volume 4); Ion Propulsion (volume 4); Lunar Bases (volume 4); Lunar Outposts (volume 4); Mars Bases (volume 4); Science Fiction (volume 4); Star Trek (volume 4); Star Wars (volume 4); Teleportation (volume 4); Time Travel (volume 4); Vehicles (volume 4); Wormholes (volume 4).

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Nanotechnology

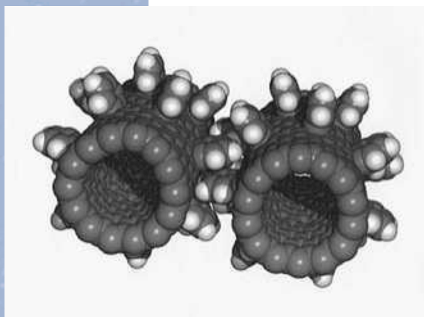
N

Like a swarm of bees, tiny humanmade satellites—called nanosatellites or picosatellites, depending on their size—may one day fly in formation to remote destinations throughout the solar system. Upon reaching their targets, they will spread out to investigate the area, perhaps one satellite landing on each of a thousand asteroids, crawling around its surface, and sending data back to scientists waiting on Earth. Another swarm might cover the surface of Mars with an army of explorers, investigating more area in one day than a standard rover could reach in several years. Alternatively, the group might be designed to stay together to accomplish its mission: a cluster of satellites each carrying a tiny mirror could be coordinated to act as one giant telescope mirror, surpassing the Hubble Space Telescope's light-gathering power by a factor of a thousand.

Problems with Large Satellites

Typical satellites deployed in the early twenty-first century weigh more than 1,000 kilograms (2,200 pounds). To qualify as a nanosatellite, the device must weigh less than 20 kilograms (or 44 pounds); a picosatellite less than 1 kilogram (2.2 pounds). Such small nano- or picosatellites could address two of the major problems involved with traditional satellite technology:

1. Cost. The major expense of deploying a traditional satellite lies in transportation costs. A ride on the shuttle averages $6,000 per pound, so the lighter the better. Tiny satellites could possibly be launched using small rockets or electromagnetic railguns, bypassing the expensive shuttle ride altogether.
2. Failure due to one faulty system. If the communications system of a traditional satellite fails, or if the satellite is damaged during deployment, the whole mission might be scrapped, at a loss of millions of dollars. But nano- and picosatellites could be designed with distributed functions in mind: Some may be responsible for navigation, some for communication, and some for taking photographs of target sites. Should a problem develop in one of the units, others in the group with the same function would take over. Distributed functions and built-in redundancy would save the mission.



These "Fullerene Nanogears" were developed by NASA as a prototype for similar future products, constructed of thousands of tiny machines that could adapt to their environment without human interaction and repair themselves.

Early Attempts: OPAL

Thanks to the miniaturization of off-the-shelf computer components, satellites the size of a deck of cards have already orbited Earth, performing simple tasks, and sending signals back to interested parties on Earth. These include groups of college students at Stanford University in California, who designed and built a satellite "mothership" called OPAL (Orbiting Picosatellite Automatic Launcher) as part of their master's degree program; a group called Artemis at Santa Clara University in California, who designed three of the picosatellite "daughterships" for the mission; and a group of ham radio operators from Washington, D.C., whose StenSat picosatellite was also included aboard the mothership. The Aerospace Corporation in El Segundo, California, manufactured the final two picosatellites for the mission to test microelectromechanical systems (MEMS) technology.

OPAL was launched onboard a JAWsat launch vehicle on January 26, 2000, from the Vandenberg Air Force Base in California. It consisted of a hexagonal, aluminum mothership 23 centimeters (9 inches) tall, weighing 23 kilograms (51 pounds), and containing the six small daughter satellites described earlier, weighing about 0.45 kilograms (1 pound) each. When it reached its orbiting altitude of 698 kilometers (434 miles) above Earth, the picosatellite daughterships were deployed by a spring-launching device.

Once free of the mothership, the picosatellites went into operating mode. One of the three Artemis satellites began transmitting the group's web site address in morse code, while the other two measured the field strength of lightning strikes. StenSat's **transponder** sent telemetry signals to ham radio operators around the world. The two satellites from the Aerospace Corporation were tethered together, and communicated with each other and the engineers on Earth using MEMS switches that selected between various experimental radio **frequencies** for transmission. OPAL was still operating a year after launch.

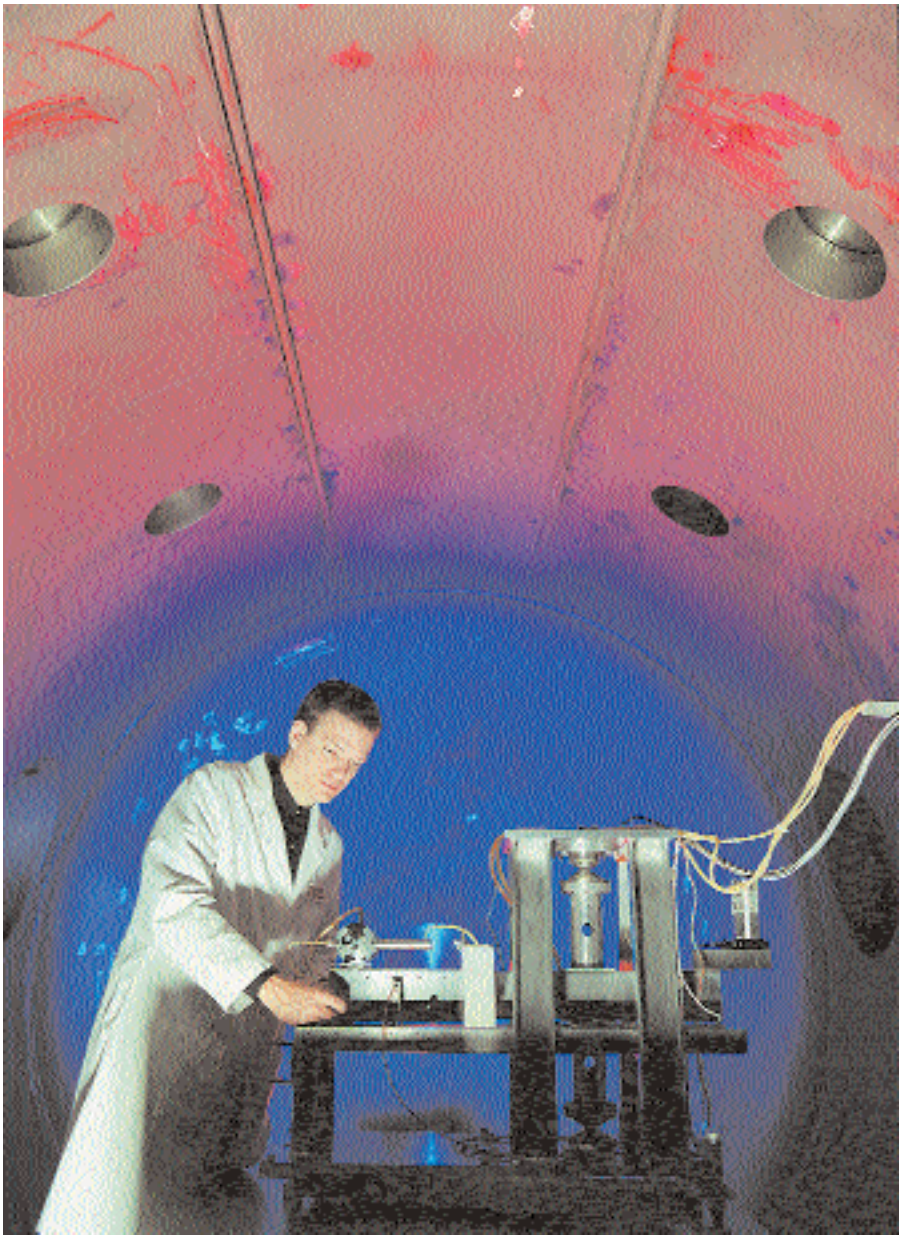
transponder bandwidth-specific transmitter-receiver units

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

Micro- and Nanotechnologies

The technology that made OPAL possible is as near as one's laptop computer or personal digital assistant. Computing power that used to require a mainframe computer in a room of its own can now fit into a laptop, thanks to innovative engineers who continually cram more and more memory onto smaller and smaller silicon chips. The student engineers used a Motorola microcontroller with 1 MB of onboard RAM operating at 8.38 MHz as OPAL's central processing unit. It was powered by commercially available solar panels, and backed-up by rechargeable nickel cadmium batteries.

But off-the-shelf components, while sufficient for student projects, will not survive at the cutting edge of nanosatellite technology; other technologies will be necessary to keep the smaller-and-smaller trend going. MEMS are tiny devices—gears, switches, valves, sensors, or other standard mechanical or electrical parts—made out of silicon. The technology arose out of the techniques used by microchip designers: pattern a wafer of pure silicon with the dimensions of the transistors, resistors, logic gates, and connectors required for the chip, etch away the material surrounding the pattern, and one has the beginnings of an electronic circuit. So why not do the same for mechanical systems? Lay out a pattern for a tiny gear on a silicon wafer, etch



An engineer at the Marshall Space Flight Center tests a microthruster model. Through development of this nanotechnology, it is hoped that microthrusters will be able to propel future spaceships with a small amount of expended energy.

away the surrounding material, including the material underneath that holds the gear to the wafer and to its axle, and one has a working gear that can mesh with other gears. By making sandwiches of different materials and etching them in a carefully controlled manner, scientists have been able to make gears, valves, pumps, switches, and sensors on a very small scale—the microscale. MEMS technology is often called a "top-down" approach: start with a large wafer of silicon and make microcomponents out of it.

To reach the even smaller nanoscale requires a "bottom-up" approach. Using instruments such as an atomic force microscope that can manipulate individual atoms, engineers can build tiny devices an atom at a time. Or, by understanding how atoms tend to bond together naturally, scientists can create conditions where nanoscale devices "self-assemble" on a patterned surface out of the atoms in a vapor. Such precise control will enable them to build nanostructures 1,000 times smaller than MEMS devices. This level of structural control will be necessary for the next generation of sophisticated nano- and picosatellites currently in the planning stages.

What Is Next?

The National Aeronautics and Space Administration's (NASA) Space Technology 5 (ST5) mission is scheduled to launch three nanosatellites into low orbit in 2003. The ST5 nanosatellites will be small octagons about 43 centimeters (17 inches) in diameter and 20 centimeters (8 inches) high—about the size of a big birthday cake. They will be complete systems in themselves, each having navigation, guidance, propulsion, and communications abilities. In addition, the ST5 nanosatellites will be test platforms for new space technologies. One of these, called A Formation Flying and Communications Instrument is a communications system designed to monitor the positions of small spacecraft relative to each other and the ground—a first attempt at making satellites fly in formation. Other technologies to be tested on ST5 include a lithium-ion power system that can store two to four times more energy than current batteries, an external coating that can be tuned to absorb heat when the spacecraft is cold or to emit heat when it is too warm, and a MEMS chip that makes fine attitude adjustments to the spacecraft using 8.5 times less power than 2002 devices.

By 2020 NASA hopes to deploy ANTS to the asteroid belt between Mars and Jupiter. ANTS stands for Autonomous Nano Technology Swarm. Each tiny spacecraft would weigh about 1 kilogram (2.2 pounds) and have its own solar sail to power its flight. After a three-year trip, the swarm would spread out to cover thousands of asteroids. The swarm would have a hierarchy of rulers, messengers, and workers. Each satellite would carry one type of instrumentation to perform a specific function: measure a magnetic field, detect gamma rays, take photographs, or analyze the surface composition of an asteroid. Messengers would relay instructions from the rulers to the workers, and also inform the rulers of important information collected by the workers. The rulers could then decide to reassign some of the workers to explore the more promising areas. In the end, a small number of messengers would return to the space station to deliver the data to scientists; the rest of the swarm would perish in space, having finished their duties. Scientists hope to obtain valuable information about the mineral resources of the asteroid belt, which could be a source for metals and other raw materials needed to build colonies in space.

Future Prospects

Nano- and picosatellites will also be useful in Earth orbit in situations where information from a large area is needed simultaneously. Traditional satellites can only be in one place at a time, but picosatellites can be everywhere, if enough of them are deployed. A swarm of picosatellites equipped with cameras and communications links could gather vital information from a battlefield on Earth, relaying enemy positions and troop counts to generals behind the lines. Or an array of satellites could be launched to gather atmospheric information that could help to predict the formation of hurricanes and tornadoes in time to warn the population. The Earth's entire magnetic field might be captured in one instantaneous "snapshot" by widely scattered swarms of satellites.

Projecting far into the future, perhaps a picosatellite could be made that would travel as far as possible into space, then manufacture a copy of itself before its mechanisms failed. This second generation robot/satellite could then travel as far as it could before making another replica, and so on. By sending out millions of tiny, affordable, self-replicating satellites, humankind's reach might one day extend to the farthest parts of the solar system. SEE ALSO MINIATURIZATION (VOLUME 4); ROBOTIC EXPLORATION OF SPACE (VOLUME 2); ROBOTICS TECHNOLOGY (VOLUME 2); SATELLITES, TYPES OF (VOLUME 1).

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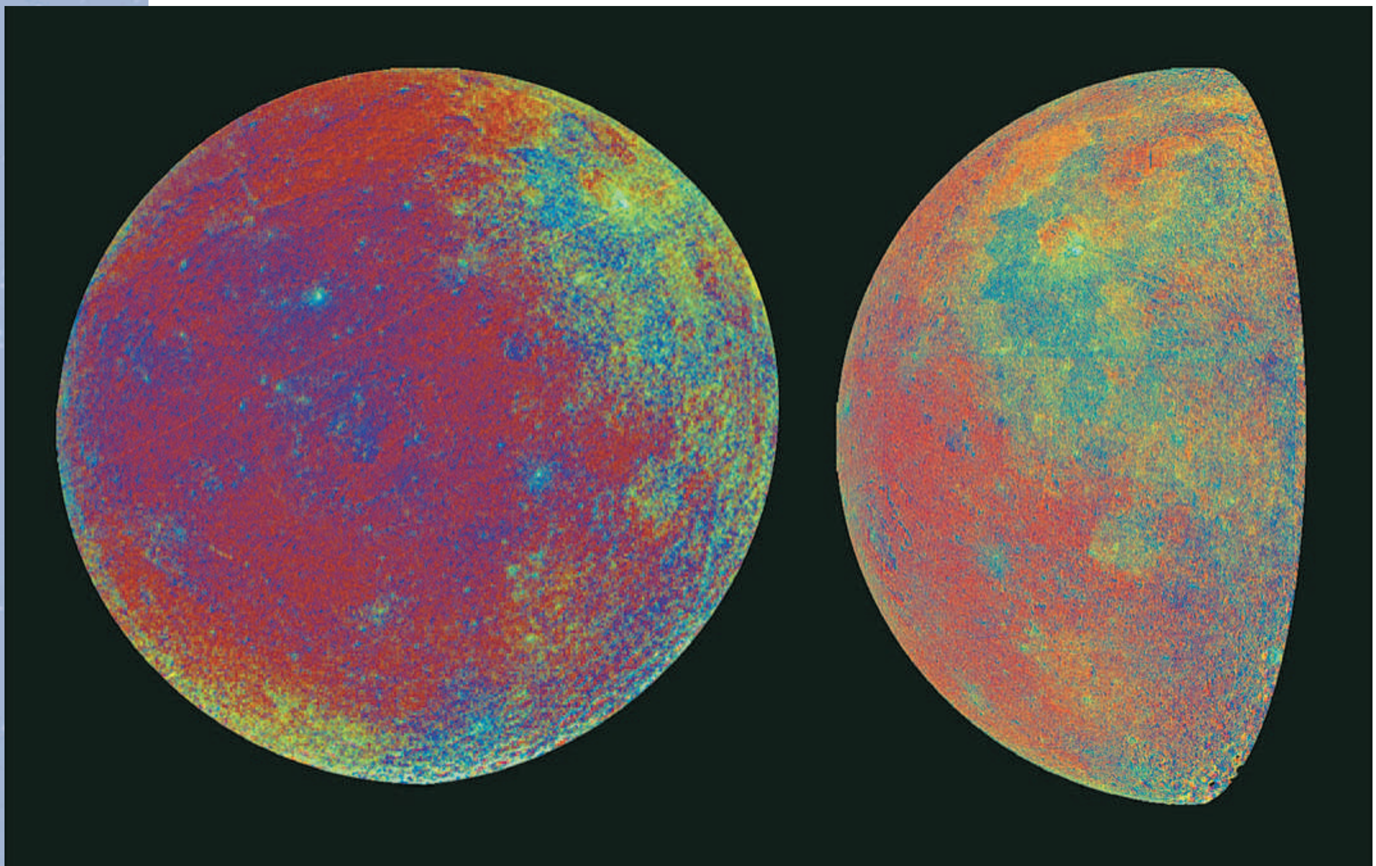
Natural Resources

Exploration is hard. After all, it involves being in a place where few or none have been before, whether it is the top of a mountain, the bottom of the ocean, or the surface of another world. Historically, part of the reason that exploration is so difficult is because most explorers have had to be self-sustaining; that is, most explorers have had to bring their own provisions, whether it was food or water or heat or tools, and the portage and maintenance of these provisions naturally limits the scope and pace of exploratory activities. The most successful explorers have been those who learned to use the natural resources that they encountered along the way to enable new and unanticipated discoveries and to increase their chances of successfully reaching their goals. This "living off the land" philosophy has been crucial for the exploration of Earth, and it also applies to the exploration of space.

During the latter half of the twentieth century, humans took baby steps out into the solar system. Exploratory ventures ranged from modest robotic missions designed to perform **reconnaissance** of planets, moons, asteroids, and comets to the bold and expensive human missions to the Moon as part of the Apollo program. These initial forays provided a sound foundation of scientific knowledge and tested many of the basic engineering principles required for human spaceflight. However, almost all of those missions were self-sustaining. For example, robotic orbiters and landers had to carry their own propellant, which, when exhausted, meant the end of those missions. The Apollo astronauts had to bring their own oxygen and water, as well as the rocket fuel for the return trip, which ultimately limited their duration on the lunar surface. If humans are to venture farther into the solar system in the twenty-first century, it will be necessary to learn how to identify and exploit the abundant natural resources available in the places they wish to explore.

reconnaissance a survey or preliminary exploration of a region of interest



Galileo spacecraft captured these color visualizations, which are helpful in locating the Moon's natural resources. The deeper blue sections are relatively rich in titanium, while the greens, yellows, and light oranges indicate areas rich in iron and magnesium. The yellowish area is part of the South Pole Aitken basin, a large circular crater, which may be rich in iron and magnesium. The reds are cratered highlands, which contain few resources.

The Moon

The Moon provides a good example to demonstrate this point, because the lunar surface contains a number of natural resources that could substantially enhance both exploratory and commercial space activities. For example, the lunar surface consists of **minerals** containing iron, silicon, titanium, aluminum, oxygen, and other elements. Experiments on the Apollo samples have demonstrated that it is fairly simple to extract these elements from lunar rocks and soils. Oxygen, especially, is a critical resource that can be used for breathing as well as generating rocket fuel. Extracted metals could be used for habitat construction or tool fabrication, and because they are dense, they offer the potential for enormous savings in the mass of raw materials that would have to be sent from Earth.

The Moon is also constantly bombarded by **solar wind** particles that implant hydrogen and helium into the surface. When extracted, hydrogen can be used for propellants or combined with extracted oxygen to make water. Water is another critical resource for life support, radiation **shielding**, and self-sustaining agriculture. Extracted helium could be used for power generation on Earth or the Moon once the technology for large-scale **fusion** power production matures. At a more basic level, unprocessed lunar rocks and soils are a resource that can be used for solar wind radiation shield-

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials ing, thermal isolation, and heat storage for habitats and other structures built on the Moon. There may be other natural resources on the Moon, such as subsurface water or ice deposited by asteroid or comet impacts, which will be discovered only through continued exploration that is enabled by the utilization of resources that are known to be there.

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

Asteroids and Comets

Asteroids and comets are important space exploration targets because of their scientific value as samples of the early solar system as well as the threat to Earth posed by potential impacts. In many ways asteroids and comets are likely to offer more varied and abundant natural resources than the Moon. Like the Moon, asteroids and comets are bombarded by solar wind and have silicate minerals on their surfaces, and those surface materials can be processed to yield oxygen and hydrogen and the other potential resources. However, several asteroids are known to have abundant metallic deposits on their surfaces that are likely to be rich sources of ores for construction materials and shielding. Many asteroids and most comets are also known to be rich in volatile materials such as water ice, dry ice, and hydrated minerals as well as carbon-rich organic compounds. Once extracted, these resources could be used for life support, propellant production, and construction and shielding. Perhaps most importantly, many near-Earth asteroids and some comets are easier to get to and launch from than the Moon because of their small mass and occasional close passes by Earth. Ease of accessibility is itself a natural resource and opens up the economic possibility of efficient exportation of asteroidal or cometary natural resources to Earth and other exploration targets.

Mars

Finally, Mars will be an important focus of space exploration in the twenty-first century because of its spectacular geology and **meteorology** and the discovery in the twentieth century that it once may have been much more Earthlike and perhaps even hospitable to life. Mars offers abundant natural resources that will almost certainly have to be tapped to enable efficient and long-term exploration so far from Earth. These resources include many materials that are extractable from the silicate-rich rocks and soils. However, Mars is also a volatile-rich planet and has an atmosphere containing carbon dioxide and other gases with resource potential. Water is known to be trapped in a small percentage of the surface soils and is hypothesized to exist either in subsurface liquid water aquifers or in water ice permafrost deposits. Self-sustaining agriculture and oxygen production are possible by extracting or accessing this water and using the abundant atmospheric carbon dioxide to fuel photosynthesis. Light elements such as hydrogen, carbon, nitrogen, and oxygen are much more abundant on Mars than on the Moon or most asteroids, and extraction of these volatiles from crustal rocks and soils could provide raw materials for the production of propellant and manufactured goods. And because of the role of water in its geologic history, Mars is likely to have rich deposits of metals, salts, and other minerals or ores. Even modest initial developments in natural resource usage on Mars, such as those planned for robotic missions, are likely to enormously increase the efficiency and capability of Mars exploration.

meteorology the study of atmospheric phenomena or weather

Issues

There are many other potential sources of natural resources in the solar system, including cosmic dust, solar wind, and the atmospheres of gas giant planets. There are also important political, ethical, technological, and economic issues regarding natural resource exploitation that need to be addressed: What are the most energy-efficient ways to generate propellants from raw materials? Who owns mining rights on Mars and the asteroids? Will extraction activities irreparably harm the environments of other worlds? Given the difficulty of balancing environmental stewardship and natural resource extraction on Earth, this issue is particularly important and will require substantial global cooperation among all of the nations involved in future space exploration. SEE ALSO ASTEROID MINING (VOLUME 4); COMET CAPTURE (VOLUME 4); EARTH—WHY LEAVE? (VOLUME 4); ENVIRONMENTAL CHANGES (VOLUME 4); LIVING ON OTHER WORLDS (VOLUME 4); LUNAR BASES (VOLUME 4); LUNAR OUTPOSTS (VOLUME 4); MARS (VOLUME 2); MARS BASES (VOLUME 4); MARS DIRECT (VOLUME 4); MOON (VOLUME 2); RESOURCE UTILIZATION (VOLUME 4); TERRAFORMING (VOLUME 4).

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Nuclear Propulsion

Nuclear energy remains an attractive potential means of propulsion for future spacecraft. When compared with conventional rocket engines, a nuclear propulsion system would in theory be less massive, and could provide sustained thrust with greater energy. Many believe nuclear-powered spacecraft can and should be built, but first many technical problems and other hurdles must be overcome.

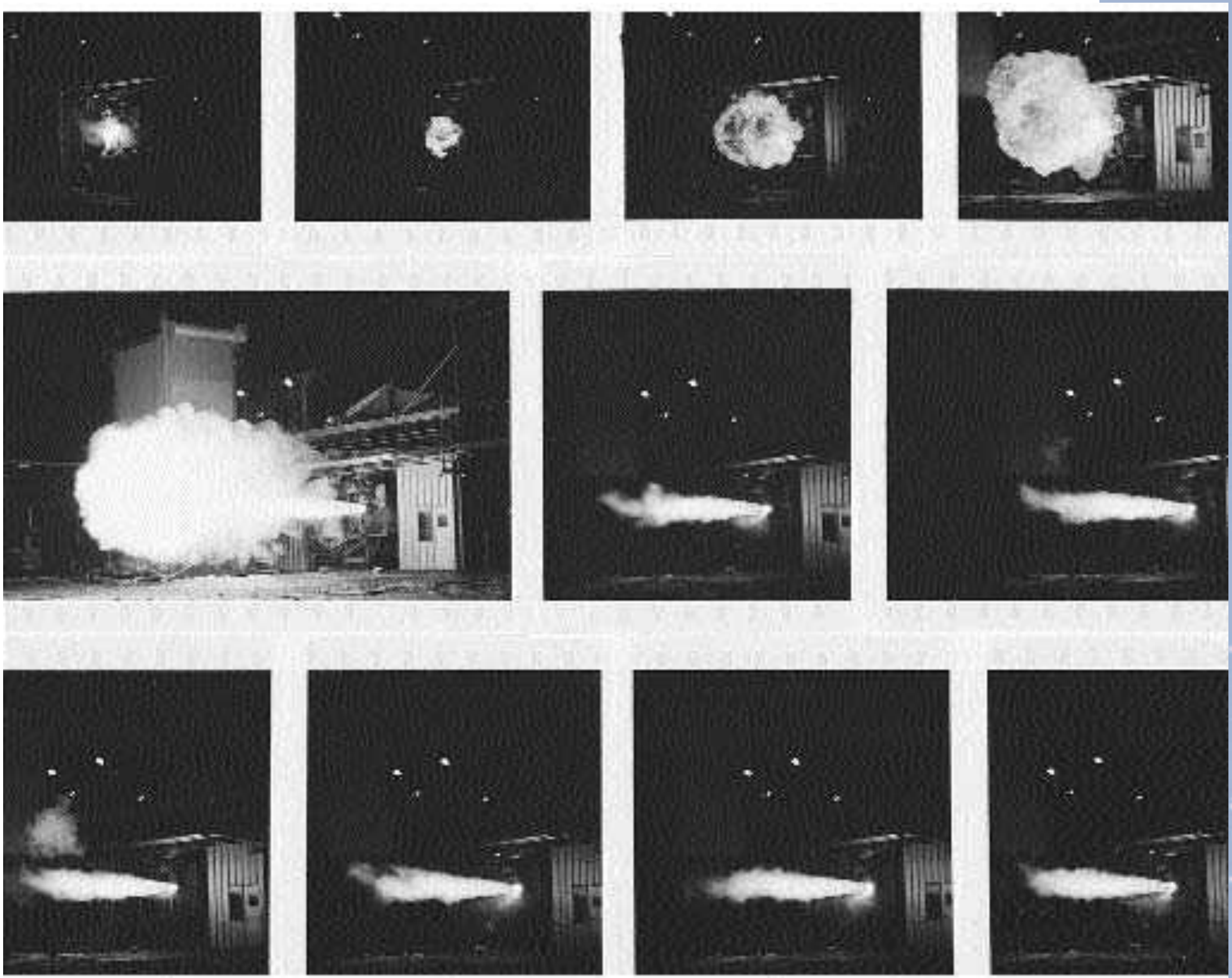
Both the U.S. and Soviet space programs were researching nuclear propulsion as far back as the early 1960s, and since then, dozens of ideas for nuclear propulsion systems—and the spacecraft they would power—have been proposed. Each system, however, is based around one of the two methods of generating nuclear energy: fission and fusion.

Fission Propulsion

atomic nucleus the protons and neutrons making up the core of an atom

Fission is the act of splitting a heavy **atomic nucleus** into two lighter ones, which results in a tremendous release of energy. Common fuels for fission reactions are plutonium and enriched uranium, a soft-drink sized can of which carries 50 times more energy than the space shuttle's external tank.

Fission has been used to generate electricity on Earth for six decades, often by using the heat from the reactor core to boil water and spin a tur-

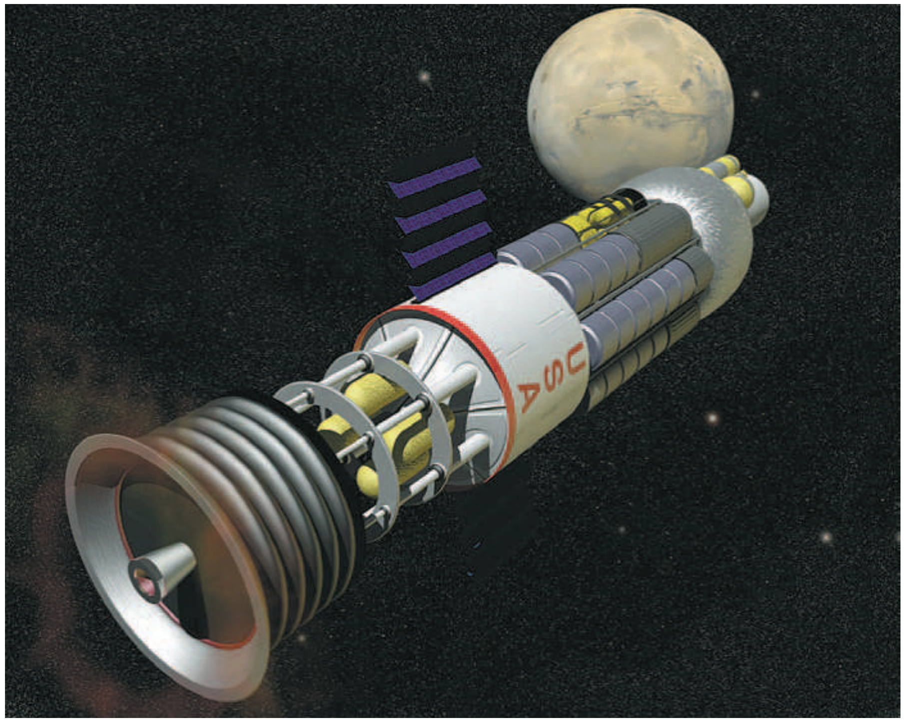


The Plum Brook Station, at the Glenn Research Center, is the site of the 28,000 pound Nuclear Transfer Copper Engine, used in testing nuclear propulsion, which one day may propel humans to Mars.

bine. But a reactor core could also be used to heat a propellant such as hydrogen into a super hot gas. The gas could then be expelled out of a nozzle, providing thrust, just like in a conventional chemical rocket. Engines of this type are called nuclear thermal rockets (NTRs), and were ground-tested by the United States in the Rover/NERVA program of the 1960s.

A related method, being studied by the National Aeronautics and Space Administration (NASA) in the early 2000s, would give an NTR the equivalent of a military jet's afterburner. In this scheme, liquid oxygen could be pumped into the exhaust nozzle. This would cool the hydrogen enough that it could combine with the oxygen and burn, providing additional thrust and leaving water vapor as a by-product.

NTRs could produce enough thrust to carry a spacecraft into orbit, but because the propellant itself would quickly run out, they are unsuitable for longer missions to Mars or beyond. An alternative approach to NTRs is to use the reactor to produce electricity, which could power various types of electrical thrusters. Such nuclear-electric propulsion systems (NEPs) would use electric fields to ionize and/or accelerate propellant gas



This concept spacecraft was developed under Project Orion in the 1960s by the U.S. government. In theory, small nuclear pulses would propel the craft.

such as hydrogen, argon, or xenon. NASA plans to put development of NEPs on a fast track beginning in 2003.

NEPs would be able to produce smaller amounts of continuous thrust over periods of weeks or months, making them extremely suitable for robotic missions to the outer planets or slow journeys between Earth orbit and the Moon. For human missions, when diminishing supplies for the crew make speed a more important factor, a combination of NTRs and NEPs could be used.

Fusion Propulsion

We have nuclear fusion to thank for life on Earth: Most solar energy comes from the four million tons of hydrogen that is converted into helium every second in the interior of the Sun. But fusion can only occur in superheated environments measuring in the millions of degrees, when matter reaches a highly ionized state called plasma. Since plasma is too hot to be contained in any known material, controlled nuclear fusion remains one of humanity's great unrealized scientific goals.

However, plasma conducts electricity very well, and it could be possible to use magnetic fields to contain and accelerate it. It might even be more feasible to use fusion in space, where it would not be necessary to shield the reactor from the environment in all directions, as it would be on Earth.

Experiments toward developing a fusion propulsion system are underway at NASA's Marshall Space Flight Center in Huntsville, Alabama. The Gas Dynamic Mirror (GDM) Fusion Propulsion system would wrap a long, thin current-carrying coil of wire around a tube containing plasma. The current would create a powerful magnetic field that would trap the plasma in the tube's center section, while each end of the tube would have special magnetic nozzles through which the plasma could escape, providing thrust.

The amount and efficiency of the energy released by fusion makes it a good candidate for interplanetary travel. As a comparison of their efficiency, if a chemical rocket were an average car, a fusion rocket would get about 3,000 kilometers (1,864 miles) per liter! Fusion also has great potential as an energy source because of the nature of the fuel and reaction—hydrogen is the most common element in the universe, and the by-products are non-radioactive (unlike fission products, which remain hazardous for many years). But until fusion becomes a reality, fission is humanity's sole option for nuclear-powered space travel—and is not without strong opposition.

Pros and Cons

Plutonium is one of the most poisonous substances known; doses of one millionth of a gram are carcinogenic, and it is difficult to contain the radioactive by-products of fission safely. These dangers have made nuclear fission controversial from the outset, and the prospect of a nuclear reactor reentering Earth's atmosphere and scattering radioactive material over a wide area makes many people nervous.

Many space probes have not carried reactors but are powered by radioisotope thermoelectric generators (RTGs), which derive electrical power from the slow decay of radioactive material. There was concern in 1997 that the Cassini probe to Saturn might meet with an accident as it flew by Earth, scattering its RTG's 33 kilograms (72 pounds) of plutonium into the atmosphere. This did not occur and Cassini continued on its route to Saturn. However, such concerns, along with the high projected cost of research and construction, have been obstacles in the way of nuclear-propelled spacecraft.

Still, nuclear propulsion could dramatically decrease travel time to the planets. A round trip to Mars could be accomplished in half the time with fusion power, which would lessen the crew's exposure to the hazards of weightlessness and **cosmic radiation**. A nuclear-propelled craft could conceivably be used repeatedly for round trips to the Moon and planets, cutting down the cost of operating such a long-term transit system. Funding for the development of new nuclear propulsion will be boosted in 2003 with a view to production of an operational system within a few years. SEE ALSO Accessing Space (volume 1); Antimatter Propulsion (volume 4); External Tank (volume 3); Faster-Than-Light Travel (volume 4); Interstellar Travel (volume 4); Ion Propulsion (volume 4); Laser Propulsion (volume 4); Lightsails (volume 4); Power, Methods of Generating (volume 4).

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

Chad Boutin

Internet Resources

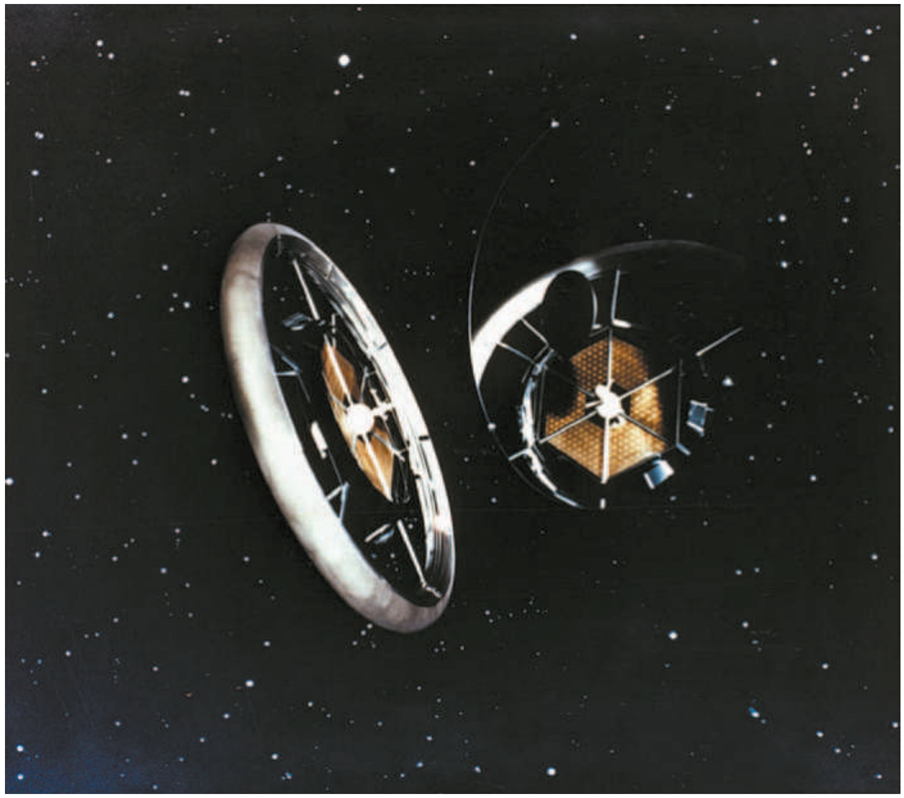
Advanced Plasma Propulsion. Space Transportation, Marshall Space Flight Center. <http://astp.msfc.nasa.gov/sciresearch/adv_plas_prop.html>.

High-Powered Electrical Propulsion. Space Transportation, Marshall Space Flight Center. <http://astp.msfc.nasa.gov/sciresearch/nuclear_prop.html>.

O'Neill Colonies

O

Gerard K. O'Neill (1927–1992), a particle physicist who spent most of his career at Princeton University, was the driving force behind the first serious space colony design study. Conducted in 1975, this study took the form



Settlers would reside in the ring circling the central hub of the colony, while a large circular mirror with a hole in its middle would be positioned directly above the settlement to beam sunlight into the structure for power.

of a ten-week program held jointly at the National Aeronautics and Space Administration (NASA) Ames Research Center and at Stanford University, outside San Francisco, California. NASA and the American Society for Engineering Education sponsored the program. The program's work laid out the basic requirements for large-scale human settlement of the solar system. As technical director, O'Neill guided the study towards its basic conclusion that the best way to begin the human colonization of space was to build a large space colony at **L-5**, with the colony being dedicated to using lunar materiel to build a series of solar power satellites to beam electricity down to an energy-hungry planet.

L-5 the gravitationally stable Lagrange point 60 degrees behind the orbiting planet

Colony Basics

The colony would be a home for 10,000 people living and working in a round tube 130 meters (425 feet) across and 1,790 meters (5,870 feet) in diameter. The ring would rotate around a central hub, providing artificial gravity. It would be shielded from **solar radiation** by 9.9 million metric tons (10.9 million tons) of lunar material, built up as a stationary ring—stationary relative to the habitation structure. At the center of the ring would be a hub where spaceships would dock and where cargo and passengers would be transferred back and forth.

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

photovoltaic cells cells consisting of a thin wafer of a semiconductor material that incorporate a p-n junction, which converts incident light into electrical power; photovoltaic cells connected in a series make up a solar array

A large circular mirror with a hole in its middle would be positioned directly above the colony to beam sunlight into the structure, bypassing the shielding and providing both light and solar energy to power the **photovoltaic cells** arrayed around the hub. Underneath the main structure would be a large heat radiator that would collect and expel waste heat generated by the colony. At the bottom of the structure, at the end of a long access tube, would be a solar furnace where lunar ore (or ore from elsewhere in the solar system) would be converted into material with which to build solar power satellites and other space habitats.

What Motivated O'Neill's Vision?

At the time of the initial study, O'Neill was partly motivated by the worldwide energy crisis of the early seventies and the popular "Limits to Growth" movement. This movement was embodied in such documents as the famous Club of Rome report, which summed up Limits to Growth's attitude with the declaration that "the world has a cancer and the cancer is man." O'Neill rejected the grim future implied by this group. He saw that this powerful movement required that future "limits will almost surely be more than physical, and that in the long run the freedom of the human mind will have to be limited also. . . . For me the age old dreams of improvement, of change, of greater human freedom are the most poignant of all; and the most chilling prospect that I see for a planet bound human race is that many of those dreams will be forever cut off for us." (O'Neill 1982, pp. 39–40).

As he refined his vision, O'Neill began to ask basic questions about the world: "Is a planetary surface the right place for an expanding technological civilization? There is no clear answer except to say that my own interest in space as a field for human activity went back to my own childhood, and that I have always felt strongly a personal desire to be free of boundaries and regimentation. The steady state society, ridden with rules and laws, proposed by the early workers on the limits to growth was, to me, abhorrent" (O'Neill 1982, p. 279).

In order to make his vision of the humanization of space plausible, O'Neill had to invent a new way of looking at the resources and the economics of human space activity. He imagined a space economy in which 90 percent or more of the raw materials needed for survival would come from the Moon, the asteroids, or elsewhere in the solar system. Only an indispensable small amount would have to be brought up from Earth.

Obstacles to Permanent Space Colonies

Then, as now, the greatest obstacle to building a permanent human colony in space was the expense of getting into **low Earth orbit**. In the late 1970s and the early 1980s it was thought that NASA's space shuttle would provide reliable, relatively inexpensive, access to space. O'Neill expected that there would be a minimum of twenty-five shuttle flights a year. The reality is that in the early twenty-first century NASA is struggling to fly the shuttle more than six or seven times a year at a cost of between $300 million and $400 million per flight.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

O'Neill accurately foresaw that the shuttle could be improved. The weight of the main fuel tank has been considerably reduced, the main engines have been made lighter and more efficient, and, after the Challenger disaster in 1986, the whole system has been made safer and more reliable. Unfortunately, this has not been enough to make the space shuttle into the all-purpose, reliable vehicle that NASA had promised. The heavy-cargo version of the shuttle, the so-called Shuttle-C, which O'Neill had been depending on to build the initial elements of his dream, never materialized.

For moving large tonnages of material from the Moon's surface to the space colonies, O'Neill imagined a mass driver, a type of electromagnetic catapult. Powered by solar-generated electricity, this machine would have very low operating costs and would be the centerpiece of lunar mining. Longer term, mass drivers would be used to move heavy loads of material throughout the solar system.

O'Neill's Ultimate Dream

Ultimately, O'Neill imagined that humanity would gradually move out into the solar system, leaving Earth with a much smaller population that was dedicated to tending the planet's magnificent, unique environment and its historical treasures. Thousands, perhaps millions, of visitors would come to see the wonders of humanity's original home world. The vast majority of the human race would live, work, and thrive elsewhere in the solar system.

The resources needed to accomplish this goal and to fulfill O'Neill's great dream already exist. O'Neill concluded that space "is nothing less than a rich, wholly new frontier—a new ecological range for humankind. . . .The untapped resource of clean, unvarying solar energy waiting on that frontier is more than a hundred million times as much as the sunlight we intercept on Earth. The material resources waiting there, in the form of small asteroids whose diameters have been measured and whose orbits have been plotted, are enough to let us build Earth-like colonies with a total land area of three thousand Earths. So much for the limits to growth" (O'Neill 1982, p. 321). SEE ALSO Communities in Space (volume 4); O'Neill, Gerard K. (volume 4); Settlements (volume 4).

Taylor Dinerman

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American Physicist and Visionary
1927–1992

Gerard K. O'Neill is sometimes considered the father of space colony design. Born in Brooklyn, New York, O'Neill served as a **radar** technician in the navy, then earned a bachelor's degree from Swarthmore College in 1950 and a doctoral degree in physics from Cornell University in 1954. Upon earning his doctorate, O'Neill joined the faculty of Princeton University's physics department, where he remained until his retirement in 1985.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

O'Neill's early research focused on experiments in high-energy particle physics. He invented the colliding-beam storage ring and developed the technology that is now the basis of all high-energy particle accelerators. By the end of the 1960s, O'Neill became very interested in the idea of space colonization. In 1977 he founded the Space Studies Institute at Princeton, the purpose of which was to develop tools for space exploration. The institute today is a major source of funds for research on space resources and manufacturing. O'Neill became world-famous in 1977 with the publication of his book *The High Frontier*. It was here that he described plans for the construction of large, cylindrical space colonies. Such a colony, O'Neill said, could become self-sustaining when placed in a stable orbit between Earth and the Moon. This was the first serious description of how a space colony could be sustained and it continues to serve as a model as such settlements are planned. SEE ALSO DYSON SPHERES (VOLUME 4); DYSON, FREEMAN JOHN (VOLUME 4); O'NEILL COLONIES (VOLUME 4); SPACE STATIONS OF THE FUTURE (VOLUME 4).

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Planetary Protection

P

Since the early days of the space program, there has been concern about planetary protection: the prevention of human-caused biological cross-contamination between Earth and other bodies in the solar system. After the launch of Sputnik in 1957, scientists cautioned about the possibility of contaminating other places in the solar system with microbes from Earth: "Hitchhiker" bacteria and other organisms on spacecraft and equipment might cause irreversible changes in the environments of other planets. Moreover, these changes could also interfere with scientific exploration. In addition, it was felt that spacecraft or extraterrestrial samples returned from space might harm Earth's inhabitants and ecosystems.

The Outer Space Treaty of 1967 requires that exploration of outer space and other celestial bodies "avoid their harmful contamination" and "adverse changes in the environment of Earth" caused by the "introduction of extraterrestrial matter." In practical terms, the concerns are twofold: avoiding (1) forward contamination, the transport of terrestrial microbes on outbound spacecraft, and (2) back contamination, the introduction on Earth of contamination by life-forms that could be returned from space.

Protection Policies

The issues involved in planetary protection are similar to those associated with environmental and health policies. Just as there are rules and laws about moving certain types of organisms from one place to another on Earth, so it is with space exploration. But there is a difference. On Earth, those regulations are intended to prevent the spread of serious disease-causing microbes (e.g., HIV/AIDs, tuberculosis, or Dutch Elm disease) or limit the movement of invasive pests (e.g., Medflies, gypsy moths, zebra mussels, kudzu vine, or water hyancinth). In space exploration, the issues are the same, although the existence of extraterrestrial organisms is unknown. Nonetheless, in space exploration there are domestic and international policies to regulate spacecraft and mission activities before launch and upon return to Earth.

President Richard Nixon greets the successful Apollo 11 astronauts who, upon their return from the Moon, were placed inside a hermetically sealed trailer to prevent possible cross-contamination.

synthesis the combination of different things so as to form new and different products or ideas

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

Worldwide, planetary protection policies are recommended by the international Committee on Space Research (COSPAR), which reviews the latest scientific information. In the United States the National Aeronautics and Space Administration (NASA) issues guidelines and requirements for solar system exploration missions. Planning planetary protection measures requires **synthesizing** information about biological systems and extraterrestrial environments while acknowledging uncertainties about the conditions that exist in the locations that spacecraft will visit or where samples might be collected. Planetary protection policies must take into account these uncertainties, even while exploration tries to determine whether life exists elsewhere. It is necessary to be conservative to prevent the act of exploration from disrupting or interfering with extraterrestrial life.

Controls to implement planetary protection policies may consist of procedures and measures that depend on the solar system body that will be explored and whether its environment could harbor living organisms or support Earth life. For example, before launch, spacecraft are assembled in clean rooms and scientific instruments may be heat treated or specially packaged to reduce the bioload, or the number of microbes they carry. Spacecraft **trajectories** are designed to avoid unintended impacts on other bodies. For round-trip missions to places such as Mars, returned samples are treated as potentially hazardous until proven otherwise.

In addition to extensive cleaning and decontamination of the outbound spacecraft, the return portion of the mission requires a fail-safe durable container that can be remotely sealed, cleanly separated from the planet, monitored en route, and opened in an appropriate quarantine facility. If containment cannot be verified during the return flight to Earth, the sample and any spacecraft components that have been exposed to the extraterrestrial environment will be sterilized in space or not returned to the planet. Pristine sample materials will not be removed from containment until they are sterilized or certified as nonhazardous, using a rigorous battery of life detection and biohazard tests. Although the likelihood of releasing and spreading a contained living organism is low, special equipment, personnel, and handling are warranted to minimize harmful effects if a life-form is discovered.

The Apollo Missions

A similar approach to extraterrestrial quarantine was used during the Apollo program, when lunar samples were returned to Earth along with lunar-exposed astronauts. Before the first Moon landing, the Interagency Committee on Back Contamination (ICBC) was formed to coordinate requirements for the quarantine of astronauts, spacecraft, and samples returned from the Moon. The ICBC also developed and oversaw plans for a special Lunar Receiving Laboratory (LRL) at what is now the Johnson Space Center in Houston, Texas. At the LRL, an elaborate series of tests and analyses were conducted before astronauts and samples could be released from quarantine. Strict quarantine testing ended with the Apollo 14 mission because lunar samples were determined to be lifeless and not biohazardous. There were a variety of problems in implementing the Apollo quarantine, but it provided a wealth of information useful in planning future missions that will require planetary protection and quarantine on Earth.

Future Missions

Future round-trip missions to Mars or other extraterrestrial locations will differ from Apollo in several ways. Because no astronauts will be involved in the initial sample-return missions and because sample amounts are anticipated to be limited (less than 1 kilogram [2.2 pounds] of rocks and soils), quarantine procedures and flight operations will be less complex. However, the missions will still be challenging because of the distances involved. In addition, advances in microbiological and chemical techniques since Apollo have increased knowledge about life in extreme environments on Earth and expanded the ability to detect life or life-related molecules in samples. A heightened awareness of microbial capabilities and microbe-caused diseases has developed, with corresponding public concern about the risks of sample-return missions.

As solar system exploration continues, so too will planetary protection policies. Revisions to planetary protection policies will depend on an improved understanding of extraterrestrial environments and the emerging awareness of the tenacity of life in extreme environments on Earth. It appears increasingly likely that there are extraterrestrial environments that could support Earth organisms. Equally important, future missions may find distant environments that support their own extraterrestrial life. Planetary protection provisions will be essential to the study and conservation of such environments. SEE ALSO Astrobiology (volume 4); Environmental Changes (volume 4); Human Missions to Mars (volume 3); Mars Missions (volume 4).

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Political Systems

As space is the heritage of all people, so the political systems of Earth are our heritage for governance in outer space. There are many questions that remain to be answered when it comes to maintaining law and order in space's vast territory. Which of Earth's political systems will be molded to fit into the unique requirements of space law? Will controversy over governance cause international disputes on Earth? Which system will prevail?

Currently, we can only speculate about how a political system in space would operate. These theoretical systems are informed by Earth's various political models as well as modern international space treaties, which are indicative of what the international community has or has not been able to agree upon regarding the space infrastructure.

Types of Political Systems

The purpose of political systems is to address any conflicts that may arise in a relatively peaceful manner. One type of governmental system that may be adopted for space governance would be one that is organized with a constitution that establishes a legislature, a court system, and police powers charged with protecting us. The following are some political systems that are derivable from the experiences of humankind that could pertain to space society.

Democracy. There exist two different kinds of democracies. One is government by the people, whereby the people retain supreme power and directly exercise it. The other type is government by popular representation, whereby the people retain supreme power but indirectly exercise it by delegating their power to delegates who represent the people. This second type of governmental system would most likely be the one adopted for governance of the entirety, but self-governance could be more appropriate to space settlements that are small and isolated.

Socialism. Many developed countries have a "quasi-socialist" system. Consequently, some socialist ideals are likely to be a part of any space system of government. Socialism is a political system wherein the methods of production, distribution, and exchange are mainly state-owned. The state distributes the wealth among all members of society. The influence of socialism is evident in some of the United Nations' space treaties, particularly the Moon Treaty of 1979. The United States and Russia have not signed the Moon Treaty because of the issue of space being the "common heritage of mankind" and what that means for the development of lunar resources that all people are to benefit from.

Libertarianism. Central to American government is the philosophy of freedom. The libertarian viewpoint emphasizes the concept of liberty, particularly freedom from any unnecessary restraints that a government might impose on it. A problem with libertarianism is the absence of police powers and how to address crime. A small society in space could possibly adopt a libertarian approach. This system could be appealing to individualistic types of people who would likely be interested in space exploration, settlement, and development.

Any further advances in the realm of space governance will most likely continue to be under the auspices of the United Nations' Office of Outer Space Affairs, as well as its Committee on Peaceful Use of Outer Space. SEE ALSO GOVERNANCE (VOLUME 4); LEGISLATIVE ENVIRONMENT (VOLUME 1); LIVING IN SPACE (VOLUME 3); LIVING ON OTHER WORLDS (VOLUME 4).

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Pollution

Pollution and other environmental impacts have been unwelcome companions in humanity's voyage to space. They shadow all stages of the journey, from manufacturing, to launch, and even to space and other worlds, as debris may be strewn along the way to a planet, causing navigational hazards in Earth orbit and possibly contaminating the other world with chemicals and infection. Awareness of these problems has grown as a concern about global environmental problems has spread across the world.

Government Regulations

In the United States and many other nations, government regulations are the first line of defense against these problems. These regulations control manufacturing-related pollution in industries, including space-related ones, and are designed to prevent or reduce the escape of toxic chemicals into the environment and protect groundwater, the air, and the quality of life.

The regulations cover routine releases of propellant combustion products during testing, which in addition to their effects on human health can contribute to the formation of acid rain. Also, noise levels generated by the testing are strictly limited to prevent harm and disruption to people, animals, and property. The regulations also cover the disposal of **rockets** and

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

Government regulations exist as a defense against excessive pollution caused by testing, launching, and disposing of NASA rockets.

missiles at the end of their useful lives. This too can involve harmful air emissions and hazardous chemical spills.

These environmental protections extend even to the early launch period. For example, the heat, vapors, and intensity of the space shuttle launch pose problems for the environment around the launch pad. In response, the National Aeronautics and Space Administration (NASA) ensures that the coastal wetlands and estuaries surrounding the launch center are not stressed beyond recovery. Trenches at the launch facility divert the boiling, mildly toxic ground cloud made of water from the main engines, which use the energy that results when hydrogen and oxygen combine to form water, and the more complex and damaging cloud from the boosters, which burn a solid propellant. The solid propellant cloud damages vegetation, increases water and soil acidity, and kills fish, but alternating launches between two pads and treating the soil and water reduces these problems and keeps them from expanding. Innovative reprocessing programs also lessen the impact. At the shuttle launch facility some of the launch emissions are rendered into a fertilizer used in local orange groves. But there are some environmental hazards rarely found outside the space industry that are associated with rocket exhaust and space debris.

Rocket Exhaust

Chlorine, nitrogen, and hydrogen compounds in both liquid and solid rocket propellants, such as the propellant used in the shuttle's boosters, were recognized in the early 1970s as agents of ozone destruction. Ozone protects us by absorbing the Sun's harmful **ultraviolet** rays and is concentrated between 15 and 30 kilometers altitude (9.4 and 18.8 miles), in the **stratosphere**.

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

stratosphere a middle portion of Earth's atmosphere above the tropopause (the highest place where convection and "weather" occur)

Recent work indicates that significant ozone destruction resulting from rocket exhaust is brief and short-lived because launches are infrequent. Instead, the ozone loss is dominated by other sources of atmospheric pollution, such as the chlorofluorocarbon compounds used as a refrigerant and to make plastic foam. But other aspects of rocket exhaust affect the climate. Combustion products in the exhaust such as carbon dioxide, nitrous oxide, and water vapor are greenhouse gases and may contribute to global warming.

Particulates in the exhaust can interfere with the passage of sunlight and promote cloud formation, leading to unforeseen effects on the climate. These particulates can provide sites for ozone-depleting chemical reactions and thus boost the destructive power of the reactions.

Some propellants are highly toxic. Spills of the propellant heptyl left over in Soviet booster stages that have fallen to the ground in Russia's Altai Republic for decades may have caused unexplained medical and environmental problems there. Solving problems related to propellant characteristics will be done on both regulatory and technological fronts. The best solution may be the creation of new, less harmful propellants and the transfer of bases of operation into space.

Space Debris

Space debris is space travel's other major pollution problem. Also called space junk, it fills the near-Earth orbit and poses a threat to current and future efforts above Earth. Missions to other worlds also have the potential for contamination.

Space debris is the accumulation of rubbish since 1957 from rockets and satellites, some exploded and some obsolete. It includes discarded hardware no longer needed by piloted missions and gumball-size spheres of coolant that escaped from satellite reactors and froze in space.

Because of high speeds relative to a passing satellite, spacecraft, or **space station**, collisions with even small bits of this debris can do serious damage. Shields offer protection from the smallest pieces, and ground-based tracking systems provide advanced warning of the biggest hunks, allowing time for evasive action. But the most troublesome pieces fall between these sizes, ranging from a 1 centimeter (a half inch) to 10 centimeters (4 inches). These pieces are hard to track and plentiful, numbering more than 150,000.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

A ground-based laser that destabilizes the orbit of this intermediate-size junk is one promising solution to this problem. Studied since the late 1970s, this approach would vaporize a thin layer of a piece of space junk as it approached, effectively creating a retrorocket that would slow it down. The laws of physics, which dictate a lower altitude when a body's orbital speed drops, then drop the piece into the atmosphere, which slows it more, eventually causing it to burn up in the atmosphere. Studies of the concept, planned for a test by 2003, estimate that Earth orbit could be cleansed of junk this size within two years.

Current Protocols

Protocols exist for avoiding pollution of other worlds. **Payloads** are scrupulously sterilized. Rocket stages that loft probes toward these targets are diverted to avoid trajectories that would follow the probe. SEE ALSO Space Debris (Volume 2).

Richard G. Adair

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

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Power, Methods of Generating

All space vehicles, whether robotic probes or vehicles for human exploration, require electrical power. Electrical power is required to run the computers and control systems, to operate the communications system, to operate scientific instruments, and to power the life support equipment to keep humans alive and healthy in space. For missions to the surface of the Moon or the planets, power may be required to run rovers, or to process material into useful products such as fuel or oxygen. Advanced **rocket** engines such as ion drives also run on electrical power.

rocket vehicle (or device) especially designed to travel through space, propelled by one or more engines

Electrical power sources can be categorized into three basic types: batteries and **fuel cells**, solar power systems, and nuclear power systems.

fuel cells cells that react a fuel (such as hydrogen) and an oxidizer (such as oxygen) together

For short missions, power can be provided by batteries or fuel cells, which produce power from chemical energy. Fuel cells are similar to batteries, producing electricity from a fuel and an oxidizer, stored in separate tanks. The space shuttle power system, for example, uses fuel cells that combine hydrogen and oxygen to produce electrical power, as well as by-product water. Primary cells produce power only until the chemical **feedstock** that powers the reaction is used up. The space shuttle's fuel cells consume about 150 kilograms (330 pounds) of hydrogen and oxygen per day.

feedstock the raw materials introduced into an industrial process from which a finished product is made

A battery that can be recharged with an external source of power is called a rechargeable (or "secondary") battery. A fuel cell is called regenerative if it can electrolyze the by-product water back into hydrogen and oxygen. Rechargeable batteries or regenerative fuel cells can thus be used to store energy from a solar array.

Solar Power Generation

Solar arrays produce electrical power directly from sunlight. Most long-duration space missions use solar arrays for their primary power. Most designs use **photovoltaic cells** to convert sunlight into electricity. They can be made from crystalline silicon, or from advanced materials such as gallium arsenide

photovoltaic cells cells consisting of a thin wafer of a semiconductor material which incorporates a p-n junction, which converts incident light into electrical power; a number of photovoltaic cells connected in series makes a solar array

(GaAs) or cadmium telluride (CdTe). The photovoltaic cells with the highest efficiency use several layers of semiconductor material, with each layer optimized to convert a different portion of the solar spectrum. The solar intensity at Earth's orbit is 1,368 watts per square meter, and the best photovoltaic cells manufactured today can convert about a third of the solar energy to electrical power. For electrical power when the Sun is not available (for example, when a space vehicle is over the night side of Earth), solar power systems typically use rechargeable batteries for storage.

Solar power systems can also be designed using mirrors or lenses to concentrate sunlight onto a thermal receiver. The heat produced by the thermal receiver then is used in a heat engine, similar to the steam turbines used in terrestrial power plants, to produce power. Systems of this type can store power in the form of heat, instead of requiring batteries, but have not yet been used in space.

Nuclear Power

Since solar power decreases with the square of the distance from the Sun, missions to the outer planets require an alternate power source. Nuclear power systems can provide power even when sunlight is unavailable. Nuclear generators are categorized as "radioisotope" power systems, which generate heat by the natural radioactive decay of an isotope, and "reactor" power systems, which generate heat by a nuclear chain reaction. For both of these power systems types, the heat is then converted into electrical power by a thermal generator, either a thermoelectric generator that uses thermocouples to produce power, or a turbine. For radioisotope power systems, the most commonly used isotope is Plutonium-238. The plutonium is encapsulated in a heat-resistant ceramic shell, to prevent it from being released into the environment in the case of a launch accident. Such isotope power systems have been used on the Pioneer, Voyager, Galileo, and Cassini missions to the outer planets (Jupiter and beyond), where the sunlight is weak, and also on Apollo missions to the surface of the Moon, where power is required over the long lunar night.

WHAT ARE RADIOISOTOPES?

Atoms of an element that have the same atomic number but a different atomic weight are referred to as isotopes. Radioisotopes are unstable isotopes that spontaneously decay into a different atom, releasing energy. This radioactive decay energy can be converted into electrical energy.

Solar Power Satellites

Scientist Peter Glaser has proposed that very large solar arrays could be put into space and the power generated by the solar arrays can be transmitted to the surface of Earth using a microwave or laser beam. Glaser argues that such a "solar power satellite" concept would be a pollution-free source of low-cost solar power, and that by putting the solar power system above the atmosphere, 24-hour power could be produced with no interruptions by clouds or nighttime. To be practical, such solar power satellites will require a reduction in the cost of manufacturing solar cells, and new methods of low-cost launch into space. SEE ALSO Solar Power Systems (volume 4).

Geoffrey A. Landis

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Property Rights

The right to own land and other property is taken for granted in many countries. It is one of the cornerstones of private enterprise and capitalism, and makes it possible for people to control where they live and work. In space, however, this right is an open issue. International treaties appear to bar people from making ownership claims to property on celestial bodies but do not explicitly prohibit it. Although the topic of property rights in space is not yet a major issue, it is something that will have to be resolved before major commercial development of space, particularly the Moon and other nearby celestial bodies, can proceed.

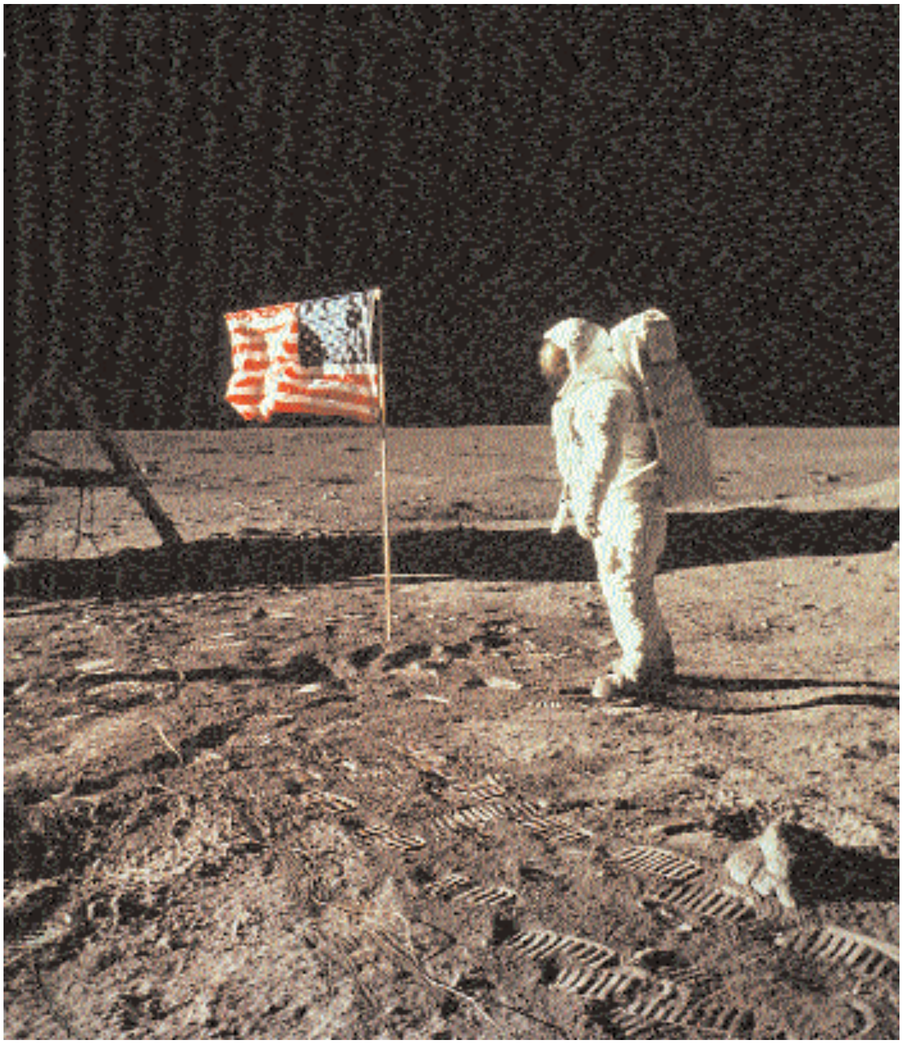
Treaties and Property Rights

Two international treaties address, at least to some extent, the question of property rights in space. The Outer Space Treaty of 1967, the first treaty to deal exclusively with space, specifically prohibits nations from making claims in outer space. Article 2 of the treaty states: "Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." This provision is similar to one in the Antarctic Treaty of 1959, which prevented countries from making new claims on territory in Antarctica, although that treaty allowed existing claims to stand.

The Outer Space Treaty does not specifically prohibit nongovernmental organizations, including individuals and businesses, from making claims to or owning property on other worlds. However, because no nation can claim another body, it becomes much more difficult for private claims to be enforced. If two people have a dispute over the ownership of a parcel of land in the United States, that dispute can be resolved through American courts because the United States clearly has jurisdiction over that parcel. However, since no nation has jurisdiction over land on another celestial body, it is unclear how disputes, registration of deeds and claims, and other aspects of property rights could be managed.

The United Nations made an effort to eliminate this concern in 1979 through a separate treaty that is known popularly as the Moon Treaty. This treaty, like the Outer Space Treaty, prohibits countries from claiming property on other worlds. However, the Moon Treaty also bars nongovernmental organizations from owning property on other worlds. The treaty considers the Moon and the celestial bodies of the solar system the "common heritage of mankind" and would require an international organization of some kind to oversee development on other worlds. That organization also would be responsible for the distribution of the benefits realized from any such development among all nations.

Although the Moon Treaty could settle the question of property rights in space, the accord has been largely ignored. Only nine nations have ratified the treaty, none of which play a significant role in space exploration. The United States and other major spacefaring nations have never signed,



Although the United States was the first country to land on the Moon, no country, private corporation, or individual may lay claim to private ownership of the Moon or any other celestial bodies.

let alone ratified, the treaty. Although the treaty technically has gone into force because of the small number of nations that have ratified it, the agreement has very little real power. This has left the question of private property rights in space unsettled.

Private Property Right Claims

Despite the current ambiguity regarding private property in space, some companies and individuals have attempted to make claims on celestial bodies. One of the best-known claims was made by Dennis Hope, an American entrepreneur. In 1980 Hope filed a claim for the surface of the Moon, the other planets in the solar system (except for Earth), and their moons. The claim was filed with a claim registry office of the U.S. government under the Homestead Act of 1862. Hope also sent copies of the claim to the United Nations and the Soviet Union, neither of which, according to Hope, contested the claim. Hope has been selling property on the Moon and other solar system bodies since he registered the claim through a company called Lunar Embassy.

Many space law experts do not believe that Hope's claim is valid. They contend that it runs afoul of Article 2 of the Outer Space Treaty, which prevents nations from claiming territory in space. Because no nation can claim the Moon or another world, there is no nation that would have jurisdiction over such a claim. Moreover, there is more than one claim to ownership of the Moon: A German, Martin Jürgens, has a declaration given to one of his ancestors by the Prussian king Frederick the Great that gives that person ownership of the Moon. While maintaining the legitimacy of his claim, Hope carefully skirts around the legal issues by noting that the deeds he sells for property on other worlds are "novelty items."

In February 2001 the National Aeronautics and Space Administration's (NASA) Near Earth Asteroid Rendezvous (NEAR) spacecraft landed on the surface of the asteroid Eros after orbiting the body for a year. Shortly afterward Gregory Nemitz, chief executive officer of Orbital Development, a San Diego company, submitted a letter to NASA headquarters. That letter stated that Nemitz and Orbital Development had filed a claim in 2000 for the asteroid with the Archimedes Institute, which maintains a registry of such claims but is not supported or endorsed by any government entity. Nemitz asked NASA for a nominal "parking/storage fee" of $20 per century for landing NEAR on the surface of Eros.

In response, NASA General Counsel Edward Frankle said that the agency would not pay the fee. Frankle cited Article 2 of the Outer Space Treaty, which prohibits nations from claiming celestial bodies, as the main reason why he believed Nemitz's claim was not valid. Although Nemitz made a number of arguments stating why he believed that article of the treaty did not apply, NASA was not swayed. The space agency continued to decline to pay the fee, saying that the claim was not sufficiently established. NASA declined to take a position on whether Article 2 of the Outer Space Treaty applied to individuals or whether the treaty should be amended to deal specifically with this issue.

Other companies have taken a more circumspect approach to the question of property rights. Applied Space Resources, an American company that is planning to land a spacecraft on the Moon, has made a conscious decision not to claim any territorial rights on the Moon. The company is concerned that any near-term debate over property rights could prove detrimental for commercial efforts because it believes that one possibility would be a moratorium on commercial space projects until the legal questions about property rights are resolved.

The Future of Property Rights in Space

A complete solution to the question of private property rights in space probably will require either changes to the Outer Space Treaty or an entirely new accord. As of this writing, however, there are no efforts under way to amend existing treaties or write new ones. In light of the relative lack of activity in commercial space enterprises to date, it may be some time until nations take action on this issue.

However, there have been some low-key efforts to address the property rights issue. Attorney Wayne White has drafted a proposed treaty that deals with property rights on the Moon and other bodies. Under his proposal, private entities—individuals or companies—that operate a space facility of some kind on the surface of another world for at least one year would be accorded the right to the property on which the facility is located as well as a "safety zone" extending up to 1 kilometer (0.62 mile) from it. This provision would prevent people from claiming entire planets without even landing a spacecraft on them. The proposal also includes provisions for transferring property and revoking property rights if the facility is abandoned or is not used for peaceful purposes. White has presented his draft treaty and papers based on it at meetings of the International Institute for Space Law, but the proposal has not been taken up by any nation.

Although property claims on other celestial bodies have not been recognized by any nation, there is a registry for tracking those claims. The Archimedes Institute, which was established by law professor Lawrence Roberts, operates a claims registry where individuals can file claims on objects throughout the solar system. Claims filed with the Archimedes Institute have no special protection or priority over other claims because no nation has recognized such claims. However, the institute hopes that the creation of the registry will encourage the formation of new agreements that will recognize private property rights in space. SEE ALSO Governance (volume 4); Land Grants (volume 4); Law (volume 4); Law of Space (volume 1).

Jeff Foust

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Rawlings, Pat

R

American Illustrator
1955–

Pat Rawlings* is one of the finest and best-known technical illustrators in the world. His extraordinarily realistic depictions of future spacecraft have been reproduced in hundreds of books and magazines, as well as in movies and on television, since the 1970s. Like the earlier visions of Chesley Bonestell, Rawlings's work has imparted a sense of reality to space travel. This quality has been instrumental in "selling" the reality of space travel to laypersons who otherwise might think of space travel as science fiction or fantasy.

*** Examples of Rawlings' art can be found in the Volume 4 articles "Lunar Bases" (page 88) and "Lunar Outposts" (page 90).**

While working for Eagle Engineering, Rawling created an internal art studio—Eagle Visuals—with a team of illustrators and model makers responsible for the majority of the artwork depicting the advanced programs of the National Aeronautics and Space Administration (NASA). Since 1989 Rawlings has worked for Science Applications International Corporation (SAIC), where he has produced artwork for nine NASA field centers and for NASA headquarters. He also has produced a series of calendars for SAIC, all of which feature his paintings. Much of the perception of the American public and that of people worldwide of the future of space exploration is due to Rawlings's visions. SEE ALSO Artwork (volume 1); Bonestell, Chesley (volume 4); Human Missions to Mars (volume 3); Lunar Bases (volume 4); Lunar Outpost (volume 4); Mars Bases (volume 4); Mars Missions (volume 4).

Ron Miller

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Religion

Wherever human beings travel, we bring our religions with us. "Godspeed, John Glenn," the farewell words spoken to the first American astronaut into orbit, exemplifies the characteristic human drive to carry faith into space.

Many astronauts who are religious have spoken of finding their faith strengthened by the experience of traveling in space. The ability to look back on Earth as a small blue planet, and to see the fragility of life and human existence, is an experience that brings many space travelers closer to the creator. The astronauts of the Apollo 8 mission, orbiting the Moon for the very first time in 1968, broadcast back to Earth a reading from the book of Genesis on Christmas day, in the belief that the passage discussing the creation of the world expressed their feelings of the awe and majesty of creation.

While some astronauts are agnostic or atheist, others have been highly religious. Astronauts from most of the major religions on Earth have been represented in space, including representatives of Islam, Christianity, Judaism, and Buddhism. Edwin "Buzz" Aldrin, one of the two astronauts who were the first men to land on the Moon, brought with him a small vial of consecrated wine and a tiny piece of communion wafer, in order to celebrate the holy sacrament on the surface of the Moon.

WHAT ARE NOETIC SCIENCES?

In the words of one of its founders, noetic science is concerned with subjective experience as opposed to materialistic science (which is essentially interested in objective experience). Noetic scientists describe the discipline as "a science of consciousness and the world of inner experience."

For other astronauts, the spiritual experience of space is not expressed in the terms of formal religion. After landing on the Moon with Apollo 14, Astronaut Edgar Mitchell founded the Institute of Noetic Sciences to reconcile the spiritual and humanistic values of religious traditions with scientific insights. The spiritual insight granted from spaceflight, and seeing Earth from orbit without political boundaries or petty human conflict, is profound. This insight has been tagged "the overview effect" by author Frank White.

Historically, religion and science have had a difficult relationship: in 1600, for example, Giordano Bruno was burned at the stake by the Roman Catholic Inquisition for writing that the universe is infinite and includes an indefinite number of worlds. In 1630 the scientist Galileo Galilei was tried by the church on a charge of "suspicion of heresy" for writing that Earth circled around the Sun. He was forced to recant his position, and was subjected to imprisonment. It would take over four centuries for the Roman Catholic Church to review the results of the trial and rescind the sentence.

It is now widely conceded by theologians that there is no inherent conflict between science and religion, and modern scientists have included fol-

lowers of all religions, as well as agnostics and atheists. Some philosophers and scientists such as Frank Tipler have looked even further, and foreseen the development of human potential into God in a future "Omega point" at the final collapse of the universe, elaborating on theological concepts developed by the Jesuit priest Pierre Teilhard de Chardin.

The Moon, pictured here over the Metropolitan Cathedral in Mexico City, has special significance in various world religions. In the Islamic faith the Muslim lunar calendar sets the beginning and ending of Ramadan by the sighting of the crescent Moon.

Religion—and religious persecution—has always been a significant force to move outward. In American history, the Pilgrims were driven to settle Plymouth, Massachusetts, as a religious colony; and the settlement of Utah was incited by intolerance toward the Mormon Church in the eastern United States. Some theorists expect that the same forces may also drive space colonization, as religious intolerance has not been eliminated in the centuries since these events.

The scriptures are silent on the subject of life on other worlds. If we explore other worlds, and find other forms of intelligent life, this will bring out many questions to be addressed by religion. Do beings of other planets have souls? Are they eligible for salvation? Do they have religion, and if so, what god or gods do they worship? Questions such as these have been addressed in science fiction. Science fiction writers who have addressed the question of the religious implications of spaceflight include, among others, Arthur C. Clarke, Mary Doria Russell, James Blish, and Philip José Farmer. SEE ALSO CLARKE, ARTHUR C. (VOLUME 1); GALILEI, GALILEO (VOLUME 2).

Geoffrey A. Landis

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Resource Utilization

in situ in the natural or original location

The purpose of resource utilization (also known as **in situ** resource utilization [ISRU]) is to reduce the mass, and thus the cost, of space missions. On Earth, explorers rarely took all the food and supplies they would need for their entire journey. Instead, they relied on the resources around them, hunting for or gathering food, chopping down trees for lumber, and so forth. By carrying with them only what they needed to get from one stop on their journey to another, they minimized the size of their expeditions and made them more adaptable to changes.

The same principle is applicable to exploration of the solar system. Carrying all the food, propellant, air, and other supplies needed for a human mission to the Moon or Mars would make a spacecraft very large and heavy. Given the high cost to launch **payloads**—up to $10,000 per pound—reducing the mass of a spacecraft can greatly lower the cost of a mission. The savings can be significant even for smaller robotic missions, such as proposals to land spacecraft on Mars, gather rock samples, and return them to Earth. The use of ISRU could make the difference between an affordable mission and one that is prohibitive.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The Moon

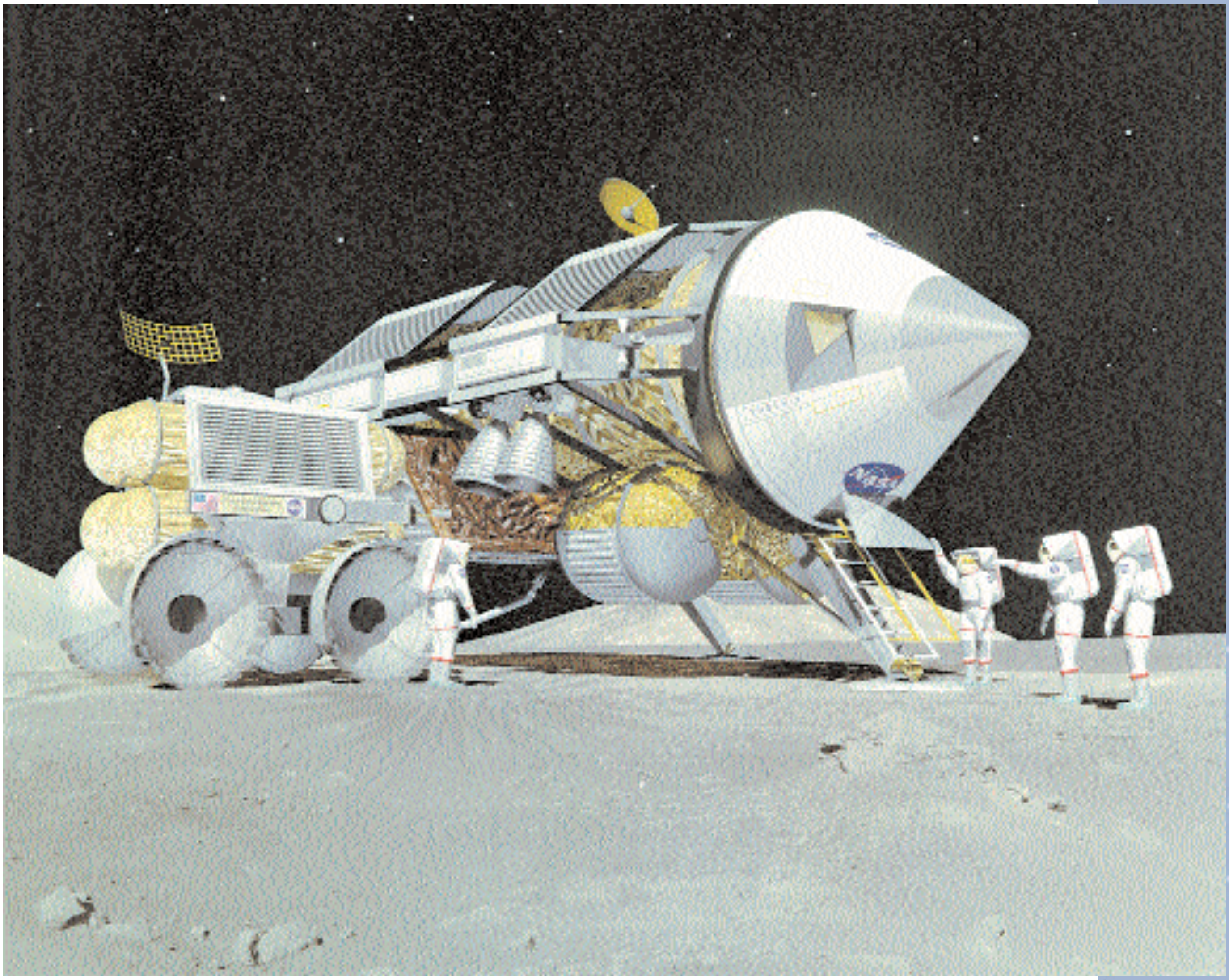
The Moon appears at first to have few resources to offer because of its barren surface and lack of an atmosphere. However, studies of lunar samples returned by the Apollo missions revealed that lunar rocks are rich in oxygen. Up to 45 percent of the mass of lunar rocks consists of oxygen locked up chemically in **minerals**. When the rocks are heated and mixed with other materials, the oxygen can be released and used as a propellant, or for breathing. The by-products of these reactions are metals such as iron and aluminum, which in powdered form could also be used as **rocket** propellant. Although there is no hydrogen contained in lunar rocks, a small amount of hydrogen has been deposited on the surface from the **solar wind**. This hydrogen could be harvested and used for propellants or combined with oxygen to make water.

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

rocket vehicle or device, especially designed to travel through space, propelled by one or more engines

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

There may be deposits of water ice on the Moon. Scientists theorized for years that ice could exist in the floors of craters near the lunar poles that are in permanent shadow. The ice would come from comets that collided with the Moon over the last several billion years. The existence of water ice in those craters was largely confirmed by the National Aeronautics and Space Administration's (NASA) Lunar Prospector mission in 1998, which found traces of hydrogen, and thus most likely ice, in the shadowed regions at either pole. If ice does exist there, it could be harvested and used for drink-



Oxygen produced on the Moon is used to refill the propellant tanks of this lunar crew's vehicle, enabling them to return directly to Earth in this artist's concept.

ing water or broken down into hydrogen and oxygen. NASA and private companies have proposed sending rovers into those craters to confirm that ice is present there and to determine how difficult it would be to harvest it.

Mars

Mars offers even more opportunities for ISRU. The planet has a thin atmosphere composed mostly of carbon dioxide, from which oxygen can be extracted. Many scientists believe that there may be extractable deposits of water ice below the surface of Mars. Even if there are no such deposits, there are small traces of water vapor in the atmosphere.

These attributes make Mars ideal for the use of ISRU. One of the first proposals to employ ISRU on Mars was developed by Robert Zubrin, an aerospace engineer who coauthored *The Case for Mars* (1996). In the early 1990s Zubrin showed how liquid hydrogen, carried to Mars on a spacecraft, could be combined with the Martian atmosphere to form methane and oxygen, which could then be used as rocket propellant. This process, known as a Sabatier reaction, dates back to the nineteenth century and has been used extensively in the chemical industry. Zubrin and his coworkers showed that a Sabatier reactor could be built easily and cheaply and generate on Mars the propellants needed to return a spacecraft to Earth.

feedstock the raw materials introduced into an industrial process from which a finished product is made

One of the disadvantages of the Sabatier reaction is that it requires a **feedstock** of liquid hydrogen on the spacecraft that must be kept at temperatures near absolute zero. This may prove difficult on long missions to Mars, so alternatives that do not require liquid hydrogen have been studied. One concept proposed by researchers at the University of Washington uses zirconia crystals and electricity to convert carbon dioxide into carbon monoxide and oxygen, which can then be used as rocket propellant. Carbon monoxide, when combined with oxygen, is not as powerful as methane in rocket engines, but it can be made on Mars without the need for an initial supply of hydrogen.

Water is another key resource that may be found on Mars. Images of some portions of the planet suggest that there may be groundwater sources a short distance beneath the surface. A future mission could bring drilling equipment to reach these water sources and pump it to the surface. Even if subterranean water deposits are not found, there may be ways to extract small amounts of water from the atmosphere. Engineers have proposed passing Martian atmosphere through zeolite crystals. The crystals would absorb water vapor but allow carbon dioxide and other gases to pass through. The water could be extracted from the zeolite later.

Moons, Comets, and Asteroids

The concept of ISRU can be extended to other bodies in the solar system. Comets and many asteroids are rich in water, carbon dioxide, and methane, which could be used by future missions as propellant for the trip to their next destination or home. Water ice may also exist on Phobos and Deimos, the two moons of Mars, allowing them to become refueling stations for missions to that planet. The moons of the outer planets in the solar system are also rich with various kinds of ices. Through resource utilization, it will be possible for future space explorers to "live off the land" as they travel throughout the solar system. SEE ALSO Asteroid Mining (volume 4); Living on Other Worlds (volume 4); Lunar Bases (volume 4); Lunar Outposts (volume 4); Mars Bases (volume 4); Mars Direct (volume 4); Mars Missions (volume 4); Natural Resources (volume 4); Power, Methods of Generating (volume 4); Settlements (volume 4); Space Industries (volume 4); Space Resources (volume 4).

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Reusable Launch Vehicles

The last decade of the second millennium saw the emergence of the idea of sending **payloads** into space with reusable launch vehicles (RLVs). It appeared to make economic sense to reuse a launch vehicle that cost as much as a small airliner, rather than throw that vehicle away after one use. Two prototypes—the McDonnell Douglas Delta Clipper and Rotary Rocket's Roton—were built and flown at low altitude. A number of small companies emerged, each seeking to build an RLV. Although this idea has gained broad acceptance, no RLV has flown in space in recent years and none is likely to for many years.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

An Old Idea and a Proven Technology

It is a misconception that a number of technological breakthroughs are required before RLVs will be feasible. An American experimental RLV, the X-15, made its maiden flight on June 8, 1959. The X-15 was not called an RLV but a **hypersonic** airplane. It was incapable of reaching orbital speed (24,000 kilometers [15,000 miles] per hour) but flew fast enough (7,160 kilometers [4,475 miles] per hour) to reach an altitude above 100 kilometers (328,080 feet), the officially recognized boundary between Earth and space. In 199 flights the X-15 topped this altitude once, on August 22, 1963. With pilot Joe Walker at the controls, the X-15 reached 109,756 meters (360,000 feet) and became the first and only successful RLV.

hypersonic capable of speeds over five times the speed of sound

The idea of the RLV can be traced back to 1928, and since that time a great many proposals have been made. The classic *The Frontiers of Space* (1969) vividly illustrates a number of RLV concepts, all of which were technically feasible at that time.

Fated by History

If technical feasibility is not an issue, why, then, has the RLV not replaced the expendable launch vehicle (ELV)? The reasons include a complex mix of economics, politics, historical accident, and human psychology. To understand them, it is necessary to appreciate how the ELV came into being, how the market for commercial ELVs emerged, and how the operational aspects of ELVs prevent new commercial space markets from developing, and consequently, why no RLVs have been or will soon be developed.

Arthur C. Clarke's *The Promise of Space*, Chapter 14, "The Birth of Apollo" (1968), gives the most concise summary of the historical events that made the ELV imperative. In essence, the space age was a child of the Cold War. If technology had evolved in a logical manner, RLVs would have been the product. In 1957, however, the Soviet Union shocked the world by using an intercontinental ballistic missile (ICBM) to launch the world's first satellite. A series of space firsts by the Soviet Union began to make the United States look technologically and economically inferior.

This perception was a threat to national security. On May 25, 1961, President John F. Kennedy responded by making a commitment to land a

The X-33 was expected to demonstrate the new technologies needed for a feasible reusable launch vehicle but the project was canceled in 2001.

man on the Moon and return him safely to Earth by the end of the decade. Such a feat required decisions to be made early on, the first of which was how to get there. The difficulties of making aircraft that could carry a large payload and fly fast enough to reach orbit were well known, and no such airplane had ever been built. However, hundreds of satellites and spacecraft had been launched on ICBMs, and it was correctly thought that there was no limit to the size of the payload that could be launched with a scaled-up ICBM. Ultimately, President Kennedy's goal was achieved by using the Saturn V rocket, a 2,902,991-kilogram (3,200 tons), 111-meter-tall (365 feet) ELV designed specifically to send astronauts to the Moon. On July 20, 1969, Neil Armstrong and Edwin "Buzz" Aldrin landed on the lunar surface, signaling the beginning of the end of the Cold War.

Sadly, that triumph closed the gates to space for future generations. By establishing the ELV as the "existing launch vehicle," a mode of space transportation had been established that was too expensive to permit any normal economic development of the space frontier. In the forty-five years since the Soviet Union launched the first satellite, only one commercial use has been found for space: as a location for relay stations (**geosynchronous** communication satellites [GEOSATs]) to bounce radio and television signals around the world.

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

Even that market would not have emerged if it had not been initiated, as a matter of national security, by the U.S. government. In 1962 Congress passed the Communications Satellite Act, which led to the formation in 1963 of the Communications Satellite Corporation (Comsat). The financing of this "risky" venture was possible only because the government backed it. The communications satellite industry grew at an astonishing rate, and was eventually was "privatized" by the Space Act of 1984. It has proved phenomenally profitable but has welded closed the gate to space that Apollo locked.

The reason for this is psychological. According to management consultant W. Edward Deming, "If you always do what you always did, you'll always get what you always got." In the case of space, doing what you always did is a matter two things: Having the government underwrite the risk of any new space venture—be it a new launch vehicle or satellite system—and reaching space by means of "launch vehicles" of any kind are things of the past. Only space projects tied to national security should be backed by the government, and since the end of the Cold War, these projects have not included commercial ventures.

The private sector has seldom had the financial courage to undertake a new kind of space venture without government guarantees. The most notable exceptions have been the global cellular telephone projects Iridium and GlobalStar. Both have been spectacular failures because they have relied on "launch" by the means used for GEOSATs. Although each GEOSAT produces revenue and requires only one launch, Iridium and GlobalStar had to place large numbers of satellites in orbit before any revenue could flow. The cost and time required to do this on single-use launch vehicles were so great that corners had to be cut in terms of the size and power of the spacecraft. The result in each case was substandard service at a price no one could afford.

The Concept of "Launch" as the Barrier to RLVs and Space

The chief barrier to large-scale commercialization of space is the concept of the launch. The practice of making each satellite a complete, independent, stand-alone unit results in an upward cost spiral for both satellite and launch vehicle (the size of both continually increases to squeeze every ounce of revenue out of the increasingly expensive hardware) and a consequent reduction in the number of spacecraft launched each year.

An RLV must fly many times to recover its cost of development and construction. Further, it would take an extremely large and expensive RLV to carry stand-alone satellites of the GEOSAT class. An expensive RLV carrying a small number of complete stand-alone satellites each year is not economically viable.

However, there is no reason, other than those imposed by launch, that every payload cannot be a complete, stand-alone unit. On Earth one does not deliver an office building to its lot on a single truck. One brings in many trucks, each carrying small components of the building. Erecting an "office building" in space is done the same way. The International Space Station could not have been "launched" on a single rocket. It had to be taken up in modules and assembled in orbit. The significance of this is that on-orbit assembly has been demonstrated on a massive, complex scale. The assembly of smaller spacecraft on orbit should be no more difficult.

The Prescription: Change the Way We Operate in Space

No technological breakthroughs are required for RLVs to flourish. What is required is the discarding of the very concept of the launch and adopting the same approach to space operations that is used routinely on Earth: build spaceplanes and other space transport systems and use them to carry components of space factories into orbit. After the factories are built, they should be used to produce the only thing that can be built better in space than on Earth: spacecraft. The parts for the spacecraft, along with the people to put them together and the supplies needed to keep them alive, can be delivered by space transports on a regular basis.

In this system a space transport that delivers a smaller payload but does so economically (i.e., a single-stage-to-orbit vehicle) has a decided advantage. Because it can deliver only a small load, it must fly frequently. It will therefore spread its cost of development and construction over a large number of flights, just as an airliner does.

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

The first spacecraft to be assembled in orbiting factories would be communications satellites, since there is an established market for them. Having put in place an orbital **infrastructure** involving people living and working in space, one then can branch out into other areas. The same habitats used as factories could be replicated, with modifications, as orbiting hotels. Because a large number of people would have already flown into space to assemble the factories, the communications satellites, and the hotels, enough experience would have been accumulated to make passenger flights safe and easy.

Once passenger travel is established, the promise of space will be realized. There are 6 billion potential payloads in the form of human beings. This far exceeds the number of spacecraft that will ever be built and represents the real market for future space transportation systems.

Wanted: A Howard Hughes

Getting to this point will not happen soon. In light of the realities of finance and markets, the only hope for change is the emergence of an individual with the personal financial resources, technical know-how, business acumen, and vision to make it happen. What is needed is a Howard Hughes,* who possessed all of these attributes and used them to advance aviation.

***In 1966 *Fortune* magazine declared aviator and financier Howard Hughes the richest man in the United States.**

When such a person appears and brings about the needed changes, the opportunities will be endless. No one knows what new activities and industries will result when large numbers of people travel into space. One can be sure that things that we have never dreamed of will emerge. When people are placed in a completely new environment, they adapt both themselves and that environment in ways that cannot be predicted. This has been the history of humanity, and it will be the future of our expansion into space.

SEE ALSO Accessing Space (volume 1); Business Failures (volume 1); Communications Satellite Industry (volume 1); Getting to Space Cheaply (volume 1); Hotels (volume 4); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Satellite Industry (volume 1); Space Tourism, Evolution of (volume 4); Tourism (volume 1).

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Satellites, Future Designs

S

The nature of the satellite manufacturing industry is changing, much as the computer industry changed in the late 1970s. The satellite industry is becoming less of a scientific enterprise, wherein each spacecraft is a unique design, handcrafted and built for a very specific purpose, and more of a commodity business, in which satellites are built around a basic model and adapted to meet the customer's needs. Shopping for a modern communications satellite is more like buying a very expensive piece of industrial machinery than building a new type of airplane.

The Spread of Satellite Technology

Still, building satellites and satellite components is a high-prestige, high-payoff industrial activity. Ambitious nations are willing to spend heavily to create a satellite manufacturing capacity for themselves. Being able to build or launch even relatively unsophisticated spacecraft is a way to assert national pride and show the world that one's country is capable of high-tech development. Argentina, Brazil, China, India, Israel, South Korea, and Taiwan all launched spacecraft in the 1990s at least partly with political and national security goals in mind. In a market in which so many nations are in competition to sell their satellites to a limited number of commercial operators, it is a classic buyers' paradise.

Orbital Sciences Corporation of the United States and Surrey Satellite Technology Limited of Britain have both helped small developing countries to build and fly their own spacecraft. The spread of satellite technology, especially Earth observation systems, is giving even the poorest nations the possibility of using spy satellites to check on their neighbors. India has developed its own series of Earth observation spacecraft, called the India Resource Satellites. Over the years, their spacecraft have gotten better and better at sending down increasingly sharp images so that now they are almost as good as the spy satellites of Western nations.

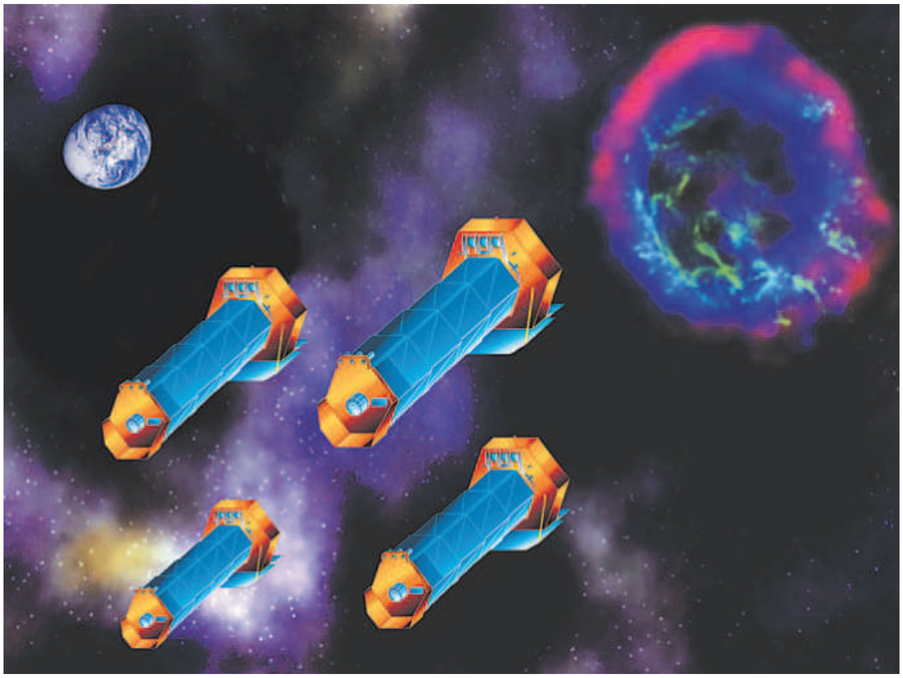
Newer and Future Commercial Communications Satellites

Nevertheless, the cost of putting a commercially viable communications satellite into **geosynchronous orbit** (GEO), 35,880 kilometers (22,300 miles) above Earth, is still anywhere from $50 million to $70 million. For the newer and more powerful communications satellites, such as the Boeing Company's 702 model, the cost of getting up there is even higher.

The Boeing 702 model is a good example of an ultramodern communications satellite designed to operate in GEO. It will carry up to 100 **transponders** providing highly reliable communications services at what Boeing hopes will be a competitive price. With its innovative new propulsion system called XIPS, Boeing hopes the 702 will stay up longer, and with less need for complicated and expensive ground control services, than any other communications satellite on the market. The trough-shaped solar wings are a new and highly efficient design intended to act as a concentrator to increase the level of electric power generated by the gallium arsenide solar cells.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis; an object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

transponder bandwidth-specific transmitter-receiver units



The Constellation X satellites, orbiting in close proximity to one another, will act as one large telescope. The combined efforts of these satellites will gather information on black holes and "missing matter."

In the early twenty-first century, positions for satellites in GEO will become more and more valuable and, probably, will become the subject of expensive and lengthy international litigation. The greater the value, the more profit investors will expect from each spacecraft placed up there. One hundred transponders will not be enough to satisfy the needs of a world that demands ever more communications capability. Commercial telecommunications satellites will soon have to carry hundreds, and eventually thousands, of transponders to meet future demand. Boeing hopes that its future generations of very large commercial satellites will be far more reliable and will remain operational much longer than the current generation, whose reliability problems are well known.

Distributed Spacecraft Systems

One way the satellite industry hopes to solve some of the reliability problems is to build satellites that will fly in formation. This is sometimes referred to as a distributed spacecraft system. The idea is to launch groups of spacecraft that will cooperate to accomplish the desired goal. Whether providing a better **multispectral** look at Earth's atmosphere, focusing on deep space, or providing less-expensive satellite phone service, future clusters of satellites will have the capability to repair the system by working around a single, broken spacecraft.

multispectral referring to several different parts of the electromagnetic spectrum, such as visible, infrared, and radar

Control techniques for these systems will need to be built into each satellite. The satellites will need to be able to communicate automatically among themselves—to autonomously maintain position both within the cluster and in relation to the mission's objectives. An objective could be something as simple as keeping together in orbit or as complex as traveling to Jupiter or Saturn and changing formation when they arrive there.

Old concepts and methods of spacecraft and mission design will simply not work for these future requirements. The satellite cluster, as a whole, must be able to adapt itself to new circumstances without waiting for orders from ground control. This will require new forms of artificial intelligence and a whole new field of software design. There are many difficulties to be overcome before satellite clusters become a reality, but they promise great improvements in reliability and performance.

The most interesting application for a distributed spacecraft design is the Constellation X mission being planned by the National Aeronautics and Space Administration. Its space segment will be composed of a group of X-ray telescopes based around one of the **libration points** or Lagrangian points. The mission is designed to give scientists a better look at **black holes** and to push ahead with the effort to unravel the mystery of **missing matter**.

Other applications of the concept of distributed spacecraft systems include the military's idea for a fleet of **radar** satellites that would provide real-time data of both ground and air movements as a long-term replacement for the AWACS radar surveillance and the J-Stars ground surveillance aircraft. Another military idea is to build a new class of satellites that can be refueled while in orbit, thus giving them a vastly longer operational life.

Future Space Probes

The need for an inexpensive way to get around the solar system is driving research into "solar sails." This type of spacecraft will be propelled by the **solar wind** in a manner similar to an ordinary sailboat. It will need huge, lightweight structures to capture the energy of the solar wind. Given the right design, solar sails could be used to place research probes on the far side of the Sun, thus providing us with three-dimensional views of such spectacular events as solar **coronal mass ejections**.

More conventional deep-space missions will eventually be launched to follow up on the **Galileo mission** to Jupiter and the **Cassini mission** to Saturn. In deep space beyond the asteroid belt, solar power arrays do not work. Nuclear power systems, such as the controversial isotope thermal generator used for the Cassini mission, seem to be the only alternative. It had been thought that no more large, expensive deep-space missions would ever be launched again. Now, however, they appear to be the most effective way to reach the outer planets of our solar system.

In the near future, satellites will be even more diverse than they are today. Everything from tiny nanosats, weighing only a few ounces, to very large satellites, weighing hundreds of tons, will be launched into space. Humanity's robotic servants in space will be as diverse, and as ingeniously made, as any of the millions of other tools we have built over the ages. SEE ALSO COMMUNICATIONS, FUTURE NEEDS IN (VOLUME 4); LIGHTSAILS (VOLUME 4); SATELLITES, TYPES OF (VOLUME 1); SMALL SATELLITE TECHNOLOGY (VOLUME 1); SOLAR POWER SYSTEMS (VOLUME 4); SPACE INDUSTRIES (VOLUME 4).

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libration point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

missing matter the mass of the universe that cannot be accounted for but is necessary to produce a universe whose overall curvature is "flat"

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

coronal mass ejections large quantities of solar plasma and magnetic field launched from the Sun into space

Galileo mission successful robot exploration of the outer solar system; this mission used gravity assists from Venus and Earth to reach Jupiter, where it dropped a probe into the atmosphere and studied the planet for nearly seven years

Cassini mission a robotic spacecraft mission to the planet Saturn scheduled to arrive in July 2004 when the Huygens probe will be dropped into Titan's atmosphere while the Cassini spacecraft studies the planet

Science Fiction

JULES VERNE (1828–1905)

Science fiction writer Ray Bradbury said that Jules Verne embodies the whole history of humanity. Indeed, Verne lived in an era marked by and obsessed with scientific developments. His novels, filled with technological descriptions, made him one of the founders of science fiction.

Astronautics is unique among the sciences in that it has its roots in an art form. For nearly 400 years space travel existed only in the minds of those faithful writers who kept the torch burning until engineers and scientists developed the technological ability to realize their dreams.

Early Space Fiction

No fiction written about space travel was written until it was known that there were other worlds to go to. This did not happen until 1610, when Galileo Galilei turned a telescope toward the heavens and discovered that what hundreds of generations had assumed were five wandering stars were in fact worlds. This discovery was immediately followed by a spate of speculation about what those worlds might be like, what kind of life might exist there, and, most importantly, how human beings might be able to travel to them. Most of this speculation took the form of fiction, but until the end of the eighteenth century those flights were the stuff of outright fantasy: Neither science nor engineering knew of any method by which a human being could leave the surface of this world, let alone travel to another one.

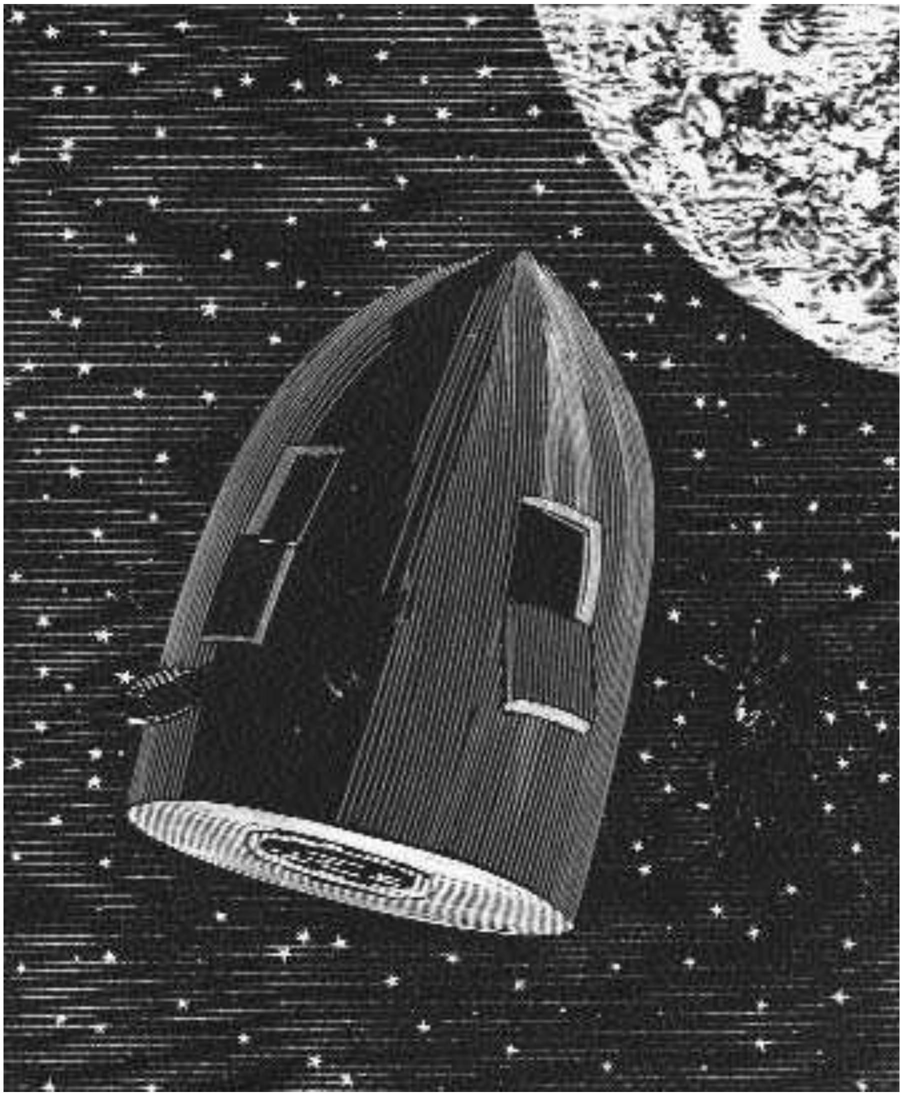
The Nineteenth and Twentieth Centuries

The invention of the balloon in 1783 by the Montgolfier brothers changed all that. It was clear that a balloon could never carry anyone to the Moon, but that invention was a watershed in perception. People now knew that science and technology had the potential to make spaceflight possible; surely it was just a matter of time and imagination. Scores of science fiction novels were written about travel to other worlds. Unlike previous stories, however, those written in the nineteenth century were much more inclined to take into account the actual conditions of outer space and the planets.

Paramount among all of these works were the two space novels of Jules Verne: *From the Earth to the Moon* (1865) and *Round the Moon* (1870). For the first time the problem of space travel was expressed in terms of a problem in engineering and mathematics: Verne scrupulously worked only with the science, technology, and materials available at the time when he wrote. As a result, he achieved a sense of realism that is still convincing. This realism was instrumental in inspiring an entire generation of young readers who decided to do everything they could to make Verne's dream come true. These readers included future scientists such as Hermann Oberth, Konstantin Tsiolkovsky, and Robert H. Goddard, without whose seminal work modern astronautics would have developed decades later than it did. Oberth, for example, said that he had never thought about space travel until he read *From the Earth to the Moon*. Verne's influence continued well into the twentieth century. The astronomer Robert Richardson said, "There can be no doubt that Jules Verne's *Trip to the Moon* with all its faults has exerted a powerful effect on human thought in preparing our minds for this greatest of all adventures."

Verne set a high standard for accuracy and believability that influenced the writers who followed him, and space fiction became much more realistic. Dozens of ideas that are thought of as products of modern space science were first proposed in the pages of early science fiction. The **space**

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period



An illustration from the 1872 edition of *From the Earth to the Moon* by Jules Verne. Nearly a century later, in 1969, Verne's fiction became a reality when astronaut Neil Armstrong became the first human to walk on the Moon.

station and the navigational satellite were invented by Edward Everett Hale in *The Brick Moon* (1869), the solar sail by G. Le Faure and Henri de Graffigny in 1889, the space suit in 1900 by George Griffith, the nuclear-powered spaceship by Garrett P. Serviss in 1910 and Arthur Train and Robert Wood in 1915, and the electromagnetic mass driver in 1930 by R. H. Romans. Even the countdown was invented by science fiction, first used in the 1929 film *Frau im Mond* (Woman in the Moon), by Fritz Lang.

The Modern Era

After World War II the influence of science fiction on the public perception of space travel shifted from the printed page to the silver screen. Although serious fans, including many scientists, preferred the written word, which was light-years ahead of Hollywood's version of science fiction, the image most Americans had of the future of space travel in that period was shaped by what they saw in movie theaters and on television screens. This was unfortunate because, with only a few exceptions, films and television lagged decades behind the literature.

While science fiction writers were working in the present day, Hollywood science fiction was more like what had been published in the pulp magazines of the 1930s and 1940s. Films such as *Flight to Mars* (1951) and *The Terror from Beyond Space* (1958) made space travel seem silly and trivial. However, a few films made a sincere effort to combine realistic drama with real science, such as *Destination Moon* (1950), *Conquest of Space* (1955), *Forbidden Planet* (1956), and *2001: A Space Odyssey* (1968). More recently, there have been films such as *Apollo 13* (1995) and *Red Planet* (2000). On television the sole exception was *Star Trek* (1966–1969). Although taking place in the far future, that series made a genuine attempt not only to keep within the bounds of science but to convey a sense of wonder about space travel.

The link between science fiction and the history of astronautics is complex. Science fiction has served as an inspiration. It also acts as a mirror of the technology of the time in which it is written. Jules Verne, for instance, chose a giant cannon over rockets for the launch of his spacecraft, primarily because of the primitive state of rocket technology in his time (he did use rockets to maneuver his spacecraft). Similarly, in 1910 Garrett Serviss recognized that the recently discovered phenomenon of radioactivity could be a potential energy source for space travel. Science fiction also acts as a gauge of public interest in astronautics, since most authors want to tell stories that incorporate subjects of interest to their readers. SEE ALSO CLARKE, ARTHUR C. (VOLUME 1); GODDARD, ROBERT HUTCHINGS (VOLUME 1); LITERATURE (VOLUME 1); OBERTH, HERMANN (VOLUME 1); *STAR TREK* (VOLUME 4); *STAR WARS* (VOLUME 4); TSIOLKOVSKY, KONSTANTIN (VOLUME 3); VERNE, JULES (VOLUME 1).

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Scientific Research

Successful human exploration of space depends on continued scientific research and innovative technology development. Advances in scientists' understanding of propulsion systems, power generation, resource utilization, and the physiological and psychological effects on humans of living in space are required if humans are to explore space and other planets or establish settlements on other planets.

reconnaissance a survey or preliminary exploration of a region of interest

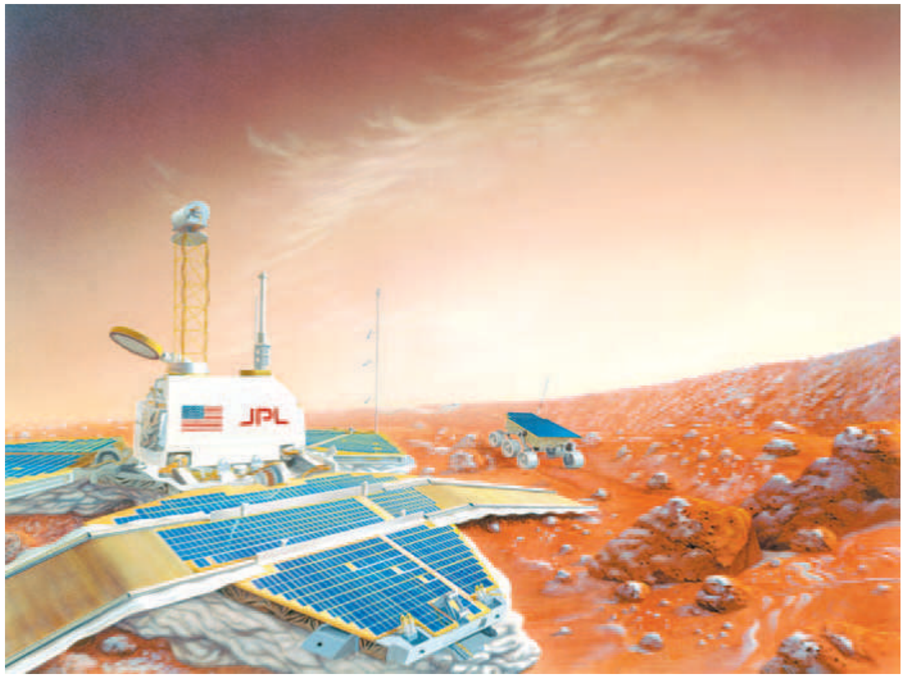
Exploration to develop knowledge about Earth and planetary evolution in general, and the origins and conditions for life, will continue to lead us to search for life throughout the solar system and beyond. An initial **reconnaissance** of all of the planets in the solar system will ultimately be com-

This mirrored test stand at the Marshall Space Flight Center is used for firing solar thermal propulsion engines. Solar engines are more efficient than combustion engines that are currently in use.

pleted with a robotic mission to Pluto. Scientists are also keen to send spacecraft to Europa, one of the moons of Jupiter, to search for signs of life in a liquid ocean thought to exist below its icy crust. And the search will continue for other planetary systems beyond our own in order to answer questions such as: How typical is the solar system? How numerous are solar systems?

At present, Earth- and space-based telescopes are used to conduct the search for other planetary systems, but in the future, squadrons of miniature spacecraft may be sent on **interstellar** journeys of exploration to help answer some of life's most demanding questions: Are we alone, or is there other life out there? Are there other planets that could support humankind?

interstellar between the stars



With knowledge, innovation, and luck, the relatively low-cost Carl Sagan Memorial Station (formerly Mars Pathfinder Lander) was placed on Mars—as depicted in this rendering—and returned several images of Ares Valles.

Propulsion Systems

All rockets in use in the early twenty-first century are propelled by some form of chemical rocket engine. Rockets with sufficient power to place a satellite in orbit use at least two stages. However, one long-term goal has been the reusable "single-stage to orbit" engine design. This would provide quick turnaround, much like a conventional aircraft, and greatly reduce the cost of getting to orbit because of reduced processing and flight preparation. An interim step may be a two-stage vehicle with boosters that fly back and land the spaceport for refurbishment after each launch.

Once a spacecraft is in orbit, other forms of propulsion are necessary. Several exotic propulsion systems have been proposed and investigated over the years. Orion was a project to design and construct a propulsion system using small atomic bombs. While this sounds impractical, many scientists think that such a propulsion system would have allowed humans to get to the Moon more quickly at a much lower cost than the Saturn V launch system. A variation of this type of propulsion is the nuclear thermal rocket. This system uses a nuclear reactor to heat a gas, which is then expelled through a nozzle, providing thrust.

The crew of a rocket ship powered by a nuclear rocket engine would need to be shielded from the reactor. One proposed solution is to place the engine at a large distance away from the crew quarters, connecting the two compartments by a long truss. In this design, distance substitutes for heavy **shielding**.✶ Many scientists believe that if humans are to move beyond Earth orbit, some version of a nuclear rocket engine will be necessary.

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

✶**This design and engine type was portrayed in the movie, *2001: A Space Odyssey.***

Between 2002 and 2007, NASA plans to develop an improved radioisotope power system for use in robotic planetary exploration and targets the first use of this power system for a Mars mission in 2009. During the period between 2003 and 2013, significant funding will be dedicated to the development of a nuclear-electric-propulsion system to enable a new class of planetary missions with multiple targets, to reduce spacecraft travel time, and to decrease mission cost.

Nuclear electric propulsion systems only use the nuclear reactor to generate electricity. The rocket engine itself is electrically powered. There are three classes of electric rocket engines: electrothermal, electrostatic, and electromagnetic. In electrothermal propulsion, the gas is raised to a high temperature and expelled through a rocket nozzle. Electrostatic propulsion systems first convert the gas to a plasma (highly ionized material) and then use electric fields to accelerate the gas to high velocity. Electromagnetic propulsion uses magnetic fields to accelerate a plasma.

Other propulsion systems include various configurations of solar sails, **ion propulsion** systems, and laser propulsion. Several systems involve the use of stationary high-powered **infrared** pulsed lasers. In one interesting system, the laser is fired at a parabolic reflector on the back of the spacecraft. This reflector focuses the laser energy, explosively heating air behind the craft and propelling it forward. In space, the reflector would be **jettisoned** and the laser would fire pulses at a block of propellant (ice would work) heating it to vapor.

ion propulsion a propulsion system that uses charged particles acclerated by electric fields to provide thrust

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

jettisoned ejected, thrown overboard, or gotten rid of

Space Power Generation

Spacecraft currently use solar power, hydrogen fuel cells, or **radioisotope thermoelectric generators** to generate electrical power and rechargeable batteries to store electrical energy. The International Space Station uses solar panels and rechargeable batteries. Solar power is converted to electrical power in large panels containing photovoltaic cells. These cells convert light directly into electricity using a **semiconductor** such as silicon or gallium arsenide. Solar panels are relatively low cost and simple. However, they are fragile, take up a lot of space, and become less effective as a spacecraft travels away from the Sun. For future missions that penetrate deeper into the solar system, and beyond, alternative power sources will be essential.

radioisotope thermoelectric generator device using solid-state electronics and the heat produced by radioactive decay to generate electricity

semiconductor one of the groups of elements with properties intermediate between the metals and nonmetals

Fuel cells combine hydrogen and oxygen to make water. When hydrogen combines with oxygen, energy is released. A fuel cell converts this energy directly into electricity. Fuel cells are relatively compact and produce usable by-products, but they are complicated and expensive to produce.

Radioisotope thermoelectric generators (RTGs) convert the heat produced by the natural decay of radioactive materials to electrical power by solid-state thermoelectric converters. RTGs are lightweight, compact, robust, reliable, and relatively inexpensive. These devices allow spacecraft to operate at large distances from the Sun or where solar power systems would be impractical. They remain unmatched for power output, reliability, and durability.

Resource Utilization

If a human colony is to be established on Earth's Moon, Mars, or elsewhere in the solar system, some means of transporting large amounts of materials to the colony site must be developed. It would be prohibitively expensive and impractical to transport materials from Earth in sufficient quantity to build a base on the Moon or Mars. However, this is not necessary, since both Earth's Moon and Mars have an abundance of raw materials that could be used for construction.

The Moon may have a substantial amount of water locked in permafrost in the bottom of deep craters near its poles where sunlight never reaches or in clays. Although it would be expensive to mine this water, it would be far cheaper than transporting water from Earth. The Moon also has surface rocks rich in light materials such as aluminum and silicon dioxide. It would require large amounts of electrical power to produce pure aluminum or glass from Moon rocks, but solar energy is abundant because of the lack of atmosphere.

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

The Moon may even have sufficient quantities of helium-3 to make a lunar settlement economically self-supporting. The helium-3 would be extracted from lunar soil, packaged as a compressed gas or liquid, and returned to Earth for use in **fusion** reactors. Due to the lower gravity, launching a rocket from the surface of the Moon for return to Earth is far less costly than launching a rocket from Earth.

Mars also has significant resources available. The red color of Martian soil is due to the presence of large quantities of iron oxide. Other **minerals** and elements are also present. In addition, Mars is thought to have vast quantities of subsurface water. Asteroids have long been recognized as accessible, mineral-rich bodies in the solar system and are a ready target for resource mining. SEE ALSO Asteroid Mining (volume 4); Ion Propulsion (volume 4); Lightsails (volume 4); Lunar Bases (volume 4); Lunar Outposts (volume 4); Mars Bases (volume 4); Mars Missions (volume 4); Power, Methods of Generating (volume 4); Solar Power Systems (volume 4).

Elliot Richmond

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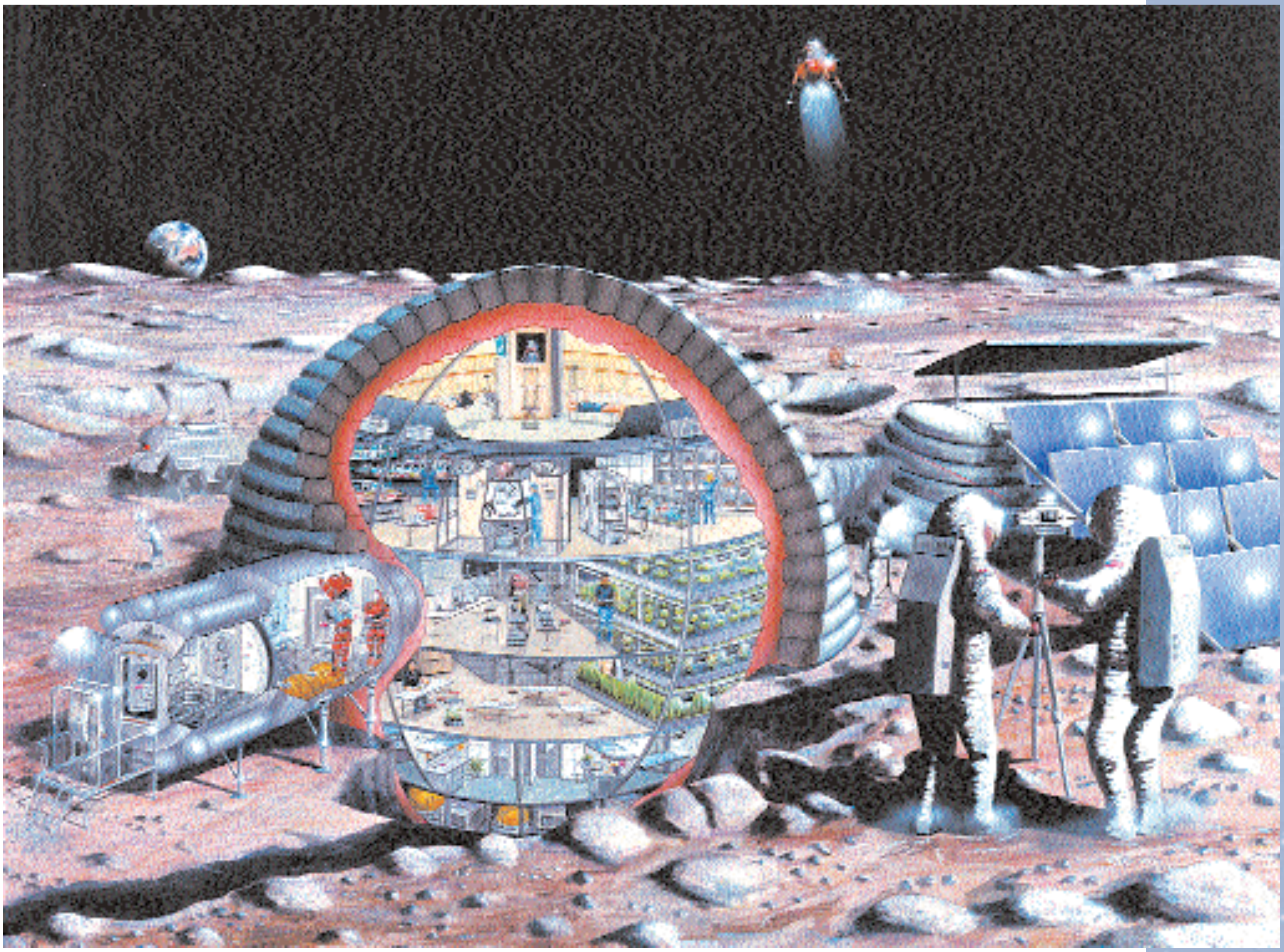
Settlements

At the beginning of the twenty-first century, people are excited by the prospect of visiting new worlds in outer space. While international space



A proposed inflatable habitat is illustrated here. This habitat could be used as a possible lunar settlement for future astronauts living and working on the Moon.

agencies continue robotic exploration of planets and asteroids in the solar system, other government agencies are planning a return to the Moon and expeditions to Mars. What is the logic of establishing a settlement on the Moon as a precondition for human settlement of Mars and beyond? Answers to this question include satisfying the need to explore, increasing scientific knowledge, enhancing understanding of life in the universe, discovering whether life existed on Mars, igniting the human spirit, making use of resources on the Moon and Mars, and ensuring the survival of humankind. Once humans have mastered the lunar environment, they will have the technical knowledge to reach Mars, Jupiter, and the stars.

Settlement of the Moon: First Lunar Base Siting

The first step towards human settlement of the Moon is the determination of the best site for a lunar base. As a result of information gained from the Clementine mission that observed the Moon for 71 days in 1994, supported by data from Lunar Prospector (January 6, 1998–July 31, 1999), it appears that a permanently shaded region inside Shackleton crater at the Moon's south pole, 30 kilometers (18.5 miles) in diameter, contains hydrogen, likely in the form of water ice, and ammonia. Ice would not only supply water for settlers but could also be used to generate fuel for spacecraft.

The rim of the crater is illuminated over 80 percent of the time. Nearby there are two other places, only 10 kilometers (6.2 miles) apart, which receive illumination over 98 percent of the time. Solar energy in those areas could be used to sustain an extraction industry. In the permanently shadowed areas astronomical instruments could be operated with telescopic optics kept cold and stable using **cryogenics**. Shackleton crater could be the best site for a Moon base.

cryogenics related to extremely low temperatures; the temperature of liquid nitrogen or lower

Planet Moon: Phases for Development. David Schrunk and his associates call the transformation of the Moon into an inhabited sister planet of Earth the "Planet Moon Project." This endeavor will draw upon every science and engineering discipline, as well as the social, economic, and political expertise of all nations. It will also provide virtually unlimited energy and material resources for humankind. Schrunk foresees an autonomous, self-governing society of over 100,000 people living on the Moon by the end of the twenty-first century. A global utility **infrastructure** would be in place to provide electrical power, communication, and transportation for the entire Moon. The global lunar electric grid network could beam substantial amounts of energy to Earth and other sites in the solar system. Manufacturing facilities would use lunar **regolith** for **shielding** against cosmic rays and as insulating material. As processing facilities gradually come into operation, various cements and building blocks, then ceramics, glasses, fibers, and metals will become available.

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

regolith upper few meters of the Moon's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

extrasolar planets planets orbiting stars other than the Sun

interstellar between the stars

The Moon could also become the principal astronomical observation platform in the solar system. Very large aperture optical interferometry–based telescopes will detect **extrasolar planets**, analyze their atmospheres, and characterize their habitability, and will lay down the foundation for the human **interstellar** migration often referred to as the "Great Diaspora." The Moon will become the primary site for the construction and launch of satellites, probes, autonomous mobile robots with television cameras, and scientific instruments. Thousands of near-Earth objects will be analyzed by lunar-based telescopes and lunar-launched probes. Those objects that pose a threat will have their orbits altered by spacecraft made on the Moon. Asteroids and comets that approach the Earth-Moon system will be mined.

Human Return to the Moon. In the first stages of lunar development humans will return to the Moon to conduct astronomy, science, and engineering experiments and supervise ongoing construction of the lunar base. Technology to bring humans back to the Moon, possibly by 2007, already exists. Buzz Aldrin✶ stated before Congress that "the only obstacles to that future are complacency and a lack of clear commitment" and cautioned that "if we insist that the human quest await the healing of every sore on the body politic, we condemn ourselves to stagnation."

✶In July 1968, Buzz Aldrin made history by becoming one of the first humans to walk the surface of the Moon.

Building a Lunar Civilization. Once consensus is reached that a settlement will be developed on the Moon, the next probable step will be the building of a crater lunar base. After the gathering of scientific and technical data by satellite, a domed crater serving as the site of a largely self-sufficient outpost would be developed in three phases: construction, remote systems trials, and occupied operations. Crater walls would form the base of support for a dome over the center. The circular shape of the crater would lead to a spherically efficient geometry of gracious appearance and create a circular transportation/robotic capability. Occupants would be able to look toward a central agricultural zone that receives sunlight.

Candidate power supply systems can be divided into two basic categories: solar power and nuclear power. Other potential power sources include stored energy and beamed power such as microwave or laser. Another option would be to illuminate **photovoltaic arrays** on the lunar surface from Earth, using lasers. In that case, no power-beaming equipment would have to be launched into space.

Harnessing the Moon's Resources. An essential requirement for cost-effective lunar base development and operation is the ability to locate, mine, process, and utilize the natural resources of the Moon. Although the Moon has essentially no atmosphere, its surface is composed of oxygen, silicon, and other elements and **minerals**. The environment features **solar radiation**, **vacuum conditions**, and low gravity that can be used for power and materials processing. The surface contains bulk soil/regolith that can provide radiation shielding. Oxygen and water from ice or extracted from clay could support life and serve as a propellant. Facilities, equipment, and solar cells could be constructed from native metals. Hydrogen is another possible source of propellant. Fusion power could come from helium.

Beyond the Moon towards Mars

According to Mars Society founder Robert Zubrin, Mars is humanity's new frontier because it can be settled and altered, thus defining it as a New World that can create the basis for a positive future for terrestrial humanity for the next several centuries. Projections for human missions to Mars range from 2012 to 2020 and beyond. It will take many months for people to make the first trips to Mars. Advanced propulsion could shave months off the travel time, but even the most optimistic plans consider nonchemical propulsion as being somewhat down the road. Most mission scenarios show this trip happening without artificial gravity, and permanent Mars settlements remain far in the future.

Power Generation and Storage. The primary surface power source will be 160-kilowatt nuclear power modules that will have a lifetime of more than fifteen years and provide power to the Mars outpost for each mission. Deployment will be about 1 kilometer (0.62 mile) away from the crew habitat. As Mars receives about 44 percent as much solar radiation as Earth does, solar power is another possible power source. Power systems for pressurized long-range surface rovers would likely consist of a methane fuel cell or a **dynamic isotope power system**.

Life on Mars: Follow the Water. Scientists continue to debate whether the Antarctic-recovered Martian meteorite ALH84001 contains evidence of ancient life. Liquid water does not and cannot exist on the surface of Mars today, although it may have in the past. In 2003 the National Aeronautics and Space Administration (NASA) will send two rovers to Mars to hunt for signs of water in the rocks and surface soil. The European Space Agency will launch Mars Express in that year with a lander, Beagle-2, with a scientific **payload** dedicated to detecting signs of **biogenic** activity on Mars.

photovoltaic arrays sets of solar panels grouped together in big sheets. These arrays collect light from the Sun and use it to make electricity to power the equipment and machines

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

vacuum conditions the almost complete lack of atmosphere found on the surface of the Moon and in space

dynamic isotope power system the decay of isotopes such as plutonium-238 and polonium-210 produces heat, which can be transformed into electricity by radioisotopic thermoelectric generators

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

biogenic resulting from the actions of living organisms; or, necessary for life

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

SETTLEMENTS OR COLONIES? A TWENTY-FIRST-CENTURY PERSPECTIVE

The responsibility to develop space resources completely and beneficially requires that human behavior, principles, and ethics be as advanced as the newest technologies. Reflecting the ethical aspects of space exploration, the U.S. State Department in the mid-1970s specifically prohibited the use of the term "space colony." Twenty-first-century human expansion into space must be guided by the traditional values of "liberty and justice for all." Colonialism is an inappropriate structure and value for humanity in the space age because it denies human equality. Although a new space settler or settlement (habitat, city, sphere, domicile, or residence) initially may require special status and support, progress and productive human relationships on the space frontier need to be based on equality and mutual benefit.

Jupiter and Beyond

After the establishment of the Earth-Moon baseline infrastructure, not just Mars but Jupiter and cosmic infinity lie open for exploration. The quickest way to the stars requires familiarity with the solar system, and Jupiter's size, system complexity, and location can provide that advantage. There is no reason to limit the civil space program to Mars for the next ten to fifty years.

With more than 70 percent of solar system mass (excluding the Sun), four large Galilean satellites (Io, Europa, Callisto, and Ganymede) and more than thirty others, powerful lightning charges, a far-reaching **magnetosphere**, a ring system, and a 40,000-kilometer (24,800-mile) red spot that has been swirling at 500 kilometers (310 miles) per hour for more than three centuries, Jupiter is a near solar system within a solar system.

To understand human origins and search for extraterrestrial life, NASA and other international space agencies have developed a "follow the water" strategy for solar system exploration; Europa, along with Callisto and Ganymede, is becoming as compelling a destination as is Mars. The search for water off Earth and for life leads back to the Moon, to Jupiter and Mars, and to the stars and galaxies and beyond. SEE ALSO Aldrin, Buzz (volume 1); Astrobiology (volume 4); Communities in Space (volume 4); Human Missions to Mars (volume 3); Lunar Bases (volume 4); Lunar Outposts (volume 4); Mars (volume 2); Mars Bases (volume 4); Mars Missions (volume 4); Moon (volume 2).

Michael R. Cerney and Steve Durst, 2001

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Social Ethics

Human activities in space present us with novel philosophical, cultural, and ethical challenges. Moreover, space acts as a different lens through which we can explore many of our oldest and deepest social and philosophical issues. Indeed, the broad issue of whether significant resources should be devoted to space activities at all can be considered a social ethics question. Many people suggest that resources devoted to space activities detract from solving problems on Earth that desperately need more attention. Others counter that space activities can help address those problems. This broad question can have direct relevance to the motivations for space activities because the answer could determine the extent to which space will be used primarily to address Earth-based problems directly as opposed to exploratory pursuits that may or may not have direct terrestrial relevance.

If we do think significant resources should be spent on space activities, we can ask: Should those activities be aimed primarily at implementing military and political agendas, commerce, resource utilization for some or many, pure exploration for the good of humankind, none of the above, all of the above, or something else? Arguably, all of these motivations have been pursued, but should they have been? And should people continue to pursue these aims and others? The answer would appear to be yes, but what if spending too much time and money on space detracts from the well-being of humans and life on Earth? What if resource utilization causes the extinction of a very different form of life? What is more important, and why?

Many of the motivations for space activities are addressed in the 1967 United Nations Outer Space Treaty, in which Article I states that "the exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind." Article II specifically prohibits national appropriation by stating: "Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." The 1979 United Nations Moon Treaty adds much more detail but has not been ratified by some countries, including the United States.

Arguably, two of the most challenging ethical issues presented by space exploration have to do with finding a different form of life and terraforming (changing a planet to make it suitable for Earth life), both of which relate to each other.

WHAT ARE "ETHICS"?

Ethics involves assessing what is valuable and why, informing decisions about what *should* be done. These kinds of value-based questions can be very complex and involve many points of view, which are often incompatible and contradictory. Philosophy has a long history of exploring ethical issues from many different perspectives, including "meta-ethical" points of view that explore *how* we assess what is valuable and "good." There are practical perspectives as well as ideological and metaphysical perspectives, all of which can be drawn from when thinking about what we should do in space.

A Different Form of Life

In his book *Cosmos* (1980), scientist and visionary Carl Sagan stated: "If there is life on Mars, I believe we should do nothing with Mars. Mars then belongs to the Martians, even if they are only microbes." Astrobiologist Christopher McKay has appealed to an intrinsic value of life principle, or **biocentric** view, and has suggested that Martian life-forms "have a right to continue their existence even if their extinction would benefit the biota of Earth." For some, only a noninterference policy would be acceptable, as suggested by philosopher Alan Marshall. Alternatively, McKay believes that the rights of Martian life "confer upon us the obligation to assist it in obtaining global diversity and stability."

biocentric notion that all living organisms have intrinsic value

Robert Zubrin, founder of the Mars Society, acknowledges the unique value of extraterrestrial life, but also stresses that people do not hesitate to kill terrestrial microbes in many circumstances. This is a reasonable observation, and it is also reasonable to consider that extraterrestrial life, especially of an independent origin, could be unique and valuable in a way that terrestrial microbes are not.

anthropocentrism valuing humans above all else

Steve Gillett suggests a hybrid view that combines **anthropocentrism** as applied to terrestrial activity with biocentrism for worlds with indigenous life. This kind of pluralistic approach to ethics has commonsense appeal. J. Baird Callicott invokes weak anthropocentrism, first suggested by Bryan Norton, which suggests that things that transform and ennoble human nature have enough value to require their preservation. Callicott writes: "I can think of nothing so positively transforming of human consciousness as the discovery, study, and conservation of life somewhere off the Earth."

Terraforming

cosmocentric ethic ethical position that establishes the universe as the priority in a value system or appeals to something characteristic of the universe that provides justification of value

geocentric a model that places Earth at the center of the universe

Martyn Fogg states that "the concept of terraforming is inspiring enough to perhaps generate a formal effort toward extending environmental ethics to the cosmic stage." Robert Haynes, Christopher McKay, and Don MacNiven are prompted by the prospect of terraforming to suggest the need for a **cosmocentric ethic**. They conclude that current ethical theories exclude the extraterrestrial environment because they are purely **geocentric**. These authors may be reflecting a deeper instinct, sensing deficiencies in existing ethical views in general. The new context, or "lens," of space exploration has rightly prompted the consideration of new and perhaps broader perspectives for ethics.

Holmes Rolston offers a view that appeals to the "formed integrity" of a "projective Universe" in which the universe creates objects of formed integrity (objects worthy of a proper name) that have intrinsic value and should be respected. However, Haynes points out that Rolston's view appears to conflict with modifying Earth even for the benefit of humans. Rolston's view would call for the preservation of extraterrestrial life and most likely oppose terraforming.

propagate to cause to move, to multiply, or to extend to a broader area

"Connectedness" may hold promise for a cosmocentric ethic. The interdependent connectedness of ecosystems is often cited as a foundation for justifying the value of parts of the larger whole, since the parts contribute to the maintenance of the whole. Mark Lupisella has suggested that connectedness itself may be a necessary property of the universe and that the realization of connectedness requires interaction. This view might favor realizing interaction in the form of complexity, creativity, uniqueness, diversity, and other characteristics that may further realize the dynamic interactive nature of the universe. In making choices consistent with this view, humanity might help encourage and **propagate** life and diversity on Earth and throughout the universe. Freeman Dyson writes: "Diversity is the great gift which life has brought to our planet and may one day bring to the rest of the Universe. The preservation and fostering of diversity is the great goal which I would like to see embodied in our ethical principles and in our political actions."

Ultimately, as we have been able to do in many areas of space activity, a thoughtful balance incorporating many different views is likely to be the best approach to realizing a healthy future in space for humankind. SEE ALSO Communities in Space (volume 4); Governance (volume 4); Law (volume 4); Living in Space (volume 3); Settlements (volume 4); Terraforming (volume 4).

Mark L. Lupisella

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Solar Power Systems

The first use of solar cells in space occurred on the satellite Vanguard I, which was launched on March 17, 1958. Eight tiny panels were installed symmetrically around the satellite to ensure power generation during the satellite's random tumbling. They delivered 50 to 100 milliwatts of power and provided secondary electricity for a **beacon signal generator**. Each panel had six square silicon cells, measuring 2 centimeters (0.79 inch) by 2 centimeters (0.79 inch) by 0.4 centimeters (0.16 inch), with a **photovoltaic** (PV) conversion efficiency of approximately 10 percent. The panels of solar cells were protected by a thick cover glass to avoid radiation damage from electrons and protons trapped in the **Van Allen radiation belts** that surround Earth.* The longevity of Vanguard I's beacon signal surpassed all expectations—lasting until May 1964. As a result, future regulations required shutting down power supplies of satellites to avoid cluttering the radio wave spectrum with unwanted signals.

The early use of solar cells was tentative, but they eventually emerged as the only viable source for satellites that were required to operate for more than a few weeks. Solar cells improved steadily and successfully met the

beacon signal generator a radio transmitter emitting signals for guidance or for showing location

photovoltaic pertaining to the direct generation of electricity from electromagnetic radiation (light)

Van Allen radiation belts two belts of high energy charged particles captured from the solar wind by Earth's magnetic field

***The radiation belts are named after American physicist James Van Allen, who discovered them.**

Solar power panels flare to the sides as the Hubble Space Telescope is lifted into position by the Remote Manipulator System from the cargo bay of the space shuttle Discovery.

unique power requirements of space travel while other possible competitive sources were proven inadequate. Over the years, solar cells have provided electricity to thousands of space missions that operated near Earth, on the Moon, and in planetary or interplanetary missions.

Power Requirements

Telecommunication satellites require several kilowatts of electric power, while most other satellites require several hundred watts. The long-duration human missions, Skylab, launched in 1973, and the Russian space station Mir, launched in 1986, each used 25 kilowatts from solar cells.✶ The International Space Station has solar PV modules with a total rated generation capacity of 240 kilowatts at the beginning of life and 168 kilowatts at the end of life, with the life duration expected to be fifteen years. The space station's **solar array** has eight wings and operates at 160 volts DC. Each half-wing is 11.6 meters (38 feet) by 32.9 meters (108 feet). In each wing, there are 32,800 square silicon cells that are 8 centimeters (3.15 inches) by 8 centimeters by 0.2 centimeters (0.08 inches) thick with an average conversion efficiency of 14.2 percent. The total power of the solar array of the International Space Station is more than 2 million times larger than the first solar panels on Vanguard I.

✶Mir returned to Earth after 5,511 days in space, plunging safely into the Pacific Ocean, on March 22, 2001.

solar array group of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

While the demand for power by commercial communication satellites is increasing, National Aeronautics and Space Administration (NASA) missions to near-Earth targets, such as Mars or the Moon, and scientific missions to the Sun and outer planets, have been requiring decreasing amounts of power. The piloted missions—whether Earth orbiting, lunar, or planetary—require power systems that are an order of magnitude larger than that of the largest telecommunication power systems.

Current Space Cells and Systems

A typical solar cell is a diode illuminated by sunlight. Diodes are prepared by forming a **pn single junction** in a **semiconductor** such as silicon. For this purpose, an n-type region in which electrons are negatively charged **majority carriers** is grown on a p-type base in which holes are positively charged majority carriers or vice versa. The early silicon cells were of p on n type. The first commercial communication satellite, Telstar I, launched in 1962, used n on p silicon cells. The cell design and performance remained fairly static during the 1960s. During the 1970s, efficiency was increased to about 14 percent by improving the cell design. The improvements were achieved by forming a heavily **doped** rear interface known as back surface field; applying **photolithography** to create finer, more closely spaced front grid fingers; and applying a texture and antireflection coating to the cell surface. Efforts were also focused on reducing costs associated with PV array components by, for example, decreasing interconnect costs and using larger cells and lighter arrays.

In the 1980s and 1990s gallium arsenide–based solar cells were developed. Gallium arsenide on germanium solar cells were developed to increase the size and to reduce the thickness of cells by increasing the mechanical strength. Multijunction cells using gallium arsenide, gallium-aluminum arsenide, and gallium-aluminum phosphide on germanium were developed to effectively use a larger portion of the solar spectrum. Typical efficiencies for gallium arsenide–based cells range from 18.5 percent for single junction diodes to 24 percent for triple junction diodes.

Gallium arsenide cells are used for critical space missions that require high power. The manufacturing costs of gallium arsenide on germanium cells are six to nine times that of silicon cells. The overall cost is reduced, however, because of the higher efficiency of the cells. More satellites can be launched on a single **rocket** because of the smaller array area. Limiting the total area of the solar array is an important factor in the viability of space power arrays because of the estimated altitude control costs, which for a ten-year **geosynchronous Earth orbit** (GEO) mission amount to $48,000 per square meter. In this regard, high-efficiency multijunction arrays are more attractive for missions requiring higher power. Megawatts of power required by larger satellite constellations will be satisfied with multijunction solar cells having still higher efficiencies of greater than 30 percent. Iridium, a constellation of sixty-six communication satellites, required a total power of 125 kilowatts and used gallium arsenide on germanium solar cells. The spectacular performance of the Pathfinder mission to Mars was made possible by the mission's gallium arsenide on germanium cells. The cells provided all the necessary power, including 280 watts for the cruise module, 177 watts for the lander, and 45 watts for the Sojourner rover.

An important consideration for satellite programs is the weight of the spacecraft. Currently, the power system typically takes up about a quarter of the total spacecraft mass budget while the solar array and support structure comprise about a third of the power system mass. Launch costs are

pn single junction in a transistor or other solid state device, the boundary between the two different kinds of semiconductor material

semiconductor one of the groups of elements with properties intermediate between the metals and nonmetals

majority carriers the more abundant charge carriers in semiconductors; the less abundant are called minority carriers; for n-type semiconductors, electrons are the majority carriers

doped semiconductor such as silicon with an addition of small amounts of an impurity such as phosphorous to generate more charge carriers (such as electrons)

photolithography printing that uses a photographic process to create the printing plates

rocket vehicle (or device) especially designed to travel through space, propelled by one or more engines

geosynchronous Earth orbit orbit of a satellite that revolves around the Earth without changing its position in the sky relative to the planet estimated to be $11,000 per kilogram in **low Earth orbit** and $66,000 per kilogram in GEO. Hence, reducing spacecraft mass has a potential added benefit of lowering launch costs.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Crystalline silicon and gallium-arsenide-based solar cells, currently employed in space solar PV power arrays, are rigid and fragile. Therefore, the PV arrays employ a honeycomb core with face sheets of aluminum or alternatively very lightweight **Kevlar®** or graphite fibers. The PV array blanket is folded in an accordion style before placement in a canister. Deploying the array can pose problems. This happened in November 2000 with the large solar array on the International Space Station.

Kevlar® a tough aramid fiber resistant to penetration

Manufacturing costs for solar arrays are an important consideration for the total spacecraft budget. The array manufacturing costs for a medium-sized 5-kilowatt satellite can exceed $2 million. Current single-crystal technology can cost more than $300 per watt at the array level and weigh more than 1 kilogram per square meter equivalent to a **specific power** of about 65 watts per kilogram.

specific power amount of electric power generated by a solar cell per unit mass for example watts per kilogram

Future Technologies

Future missions would include very large solar power satellites as well as very small satellites. Some long-term plans envision swarms of very small, distributed, autonomous satellites called microsats or even nanosats to perform specific tasks. In all these missions, reducing the total system cost would become increasingly more important. Highly efficient gallium arsenide–based multijunction cells, concentrator systems, and thin-film cells are being developed for the future space missions. Copper-indium-gallium selenide-sulfide or amorphous hydrogenated silicon thin-film solar cells may be able to reduce both the manufacturing cost and the mass per unit power by an order of magnitude from the current levels. Moving to a thin-film technology could conservatively reduce array-manufacturing costs to less than $500,000 from the current cost of $2 million for a medium-sized 5-kilowatt satellite. For small satellites, increasing the solar array specific power from a current typical value of 65 watts per kilogram will allow for either an increase in **payload** power or payload mass, or both.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Weight benefits of higher efficiency cells are decreased and high costs become less affordable in the case of flexible thin-film blanket arrays that can be easily rolled out. Nonrigid cells also have an advantage in stability. For example, flexible amorphous hydrogenated silicon solar arrays have continued to function after being pierced by tiny **meteorites**.

meteorite any part of a meteroid that survives passage through Earth's atmosphere

Solar Electric Propulsion

Some missions will use solar electric propulsion instead of rockets. In solar electric propulsion, electric power obtained from sunlight is used to ionize a gas and then to accelerate and emit the ions. The spacecraft is propelled in the forward direction as a reaction to the emission of ions going in the opposite direction. This technology has been successfully demonstrated in the Deep Space I mission. Because of the low initial velocities and steady acceleration, however, solar electric propulsion satellites must spend long periods in intense regions of trapped radiation belts. Studies since the year 2000 have clearly shown that copper-indium-gallium selenide-sulfide solar cells are superior to the conventional silicon and gallium arsenide solar cells in the space radiation environment. The potential for improved radiation resistance of thin-film solar cells relative to single-crystal cells, could extend the mission lifetimes substantially. Large-area amorphous silicon modules were successfully demonstrated on flexible **substrates** on the Russian space station Mir. The efficiency was relatively low but remained stable in the space environment.

substrates the surface, such as glass, metallic foil, or plastic sheet, on which a thin film of photovoltaic material is deposited

Studies since 1999 have shown that thin-film cells would start to become cost-competitive in GEO and LEO missions at an efficiency of 12.6 percent. Significant technological hurdles remain, however, before thin-film technology could be implemented as the primary power source for spacecraft. A large-area fabrication process for high-efficiency cells on a lightweight substrate has not been demonstrated. Research efforts are being concentrated on the development of a large-area, high-efficiency thin-film solar cell blanket on a lightweight, space-qualified substrate that will survive severe mechanical stresses during launch, then operate for extended periods in the space environment. SEE ALSO LIVING ON OTHER WORLDS (VOLUME 4); LUNAR BASES (VOLUME 4); MARS BASES (VOLUME 4); POWER, METHODS OF GENERATING (VOLUME 4); RESOURCE UTILIZATION (VOLUME 4); SPACE RESOURCES (VOLUME 4); SPACE STATIONS OF THE FUTURE (VOLUME 4).

Neelkanth G. Dhere

SOLAR POWER SATELLITES

A solar power satellite generating system was first proposed in 1969. Studies by NASA and the U.S. Department of Energy have since shown the concept to be viable. Such a system would start with geosynchronous satellites in Earth orbit that would convert sunlight into electricity and then convert the electricity into microwave energy. The satellites would then beam the microwave energy to Earth. An elliptical receiving-rectifying antenna on the ground would convert the microwave energy to direct current electricity that would be distributed along conventional lines. This type of system could provide continuous base-load power for most of the year and would require minimal storage of the electricity. Problem areas that need to be addressed include high cost, the unknown effects of microwave beams on organisms and the ionosphere, and radio-frequency allocation concerns.

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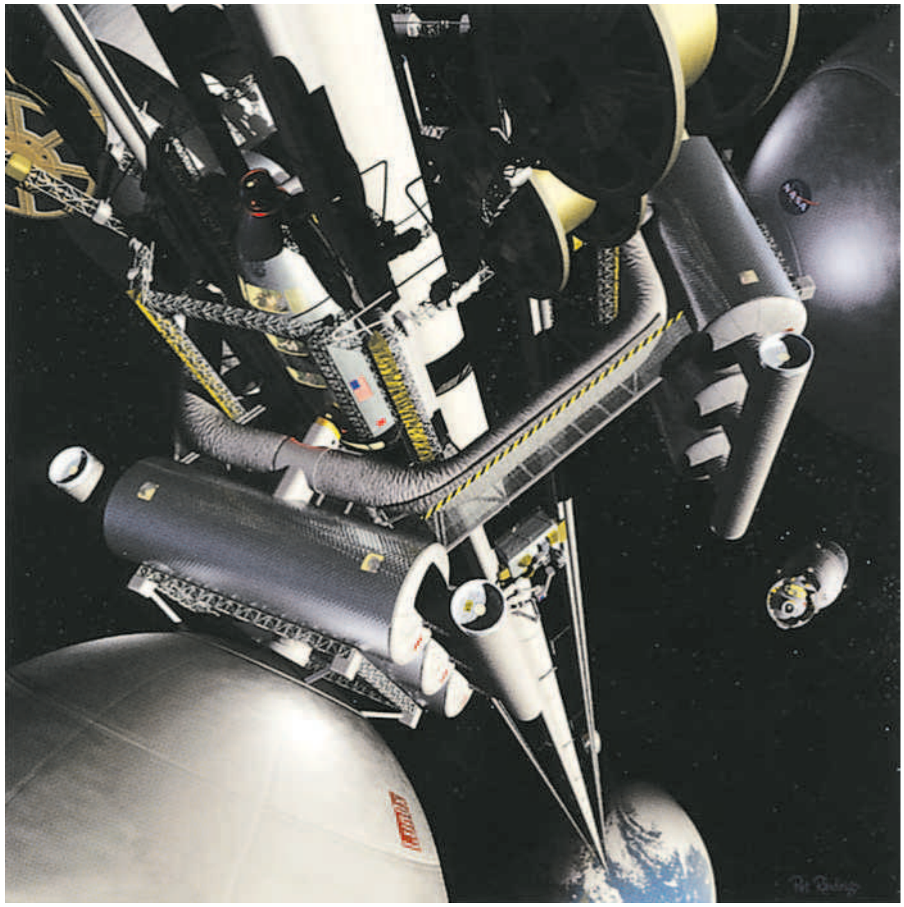
Space Elevators

> The murky views which some scientists advocate as to the inevitable end of every living thing on Earth . . . should not be regarded as axiomatic. The finer part of mankind will, in all likelihood, never perish—they will migrate from sun to sun as they go out. And so there is no end to life, to intellect and the perfection of humanity. Its progress is everlasting.
>
> Konstantin Tsiolkovsky



The perspective in this illustration of a space elevator concept is from the geostationary transfer station looking down along the length of the elevator structure towards Earth.

Tsiolkovsky made that statement as a rebuttal to the dark future predicted for humankind by Thomas Malthus, a British clergyman who believed humankind was doomed to a future of misery because of overpopulation and the inadequacy of the food supply. The year was 1895, and Tsiolkovsky, considered by many the father of the space age, went to Paris, where he saw the Eiffel Tower and had a vision of a way to make space travel affordable. His idea was an elevator that would travel up a tower that would reach into space. With easy, affordable access to space and the other planets, it would be possible for humankind to spread out across the cosmos and avoid the catastrophe predicted by Malthus.

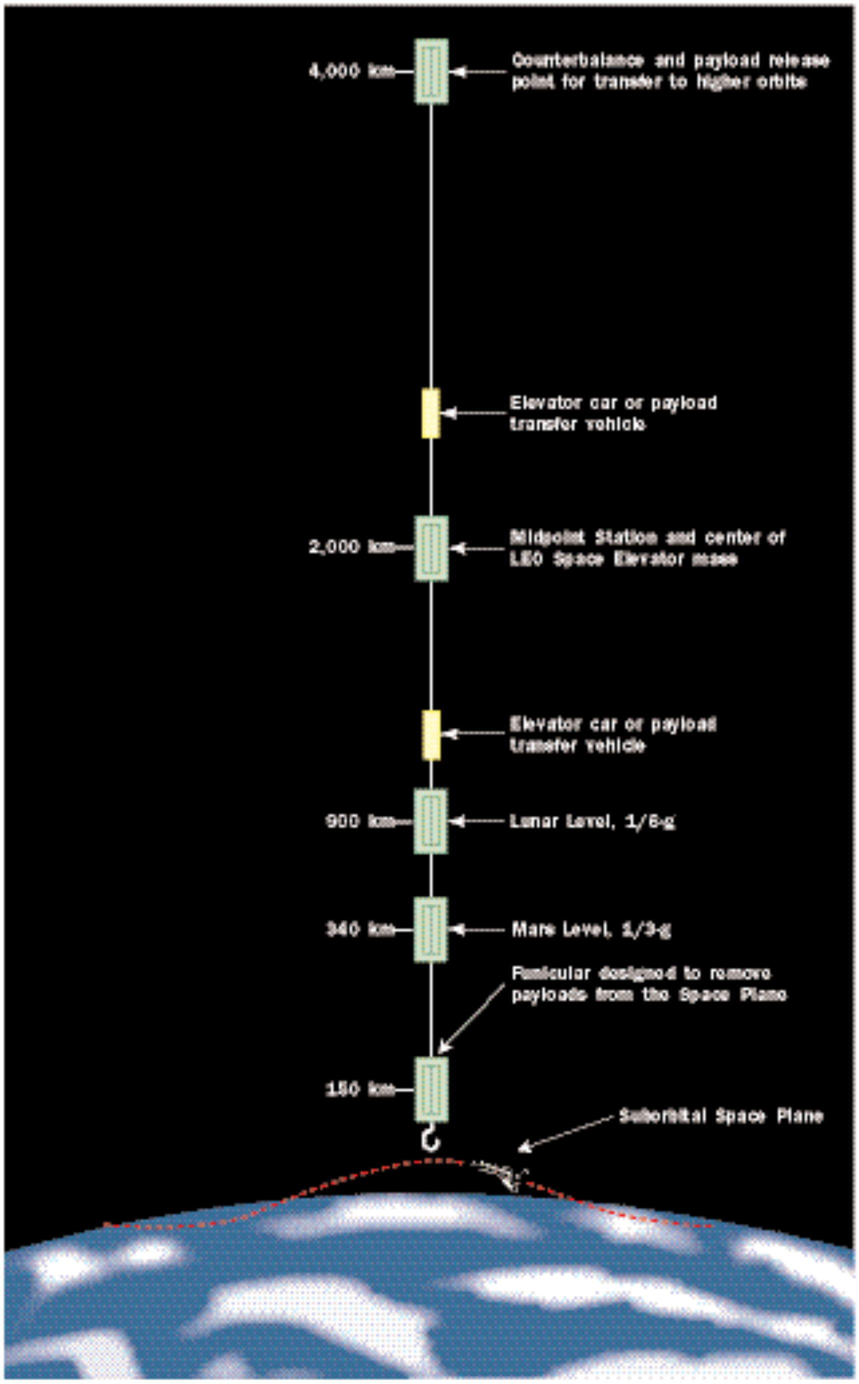
The tower Tsiolkovsky proposed was to be 35,786 kilometers (22,300 miles) tall. It needed to be that tall in order to reach the altitude of **geostationary orbit**, where the speed of orbit matches the rotational **velocity** of Earth. Anything less than that, and the people at the top of the tower would not be in orbit and spacecraft traveling to other planets would not be able to dock there to pick them up.

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis; an object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

velocity speed and direction of a moving object; a vector quantity

With such a tower, travel to other planets would become affordable to the mass of humanity, just as the steamships and transcontinental railroad made possible mass migration of Europeans to the United States. As the man who developed the mathematics for rocket-powered spaceflight, Tsiolkovsky knew that interplanetary migration would not be affordable if only rockets were used. Thus, the idea for his tower was born. Unfortunately, it is not possible to build Tsiolkovsky's tower even with today's materials.

LEO SPACE ELEVATOR CONCEPT



The Earth Surface to Geo Space Elevator

Tsiolkovsky's tower has been studied and refined, and it has evolved into a more practical concept that involves a cable hanging both upward and downward from geostationary orbit. With this concept, the upper half of the cable and an asteroid counterweight are needed to balance the weight of the lower half of the cable that reaches down to the surface of Earth. This upper and lower cable combination centered on geostationary orbit, called an

Earth Surface to Geo Space Elevator, was described by Arthur C. Clarke in 1978 in his book *The Foundations of Paradise*. Unfortunately, even this version of the tower is impossible to build. It was not until 1988 that an intermediate version of this concept that could be built with existing materials was conceived. It is called an Earth Orbiting Elevator.

The Earth Orbiting Elevator

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The Earth Orbiting Elevator works by starting from a much lower-altitude orbit and hanging a cable down to just above Earth's atmosphere. Since the bottom end of that cable is traveling at less than **orbital velocity** for that altitude, it is possible for a high-speed aircraft to fly to the lower end of that cable without the need for stages and drop-off propellant tanks. This is possible because the speed of orbit decreases as one moves farther away from Earth. Since the altitude where the cable starts to be built is quite a bit higher than the altitude at the bottom of the cable, the bottom of the cable ends up moving at noticeably less than orbital velocity for its altitude. This means that an aircraft flying to the bottom end of the elevator does not have to go nearly as fast as a rocket going to orbit. As a result, the aircraft needs less propellant, does not need stages, and can carry a larger **payload**. Less propellant, no staging, and more payload means significantly lower launch costs.

The upward-pointing half of the Earth Orbiting Elevator is needed to counterbalance the lower half, but unlike the Earth Surface to Geo Space Elevator, it does not need an asteroid counterweight. Also, like the earlier elevator, the length of the upper half of the Earth Orbiting Elevator cable is selected so that a spacecraft arriving at or departing from the upper end of the cable is already traveling at Earth escape velocity. This is done to minimize the amount of propellant spacecraft need to carry to travel between planets, keeping the cost of travel affordable.

A Comparison of the Two Elevators

The differences between the two elevators can be visualized as variations of the Indian rope trick. Using this analogy, the Earth Surface to Geo Space Elevator is an Indian rope that hangs from a very high altitude cloud down to the ground and never moves. As a result, it is very easy to use. The Earth Orbiting Elevator does not reach all the way to the ground and moves across the sky as if it were a rope hanging from a low-altitude cloud on a windy day. Although it is obviously more difficult to use, the Earth Orbiting Elevator has the advantage of a significant reduction in the required cable length. The Earth Surface to Geo Space Elevator requires a cable over 47,000 kilometers (29,140 miles) long. The Earth Orbiting Elevator can be built with a cable as short as 1,500 kilometers (30 miles) but works better if one of 3,500 to 4,000 kilometers (2,170 to 2,480 miles) is used. The magnitude of the difference is obvious, and the fact that the Earth Orbiting Elevator can be built makes the choice obvious. The end result is that it is possible to build Tsiolkovsky's tower, and so the dark future predicted by Malthus is not inevitable.

Space Elevators for the Moon and Mars

As with all transportation systems, once enough people start making the journey, there is a need for more efficient transportation systems at the points of arrival. As a result, space elevators have been proposed for both the Moon and Mars. In this way, Earth, the Moon, Mars, the asteroids, and even the **Earth-Moon LaGrange points** known as L4 and L5 can all be tied together by an affordable transportation system that opens up the entire inner solar system to humankind. SEE ALSO Accessing Space (volume 1); Clarke, Arthur C. (volume 1); Getting to Space Cheaply (volume 1); Tsiolkovsky, Konstantin (volume 3).

Eagle Sarmont

Earth-Moon LaGrange points five points in space relative to Earth and the Moon where the gravitational forces on an object balance; two points, 60 degrees from the Moon in orbit, are candidate points for a permanent space settlement because of their gravitational stability

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Space Industries

Traveling and living in the artificial atmosphere of a spacecraft, and guiding uncrewed satellites in their orbits around Earth and on missions to other stellar bodies call for specialized and creative technologies. While devised for specific, space-related purposes, many of these creations, or their spinoff products, find commercial markets here on Earth. As well, new industries are increasingly springing up to specifically exploit extraterrestrial materials and opportunities for commercial gain.

From Space to the Marketplace

Space programs have been a rich source of inventions that went on to great commercial success here on Earth. The household television satellite dish, which captures television signals beamed from orbiting satellites (their commercial function itself a spinoff benefit of orbital space travel), were originally invented to correct errors in the signals from spacecraft. Medical imaging of our internal organs and modern eye examination methods arose from the technologies developed to enhance stellar images. Another feature of our everyday lives, bar coding, arose from the need for inventory control of the myriad of spacecraft parts. The ear thermometer owes its existence to the technology developed to detect **infrared** emission from newly born stars. Smoke detectors were invented to detect noxious vapors in the Skylab Earth-orbiting station launched in 1973. Computer software utilized for the design and analysis of spacecraft now enables automobile makers to virtually design an automobile prior to building a prototype. Cordless vacuum cleaners, trimmers, drills and grass shears would not exist if not for the need for self-contained power tools used by Apollo astronauts on the Moon. The joystick controller used by computer game enthusiasts and disabled people was developed for the Apollo Lunar Rover. Finally, research to squeeze a

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

This digital data matrix (above) is an example of a "space spinoff." Originally used to identify space shuttle parts, this technology is invisible to the naked eye and is being commercialized to make barcoding tamper resistant.

vacuum an environment where air and all other molecules and atoms of matter have been removed

function into machines of molecular dimensions has spawned an explosion of research and activity into nanotechnology. The usefulness of nanotechnology ranges from tiny but extremely powerful computers to data storage on molecular tape to molecular robots capable of operations within a human. These examples are but several of many.

This legacy continues. Some space industries directly address the needs of present-day space exploration. Such direct applications may, like the above examples, find spin-off benefits in the "real world" of tomorrow. Other industries reflect a view of space as an exploitable entrepreneurial commodity. A tangible example of space science is the Space Vacuum Epitaxy Center (SVEC) at the University of Houston. Since the late 1990s, SVEC has been researching the means by which scientific experiments could be done in the **vacuum** of space. So far, the research has yielded fifteen new technologies with commercial potential. As an example, research to construct thin films of material in space has led to the use of lasers in telecommunications and environmental testing. Another spinoff of the center's research has been an electric wire that can transport up to 100 times more current than standard copper wires.

The Potential of Space

Space travel, to this point, mainly has been the domain of large space agencies. But, befitting its allure to our sense of adventure, space travel is a potentially huge industry. Various companies are exploring the feasibility of small, reusable spacecraft for both travel (suborbital flights could cut hours off of currently lengthy airplane trips), space tourism, and as transport vehicles for other space industries.

Another facet of space that holds commercial appeal is the energy possibilities of celestial bodies. Drilling technologies for mining operations and the use of satellites, lunar installations, or vast banks of mirrors deployed in space to collect solar power are just three examples. The use of solar panels as a power generating system arose out of the need to power orbiting satellites. Now, this technology is being refined to permit the construction of large banks of panels on the surface of the Moon, with materials mined from the lunar crust, such as silicon. The lunar panels would supply energy to a waiting Earth and could also be ferried to Mars for use in human expeditions to that planet. The Moon is also a potentially plentiful source of helium-3, an isotope that is rare on Earth. Helium-3 is a promising fuel for **fusion** reactors. Indeed, it has been estimated that lunar reserves of helium-3 could generate 10,000 times as much energy as Earth's entire remaining reserves of fossil fuel. Helium-3 also has an advantage of being non-radioactive, either before or after use. Thus, commercial interests are considering the Moon as a source of fuel for not only lunar missions but for an energy-hungry Earth. Harrison Schmitt, a former Apollo astronaut, is involved in efforts to commercialize the extraction of helium-3 from the Moon.

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

The prospect of mining the Moon and planets such as Mars is appealing to space agencies such as the National Aeronautics and Space Administration (NASA), because it would eliminate the need to send all materials required for a space sojourn with the departing spacecraft. This idea has created opportunities for commercial ventures. For example, there are plans for the construction of a lunar rover that would extract the material for rocket fuel on return journeys from the Moon. Similar ideas are being studied for future human missions to Mars, because local production of fuel for the return journey would greatly reduce the weight and volume of material to be carried on the outbound journey to Mars.

Another substance that potentially can be harvested from the Moon is oxygen. The Moon's crust is composed of a material known as **regolith**. Much of the regolith is enriched with oxides of silicon, from which oxygen can be extracted. In fact, upwards of 46 percent of the weight of the lunar surface may be comprised of oxygen. While much less hydrogen is present, it is there in quantities enough to produce water. In addition, evidence from the Clementine and Lunar Prospector missions to the Moon suggest that it may also be possible to extract water from more direct sources on the Moon.

regolith upper few meters of the Moon's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

The availability of similar reserves on Mars, and hence the commercial potential of mining the planet, is less clear. However, the 2001 Mars Odyssey probe is designed to gather information about the surface chemistry of the planet. More information will be obtained from the Reconnaissance Orbiter, scheduled for launch in 2005, and, beginning in 2007, from mobile laboratories that will be landed at chosen sites on the surface of Mars.

Space as a Manufacturing Facility

Another lucrative niche that space offers is in manufacturing. The low or zero gravity of space enables the growth of crystals, semiconductor films, and protein assemblies that are structurally perfect. An orbiting vacuum cleaner is being devised that would sweep away orbital dust as it is towed by a spacecraft, leaving an environment in its wake that would support such high-tech manufacturing efforts.

Finally, one pressing need on the extended forays in orbit that will be the norm on the International Space Station is the need for a source of uncontaminated water. The present and future technologies that will ensure a ready supply of drinkable water, obtained from sources as varied as sweat, exhaled water vapor, and urine, will surely find a place on Earth. Particularly in desert climates, the ability to recycle water more intensively will be valuable and life saving. SEE ALSO MADE IN SPACE (VOLUME 1); MADE WITH SPACE TECHNOLOGY (VOLUME 1); NATURAL RESOURCES (VOLUME 4); SPACE RESOURCES (VOLUME 4).

Brian Hoyle

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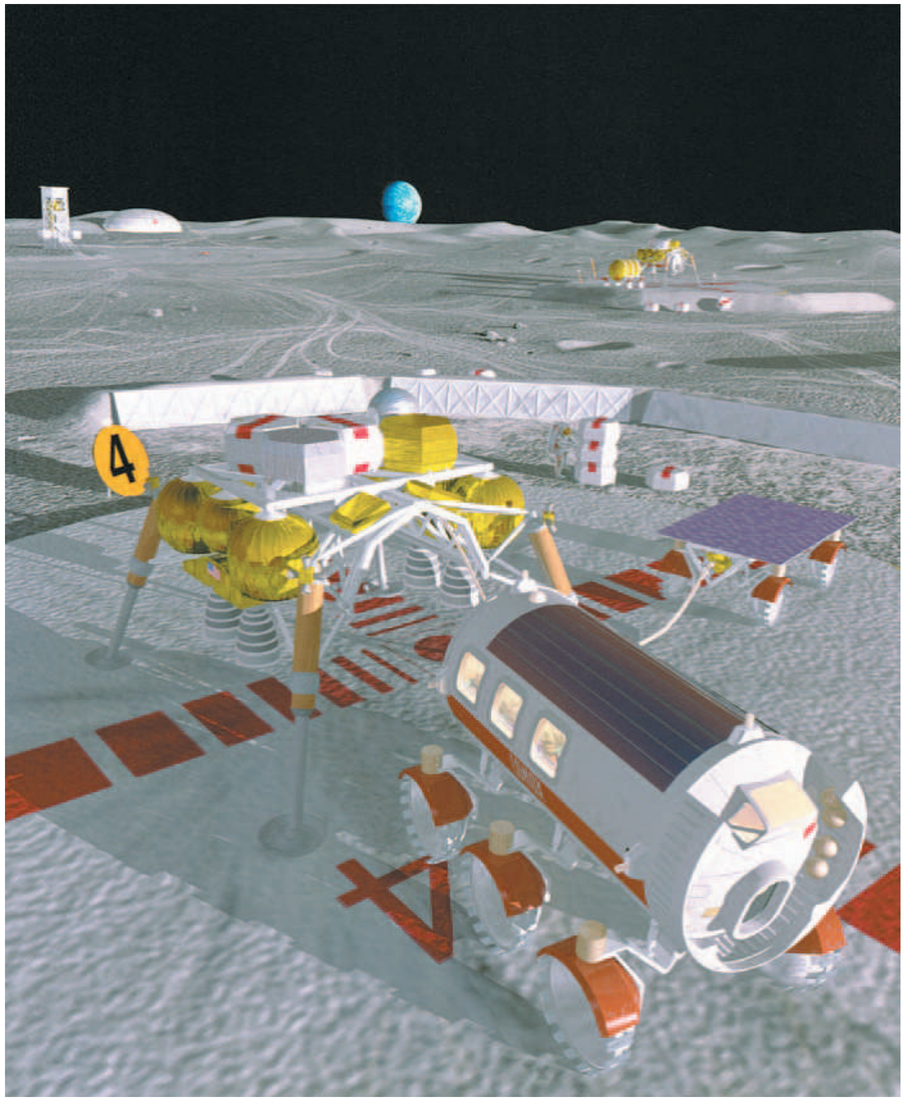
Space Resources

Future large-scale space activities will require a high degree of autonomy from Earth, with extensive reliance upon nonterrestrial sources of energy



An artist's rendition of a mining operation on the Moon. In the future, industrial operations on the Moon could increase the likelihood of lunar settlement.

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

regolith upper few meters of the Moon's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

ilmenite an important ore of titanium

rutile a red, brown, or black mineral, primarily titanium dioxide, used as a gemstone and also a commercially important ore of titanium

and materials. Ambitious missions require large masses of consumables, such as propellants and life-support fluids, which traditionally have been launched from Earth. But launch costs from Earth are so high that the greatest advantage would be realized by launching small masses of processing equipment rather than large masses of intrinsically cheap, abundant, and easily manufactured materials, such as oxygen, water, liquid hydrogen, structural metals, and radiation **shielding**. Each of the various objects in the solar system has unique potential in terms of resource extraction.

The Moon

Operations on the Moon would benefit greatly from the use of unprocessed **regolith** for shielding. Oxygen can be extracted from the common lunar mineral **ilmenite** ($FeTiO_3$) by reduction using hydrogen, carbon, or hydrocarbons, leaving a residue of metallic iron and the refractory **rutile** (TiO_2). Lunar polar ice deposits may conceivably be exploited for the manufacture of liquid water, oxygen, and hydrogen, if the difficulties of mining in permanent darkness at a temperature of 100°K (−280°F) can be mastered. On a longer timescale, lunar **helium-3**, present as an embedded **solar-wind** gas in concentrations of up to 10^{-8} g/g, may be economically extractable for export to Earth as a clean **fusion fuel**.

helium-3 a stable isotope of helium whose nucleus contains two protons and one neutron

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun

fusion fuel fuel suitable for use in a nuclear fusion reactor

Mars

Both piloted and unpiloted missions to Mars would benefit from the universal availability of the Martian atmosphere. The principal Martian gas, carbon dioxide, can be decomposed by any of several processing techniques into carbon monoxide and oxygen for use as propellants for local transportation or for the return trip to Earth. Extraction of water from the Martian atmosphere, which would enable the use of hydrogen as a propellant, seems unreasonable because of the extreme aridity of Mars. Surface snow, ground ice, permafrost, clay **minerals**, and hydrated salts are all plausible sources of extractable water. The residual atmospheric gases after extraction of carbon dioxide principally would be nitrogen (which makes up 2.7% of the atmosphere) and argon (1.6%). Nitrogen is useful not only as a fire retardant in artificial air but also as a **feedstock** for the manufacture of ammonia, **hydrazine**, nitrogen tetroxide, and nutrients such as amino acids and organic bases.

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

feedstock the raw materials introduced into an industrial process from which a finished product is made

hydrazine a dangerous and corrosive compound of nitrogen and hydrogen commonly used in high powered rockets and jet engines

Near-Earth Asteroids

The **near-Earth asteroids** (NEAs) and the Martian moons Phobos and Deimos present a rich diversity of compositions, many of them rich in **volatile materials**. A substantial fraction of these bodies are energetically more accessible than Earth's Moon, in that the **velocity** increment needed to fly from low Earth orbit and soft-land on the surfaces of nearly 20 percent of the NEAs is smaller than that needed to land on the Moon. The **L-4** Lagrangian point on the orbit of Mars has captured a swarm of small asteroids, of which four are currently known.

The asteroid belt consists of bodies that seem to be well represented among the NEAs. The resources of interest in them would be the same as those in NEAs. Most extraction facilities placed on NEAs would visit the heart of the asteroid belt on each orbit around the Sun, making transfer from an NEA "gas station" to most belt asteroids easy. In a fully recycling economy, fueled by solar power, the resources in the asteroid belt would be sufficient enough to support a population of about 10 quadrillion people from now until the Sun dies of old age.

near-Earth asteroids asteroids whose orbits cross the orbit of Earth

volatile materials materials that easily pass into the vapor phase when heated

velocity speed and direction of a moving object; a vector quantity

L-4 the gravitationally stable Lagrange point 60 degrees ahead of the orbiting planet

Gas Giants

Beyond the asteroid belt lie the orbits of the four gas giant planets: Jupiter, Saturn, Uranus, and Neptune. The total number of known gas giant satellites is close to ninety and is expanding rapidly because of advances in detection technology. We may reasonably expect several hundred satellites larger than a few kilometers in diameter to be known in a few years.

Jupiter's system consists of several very close small satellites and a rudimentary ring system; four world-sized Galilean satellites named Io, Europa, Ganymede, and Callisto; and swarms of small distant satellites, with some, like the inner satellites, orbiting in the **prograde** direction, but with the outermost satellite family in **retrograde** orbits. These may well be transient moons, captured in the recent past from heliocentric orbits (orbits around

prograde having the same general sense of motion or rotation as the rest of the solar system, that is counterclockwise as seen from above Earth's north pole

retrograde having the opposite general sense of motion or rotation as the rest of the solar system, clockwise as seen from above Earth's north pole the Sun) and destined to escape again. Jupiter is also accompanied by two vast clouds of asteroids, centered on the leading and trailing Lagrange points on Jupiter's orbit. These bodies, which are spectroscopically identified as **supercarbonaceous**, are the presumed immediate source of the outermost captured satellites of Jupiter. The innermost small satellites are embedded in the inner magnetic field of Jupiter, subject to intense charged-particle radiation bombardment from Jupiter's radiation belts. The radiation environment improves with increasing distance from the planet, but the Galilean satellites (especially Io) present a daunting technical challenge to planned landing missions. All of the Galilean satellites except Io have abundant surface ice of varying degrees of purity, suitable for manufacture of propellants for return to Earth.

supercarbonaceous term given to P- and D-type meteorites that are richer in carbon than any other meteorites and are thought to come from the primitive asteroids in the outer part of the asteroid belt

Saturn's system seems similar to Jupiter's, except that Saturn's extensive ring system suppresses its radiation belts. The largest Saturnian satellite, Titan, has a massive atmosphere of nitrogen, methane, and photochemical products that both invites detailed scrutiny and offers potential propellant for escape. Numerous small, distant satellites in both prograde and retrograde orbits have been discovered recently. Finding asteroids on Saturn's Lagrangian points is difficult and has not yet been accomplished.

Uranus and Neptune, with far lower escape velocities than Jupiter and Saturn, are readily accessible to entry probes. With a nuclear propulsion system, escape from their atmospheres is clearly possible. Both planets presumably contain about fifty parts per million of helium-3 gas in their atmospheres, making the extraction and retrieval of vast amounts of fusion fuel conceivable. There is enough helium-3 in the atmosphere of Uranus alone to power Earth with a population of 10 billion people at European or North American levels of energy use for at least 10^{15} years. The satellite system of Uranus contains several midsized moons and many small, distant satellites, most of which have been very recently discovered. Neptune's system, with the large retrograde satellite Triton, several irregular ring arcs, and a midsized distant satellite, Nereid, is dynamically interesting, suggesting violent events in its past that may have disrupted any system of small satellites that may once have been present.

The Centaurs

The Centaurs, which cross the orbits of the gas giant planets, are analogous to the NEAs in the inner solar system. These presumably cometary bodies, which reach several hundred kilometers in size, are vulnerable to severe **perturbations** by these planets. Indeed, numerical analysis of the orbit of the Centaur Chiron suggests that it could cross Earth's path someday, possessing a **kinetic energy** about 1 million times larger than the impact energy of the asteroid that is theorized to have ended Earth's Cretaceous era (and killed off the dinosaurs). The principal resource interest of such bodies lies in their possession of abundant propellant, which could be used for self-deflection in the frightening event that such a body should be found on a path that threatens Earth.

perturbation term used in orbital mechanics to refer to changes in orbits due to "perturbing" forces, such as gravity

kinetic energy the energy an object has due to its motion

The Kuiper Belt

Bodies in the Kuiper belt, which lies beyond the orbit of Neptune, follow orbits that are moderately **eccentric** and moderately inclined with

eccentric the term that describes how oval the orbit of a planet is respect to the **ecliptic**. These bodies appear to be basically cometary in composition, although recent evidence suggests that there are two populations that are compositionally distinct. The largest-known body in the population is Pluto. Theory suggests that these bodies are about 60 percent ices by mass, with total extractable volatiles possibly reaching 70 percent.

ecliptic the plane of Earth's orbit

The Oort Cloud

The Oort cloud, even more remote from human eyes and reach, consists of about 1 trillion bodies of kilometer size and larger, following orbits that are essentially random in three dimensions and lie almost exclusively outside the orbits of the planets. Typical distances from the Sun are 10,000 **astronomical units**, and typical orbital periods are on the order of 1 million years. The few Oort cloud bodies that penetrate the inner solar system are called long-period comets. The severe lack of solar energy for propulsion and processing use, and the large mean distances between nearest neighbors, makes this realm unattractive as a potential resource.

astronomical units one AU is the average distance between Earth and the Sun (152 million kilometers [93 million miles])

Programmatically, initial space resource use will be confined to the Moon, Mars, and NEAs. Asteroidal and lunar resources have clear application to support of large-scale space activities such as the construction of solar power satellites and lunar power stations. The transition from NEAs to the asteroid belt seems an obvious next step. Some asteroids and short-period comets in turn belong to orbital classes that offer access to the **Jovian** and Saturnian families. Scenarios involving helium-3 for use as fusion fuel lead to the consideration of Uranus as the next target. SEE ALSO Asteroid Mining (volume 4); Comet Capture (volume 4); Natural Resources (volume 4); Resource Utilization (volume 4).

Jovian relating to the planet Jupiter

John S. Lewis

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Space Stations of the Future

International Space Station Alpha, which has been in operation since December 2000, is scheduled for completion in 2006. "Alpha," as it is nicknamed, is becoming the site of extensive human physiological research, life and physical science investigations, and commercial work that will continue for at least ten more years. Circling Earth once every 90 minutes, and at an altitude roughly the same as the distance from Washington, D.C. to New York City, Alpha is the latest and most evolved orbital **space station**.✶ But almost certainly there will be others. What will they be like? And how might they be used?

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

✶**Alpha uses sunlight to generate its own power (as much as that used by ten American homes) and is constructed around air-filled modules with more room than a 747 jetliner.**

As the work at Alpha returns knowledge and stirs public interest, national space agencies, scientists, and business people are considering beneficial activities that could be conducted onboard future stations in orbit. Even the armed forces have considered the use of crewed space stations,

A mock-up of a potential space station work area for the future.

although no sufficient reason has yet been found to develop a capability there for the military.

In the early twenty-first century, almost all civilian interests—from basic science experiments to tourism—have found reasons to think of future facilities in space. As with other environments and territories new to human experience—such as the deep seafloor, the Antarctic continent, or even Alaska in the nineteenth century—the scope of opportunity for human activity in space is only beginning to become clear.

Politics, People, and Purposes

rocket vehicle (or device) especially designed to travel through space, propelled by one or more engines

The very nature of Space Station Alpha typifies a reason for human spaceflight: international politics. Alpha is a cooperative program of sixteen countries. Russia was admitted to the circle in part as a gesture to apply the **rocket** industry of the former Soviet Union to peaceful purposes. China is publicly stating its intention to either join the Alpha Station partnership or build a space station of its own. If the latter happens, it may be because the feat will be touted to the world as a demonstration of China's technological and economic power, as was the case in the 1970s for America and the Soviet Union. In the future, additional nations may demonstrate their status in the same manner. But other needs will also drive nations to focus portions of their space programs on new space stations. And future orbiting facilities may be single-purpose ventures as opposed to the multipurpose Alpha.

vacuum an environment where air and all other molecules and atoms of matter have been removed

Science and Technology. Proposals for scientific investigations will probably increase as new discoveries expand the interest in using the very low-gravity and high-**vacuum** environments of space. As a consequence, there will be a continuing string of future scientific space stations or laboratories. Isolation from human presence may be an important factor in the design of these lab stations. The movement of people causes vibration in the structure of space stations, and these vibrations can upset delicate experimental processes and measurements. Hence, the stations will probably be staffed by robotic systems controlled from scientists' desktops on Earth. Astronaut "maintenance" crews will visit these laboratories infrequently. Also, research on virulent diseases or genetic engineering could mean that work is better done robotically in the isolation of a medical facility off the planet.

Tourism. In 2001 the first person to join a spaceflight for pleasure, Dennis Tito, flew to the International Space Station for six days. Primarily because Alpha was still under construction, that trip caused a furor among the partner nations other than his sponsor nation, Russia. But it also set a benchmark for popular future activities in space. More "space tourists" and nonprofessional astronauts will follow Dennis Tito.✶

✶South African entrepreneur Mark Shuttleworth became the second space tourist to the International Space Station in April 2002.

There may soon be vacation or sightseeing modules orbiting Earth for the use of those rich enough to buy a rocket ride into orbit. Scientist astronauts will not want to be bothered with these wealthy tourists, so a self-sustaining "orbital cabin," outfitted at first with only a picture window and the basics for human comfort, may become the foundation for "orbital resorts" further in the future. The thrill of experiencing life without gravity and viewing the ever-changing scenery as this cabin-station orbits over Earth will fuel the desire of millions to experience it firsthand.

But spaceflight for the masses is decades in the future. Until then, the vicarious experience that can be conveyed through cinema and video will have to suffice for most people. Filming and production facilities dedicated to weightlessness and space-walking action shoots may become part of a private enterprise station in orbit. This industrial park may support various nongovernment businesses in tourism, thrill-seeking, filmmaking, and theatrical productions. While research and commerce exploit orbital space in these ways, another station will function as a staging depot for expeditions to other worlds.

Jumping Off to Other Worlds

In the near future, human expeditions to the Moon and much farther to Mars will be organized and launched from orbiting docks. Because Earth is at the bottom of a gravitational "well" that must be climbed to get anything into space, it will be useful to use Earth orbit as a kind of "ledge" near the top of that well. In terms of energy, a spacecraft is essentially halfway to any other world in the solar system once it is in orbit around Earth. Cost and risk may both be reduced by launching astronaut explorers, their vehicles, and supplies to Earth orbit, where they can be assembled and checked before propelling them completely out of Earth's gravity and outward to Mars, for instance. For that purpose, a future space station that is an orbital dock and way-station may be developed. It would be the point of departure for human or even complex robotic explorers to other planets, asteroids, or comets. This station would also be the interim stop for deep-space explorers at the end of their travels. A module or laboratory at this station will likely be the destination of the rocks, soil, and maybe even other-worldly life brought back for in-depth study. Quarantining returning explorers and their samples may be a very sensible precaution.

It is virtually certain that the twenty-first century will see increasing numbers of space stations orbiting our planet and filling diverse roles. SEE ALSO Business Parks (volume 1); Hotels (volume 4); International

SPACE STATION (VOLUMES 1 AND 3); SPACE INDUSTRIES (VOLUME 4); SPACE TOURISM, EVOLUTION OF (VOLUME 4); TOURISM (VOLUME 1).

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Space Tourism, Evolution of

In 1967 Barron Hilton, the chief executive officer of Hilton Hotels Corporation, stated that it was his dream to be a pioneer of space tourism. At that time, he spoke of his plans for hotels in space, including the Orbiter Hilton and the Lunar Hilton. The Orbiter Hilton would move freely around in space, orbiting Earth, whereas the Lunar Hilton would be located on the surface of the Moon. Hilton realized that he would have to wait until the time was right, but that time is now approaching.

Recently, Dennis Tito, a 60-year-old California tycoon, made his place in history as the first person to buy his way into space as a tourist, paying $20 million for the opportunity. After six weeks of intensive training with the Russian Space Agency, on April 30, 2001 Tito embarked on a week's vacation to tour the International Space Station. By the end of the week many of the people who viewed that historical event deemed his trek a success.

These efforts could spark the beginning of an age of adventure tourism, or tourism that involves an element of risk or perceived risk. Space tourism, a segment of adventure tourism, includes suborbital travel, or flights to the edge of Earth's atmosphere; trips to low Earth orbit (LEO), in which satellites orbit Earth at an altitude of 320 to 800 kilometers (200 to 500 miles); and vacations at an orbiting or lunar hotel/resort.

Suborbital Tourism

Currently, one form of space tourism exists. From an airfield in Moscow, tourists are paying $12,000, excluding travel and lodging costs, for a "Journey to the Edge of Space." These adventurers experience a 45- to 60-minute ride to the edge of Earth's atmosphere in a MiG-25 aircraft flying at Mach 2.5, or a mile every 2 seconds, and reaching an altitude of 25 kilometers (82,000 feet). Passengers are able to view the curvature of Earth and a horizon that is 1,100 kilometers (715 miles) across. According to *Time International*, almost 4,500 adventurers have made the trip. After taking one of these flights with Space Adventures Ltd., Wally Funk, a former astronaut and pilot, said that the flight was his most thrilling experience.

The next step in suborbital travel is a 30- to 150-minute trip that will take tourists to an altitude of 100 kilometers (62 miles). After four days of training at a cost of $98,000, "extreme tourists" will be launched just short of orbit, where "space" technically begins. When the launch vehicle approaches its maximum altitude, the rocket engines will shut down and the adventurers will experience 5 minutes of uninterrupted weightlessness. Space Adventures Ltd. has accepted 144 reservations, paid in advance, for a venture that has not yet flown its maiden voyage. The companies offering these trips had plans to take people up to 100 kilometers (62 miles) in 2001. However, those plans have been delayed until technology can be developed that is safe for the civilian public. Enthusiasts expect to be hurled into space between 2003 and 2005.

The obstacle that stands in the way of suborbital spaceflight is the construction of a reusable launch vehicle (RLV) that is reliable enough to take tourists to the perimeter of space and satisfy the safety standards and regulations of the Federal Aviation Administration. This is the reason current space tourism ventures are taking place in Russia, where the government does not regulate aviation as tightly.

The challenge in creating such a vehicle is more financial than technical. The successful manufacture of an RLV that could reduce launch costs by 90 percent of the current price per pound is necessary to make routine suborbital passenger flights financially feasible.

Dennis Tito, the world's first space tourist, gave a thumbs-up before boarding the Russian rocket that took him to the International Space Station in April, 2001.

Orbital Tourism

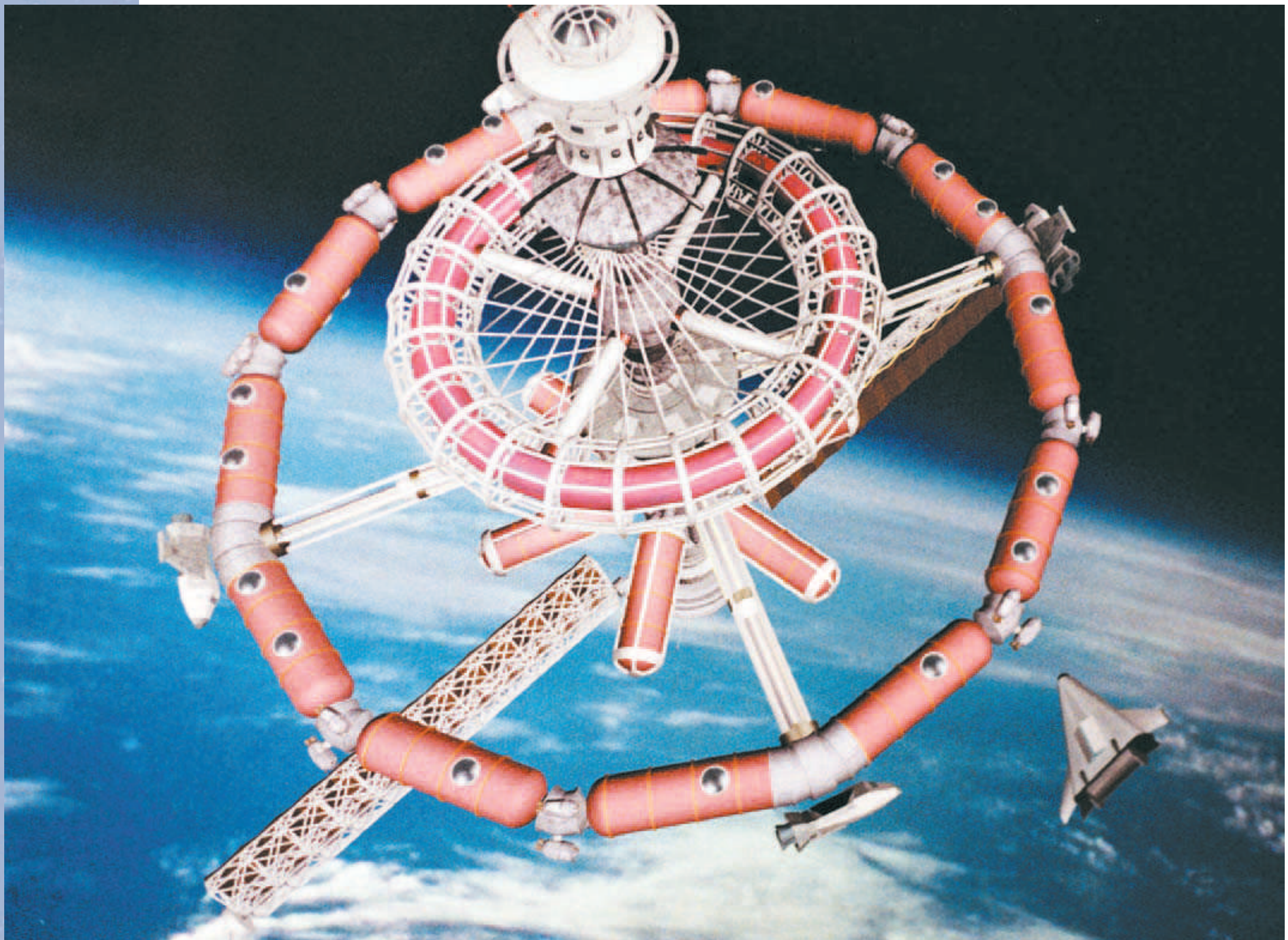
Low Earth Orbit (LEO). The construction of a reliable RLV for suborbital travel will aid the expansion of space tourism by making available a vehicle that can be adapted for travel to LEO. This RLV, used to transport passengers into LEO, will need to have more propulsion than suborbital RLVs to achieve orbit. Another challenge will be to create enough room for approximately 50 to 100 passengers so that the venture will be economically feasible.

When a satellite is in LEO, it is traveling at 27,200 kilometers (17,000 miles) per hour and circles Earth in approximately 90 minutes. If a LEO RLV were to take travelers one or two times around Earth before landing, passengers would stay in the RLV for 1.5 to 3 hours. During this time it is likely that passengers will need to use the rest room or eat a snack, as in an airplane. Therefore, space tourism companies offering these rides will have to provide amenities that are functional in a zero-gravity environment, such as the candy and peanuts astronauts eat in space.

International Space Station. Currently, orbital spaceflight is available to those who are willing to pay the price. For approximately $20 million it is possible for a private voyager to fly to the International Space Station. Individuals interested in this once-in-a-lifetime experience must be willing to undergo the rigorous training program required for civilian astronauts in Russia. After medical testing to assure readiness to fly, explorers will be flown to an altitude of 24,390 meters (80,000 feet), where they will experience zero gravity at a speed of Mach 2.5. They also will discover what it is like to experience 5 Gs✶ when they reenter Earth's atmosphere, take a space walk in the neutral-buoyancy training pool, and learn about the Soyuz spacecraft by using the cosmonaut simulator. After four to six months of training and preparation, private citizens will be given a chance to spend a week exploring the International Space Station.

✶A person subjected to 5 Gs would feel as if she or he weighed five times as much as normal.

Proposed Orbital and Lunar Hotels. The ultimate goal for space enthusiasts is the construction of the first space hotel/resort. A number of organizations



A prototype of the Space Island Group's revolving orbital hotel.

are working on space station designs for commercial purposes. It is known that an orbiting space hotel can be created. The challenge lies in the economics of the project.

There has been a significant amount of discussion among space entrepreneurs of ventures such as luxury cruise ships, orbiting hotels, and lunar hotels. The Space Tourism Society in Santa Monica, California, has plans for an "orbital yacht" featuring balloon-like rooms that would allow travelers to see Earth clearly. Passengers also would be able to enjoy activities such as dancing and sports and take a sauna while orbiting in space.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Robert Bigelow, owner of the Budget Suites of America hotel chain, has different plans. He has devoted $500 million to the research, design, and development of a space hotel by the year 2005. One Bigelow model contains two rotating modules in a **microgravity** environment similar to that of the International Space Station. One module would be used as living quarters for the passengers and crew. This section of the station would contain sleeping, cooking, showering, and rest room areas. The other module would house research laboratories. Bigelow visualizes a more spacious model than the International Space Station to create the most comfortable habitat possible for space tourists.

The Space Island Group has proposed a formation similar to a revolving bicycle wheel. The revolving motion will create an atmosphere with one-third Earth's gravity within modified shuttle fuel tanks. This amount of gravity will allow running water and a semi-normal eating, sleeping, and walking experience. For recreational purposes, passengers will be able to experience a genuine zero-gravity environment inside the station's hub. They will see cameras' views of Earth on a screen. The goal of the Space Island Group, Budget Suites, the Space Tourism Society, and many other entrepreneurial space tourism organizations is to create the ultimate tourist experience for those who can afford the voyage.

It will be interesting to watch the path space tourism takes and see how the public reacts to it. A 1997 National Aeronautics and Space Administration (NASA) study showed that one-third of Americans would be interested in taking a space voyage. Currently, many adventurers are ready to pay $60,000 to climb Mount Everest, dive to the *Titanic*, or travel to Antarctica. Although there is perceived danger in all these adventures, the companies that offer them are able to make a profit. However, there is great uncertainty about space tourism. This perception will not be altered until a greater number of extreme tourists have experienced and enjoyed a safe and reliable space adventure. The current era of space tourism can be compared to the early twentieth century, when the public saw the concept of airplane travel as absurd.

The key to the development of space tourism is its financial feasibility. Although one man has paid $20 million to visit the International Space Station, it is unlikely that many people could or would spend that kind of money. Perhaps $60,000, the equivalent of the price to climb Mount Everest, will be the "affordable ticket price" that creates a market for space tourism. As Buzz Aldrin stated, "Adventure travel will force us to improve the reliability of our launch vehicles, help to establish economic life-support systems for a large number of people, and give us experience with creating space habitats. All of these things are strong building blocks for exploration." SEE ALSO CIVILIANS IN SPACE (VOLUME 3); HOTELS (VOLUME 4); TOURISM (VOLUME 1).

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Star Trek

THE ORIGINS OF DR. SPOCK

In David Alexander's biography of Gene Roddenberry, he reports that the character of Dr. Spock was to have been a "red-hued Martian." Convinced, however, that space exploration would reach Mars during *Star Trek*'s run, Roddenberry changed Spock's origin to another planet, beyond the solar system: Vulcan.

In the daunting arena of space exploration, there is a tendency to wonder where the path that humankind is taking will lead us. Does the future hold the promise of fantastic new technologies that will be used peacefully for the benefit of humankind? Or will those technologies end up in the hands of a society that is not mature enough to wield power responsibly? The *Star Trek* television series and movies conceived by Gene Roddenberry participate in this debate by providing an optimistic view of humans in the future. In *Star Trek*'s version of history, humankind achieved an end to war, poverty, and disease on Earth shortly after the invention of warp technology, the principle that made it possible to travel faster than light.

Throughout history, people have built bigger and better telescopes and seen farther into the universe, but despite all of these exploration attempts, humankind has not made contact with intelligent extraterrestrial life. People look into the night sky and wonder whether there are other civilizations out there. If there are, the vast distances between worlds make it seem unlikely that it will ever be possible to interact with those civilizations. Since Albert Einstein's theories suggest that it is impossible for a person to accelerate to the speed of light, it would take hundreds to thousands of years for people on a spacecraft to reach a planet in another star system by conventional means.

The warp technology of *Star Trek*, however, allows a spacecraft and its inhabitants to travel many times faster than light by moving through subspace, a theoretical parallel universe in which Einstein's theories do not apply. In a matter of hours or days it is possible to travel from one star system to another by creating a warp field that allows a spacecraft to slip into subspace. With the immense distances between civilizations no longer an issue, humans on *Star Trek* interact within a universe populated by an array of alien species.

The success of the *Star Trek* series and movies reflects genuine public interest in humankind's future in space. The writers added realism by weaving plausible scientific theories into the fabric of the *Star Trek* universe. The technologies behind the warp engine–powered starship, wormholes (theoretical bridges between two points in space), and transporters (devices that can convert matter to energy and vice versa) are all based on scientific theories. For this reason, it is natural for the audience to view these things as believable future manifestations of today's science.

Another key to *Star Trek*'s appeal is that it presents such an optimistic view of human society's future. It shows a world in which humans are no longer at war with each other. Food, resources, and transportation are available at the touch of a keypad. This hopeful portrayal shows a human civilization that has survived its technological adolescence, matured, and been enriched by alien cultures, one that thrives in a well-populated intergalactic neighborhood. SEE ALSO Antimatter Propulsion (volume 4); Communications, Future Needs (volume 4); Faster-Than-Light Travel (volume 4); First Contact (volume 4); Interstellar Travel (volume 4); Lasers in Space (volume 4); Movies (volume 4); Roddenberry, Gene (volume 1); Science Fiction (volume 4); Teleportation (volume 4); Wormholes (volume 4).

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Star Wars

Star Wars: A New Hope premiered in the spring of 1977, followed by its two sequels: *The Empire Strikes Back* in 1981 and *Return of the Jedi* in 1983.✶ It quickly became apparent that this was a science fiction trilogy unlike any previous movies of this genre, a fact emphasized by the way the movie shattered previous box-office records and won awards, including seven of the ten Academy Awards for which it was nominated.

✶The prequel trilogy to *Star Wars* debuted in 1999 with *The Phantom Menace,* and the second movie, *Attack of the Clones,* was released in 2002.

The movies tell the story of Luke Skywalker (actor Mark Hamill) who—together with his Jedi mentors Ben "Obi-Wan" Kenobi (Alec Guinness) and Yoda, his friends Princess Leia Organa (Carrie Fisher) and Han Solo (Harrison Ford), and his two trusty androids C-3P0 (Anthony Daniels) and R2-D2 (Kenny Baker)—battles Darth Vader (David Prowse; voice, James Earl Jones) and the evil Empire to restore peace to the Galaxy.

The most obvious difference between *Star Wars* and its predecessors was the special effects. Computer graphics were still in their infancy in 1977, and much of the technology needed to realize director George Lucas's vision had to be developed as the production of *Star Wars* progressed. The advancement of computerized special effects can be seen by comparing the initial trilogy with the "special edition" versions released in 1997—Lucas had to wait for technology to catch up with his initial vision for scenes such as the Mos Eisley spaceport in *Star Wars* and Cloud City in *The Empire Strikes Back.* Nevertheless, the special effects in the original trilogy stunned moviegoers. For the first time, spaceships were depicted as vehicles that looked as if they had been through many battles instead of appearing as shiny flying saucers. Battle scenes looked real, and moviegoers felt as if they were in the middle of the action. Aliens displayed a wide variety of appearances rather than simply looking like bulbous-headed humans with three fingers.

The *Star Wars* trilogy represented the variety of worlds that humans might encounter throughout a galaxy. Planets ranged from the desert planet of Tatooine orbiting a double star to Yoda's swamp world of Dagobah, from

Star Wars, which received seven Academy Awards, was the top-grossing film of 1977, and remains the second highest-grossing film of all time.

the ice-covered world of Hoth to the gaseous Bespin with Lando Calrissian's Cloud City. *Star Wars* presented an array of new weapons such as the light saber and a new power, the Force, which could be used for either good or evil. Some of the concepts, such as creatures living on airless asteroids and spaceships traveling at speeds greater than the speed of light, are (at least at present) definitely in the realm of science fiction. Nevertheless, there were enough scientifically reasonable concepts in the movies to make everything seem possible at some other time or place in the universe.

As a proponent of space exploration, Lucas hoped that *Star Wars* would excite the younger generation about space and its exploration. Lucas has said, "I would feel very good if someday they colonize Mars . . . and the leader of the first colony says 'I did it because I was hoping there would be a Wookiee up there.'" SEE ALSO Entertainment (volume 1); Faster-than-Light Travel (volume 4); Interstellar Travel (volume 4); Lucas, George (volume 1); Movies (volume 4); Science Fiction (volume 4).

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Stine, G. Harry

American Engineer and Writer
1928–1997

Engineer, author, visionary, and hobbyist extraordinaire, G. Harry Stine is best known as the father of model rocketry for his efforts to bring science and safety to the building and launching of model rockets. Working as an engineer at the White Sands Missile Range in New Mexico when Sputnik was launched in 1957, Stine watched with dismay as enterprising hobbyists, in the grip of rocket fever, were injured or killed trying to launch their models. He consequently developed and published safety standards for model rocketeers, and founded the National Association of Rocketry in 1958. He also started the first model rocket company, Model Missiles, Inc., around this time. His *Handbook of Model Rocketry*, first published in 1965, remains the bible of rocket enthusiasts to this day.

As a visionary and advocate for inexpensive exploration and colonization of space, Stine was a proponent of single-stage-to-orbit vehicles, which are inexpensive, reusable, single-stage spacecraft that require no major refurbishing between missions. The multistage spacecraft used up until the present, like the space shuttle, **jettison** the spent fuel tanks during flight, and require expensive replacement and repair before taking off again.

jettison to eject, throw overboard, or get rid of

As a member of the Citizens' Advisory Council on National Space Policy, Stine contributed to the design of the McDonnell Douglas Delta Clipper Experimental craft, or DC-X, which had a successful test flight on August 18, 1993, at the White Sands Missile Range. The DC-X lifted off under rocket power, hovered at 46 meters (150 feet), then made a soft landing in its upright position with rockets thrusting. Stine predicted that such a single-stage, reusable spacecraft could reduce the cost of lifting a **payload** into space from $10,000 per pound to $1,000, making space industry and tourism an economic possibility.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

A prolific author, Stine wrote numerous nonfiction books, beginning with *Earth Satellites and the Race for Space Superiority* in 1957, and including *Halfway to Anywhere* in 1996 and *Living in Space* in 1997. From 1979 until his death in November 1997, he wrote a regular column on space issues called "The Alternate View" for *Analog Science Fiction and Fact* magazine, commenting on everything from the Moon Treaty to polluting the universe. He also wrote many science fiction novels and short stories, sometimes using the pseudonym Lee Correy. SEE ALSO LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4); ROCKETS (VOLUME 3).

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Teleportation

Humankind wanted to go to the Moon, and so the National Aeronautics and Space Administration (NASA) built a Saturn **rocket**. People wanted to live in space, and so an army of astronauts and engineers assembled a

rocket vehicle or device, especially designed to travel through space, propelled by one or more engines

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

space station. Now humankind wants to travel to Mars and send robots to explore other galaxies. Thus, it is necessary to design propulsion systems that go faster and farther than ever before. From solar sails, to nuclear rockets, to propulsion with hot gases, to wild ideas that rival *Star Trek*'s concept of "warp speed," scientists have embarked on an adventure that goes beyond the works of the most creative science fiction writers.

The first logical step in this process is to improve conventional rockets by packing more energy into a smaller volume. Instead of burning liquid oxygen and hydrogen, as the space shuttle's main engines do, a future rocket might burn solid hydrogen or use a very dense combustible. However, this method still requires that the vehicle carry its fuel into space.

NASA is working on a radical concept called the Lightcraft, a machine that resembles a flying saucer powered by air heated by a high-energy laser. An advanced version of the Lightcraft would be a large helium-filled balloon that would focus microwaves beamed from the ground or space. The balloon would be ringed by ion engines that would electrify the air to push the craft upward. Deep Space 1 is the first probe powered entirely by an ion engine, which runs on electrically charged gas.

nuclear fusion combining low-mass atoms to create heavier ones; the heavier atom's mass is slightly less than the sum of the mass of its constituents, with the remaining mass converted to energy

A more powerful rocket would use **nuclear fusion**, the power source at the heart of the Sun. Controlled fusion—combining the nuclei of two lightweight atoms and reaping energy from the process—might achieve the speed needed to get to other planets, a speed 200 times faster than that provided by the space shuttle's main engines.

Solar Sails and Antimatter Propulsion

Even more radical is the idea of the solar sail. Just as a sailing vessel uses the wind to push against the surface of its sail, satellites and small robotic spacecraft could use light particles from the Sun—called photons—to push a membrane made of very light carbon fibers. Because photons produce such small amounts of energy, the sail would have to be huge, up to several kilometers wide.

antimatter matter composed of antiparticles, such as positrons and antiprotons

electrons negatively charged subatomic particles

protons positively charged subatomic particles

One of the most eccentric concepts in intergalactic propulsion is rooted in the popular belief that an **antimatter** particle coming in contact with its matter counterpart (for example, **electrons** and positrons or **protons** and antiprotons) would yield the most energy of any reaction in physics. The theory is known as antimatter annihilation. The efficiency would be thousands of times greater than that of any other method yet considered, probably taking a spacecraft to Mars in only six weeks.

Beyond the warp drives of *Star Trek*'s Enterprise but still within the realm of the possible, there are ideas for intelligent rockets that would be able to fix themselves and evolve almost like living things, achieving propulsion without rockets. Before this can happen, however, traditional space transportation will have to become like flying an airplane: routine, safe, and inexpensive. SEE ALSO Antimatter Propulsion (volume 4); Faster-Than-Light Travel (volume 4); Ion Propulsion (volume 4); Laser Propulsion (volume 4); Lightsails (volume 4); Nuclear Propulsion (volume 4); Science Fiction (volume 4); Star Trek (volume 4); Star Wars (volume 4).

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Telepresence

Telepresence refers to the use of cameras and other equipment to remotely study a distant environment. This technology is primarily used to explore places that are inhospitable to humans. Scientists have used robotic vehicles on Earth to explore active volcanoes and the ocean floors. But telepresence has been used primarily to explore other worlds. Some vehicles, such as the Lunar Surveyor missions that set down on the Moon's surface in the 1960s and the Viking stations that landed on Mars in 1976, remained stationary and analyzed materials within the reach of their experiments. Other vehicles were mobile rovers, such as the Soviet Lunakhod missions that explored the Moon in 1970 and 1973 and the Sojourner rover, which was part of the Mars Pathfinder mission in 1997.

Sojourner was allowed to make some independent decisions regarding its movements, which occasionally got the little rover into trouble. Here the rover tried to climb over rocks but managed to get itself stuck. Engineers on Earth were able to transmit new signals that allowed Sojourner to find its way down.

Telepresence allows scientists to learn about a hostile environment without endangering human life. In some cases, such as the exploration of Venus's surface by the Soviet Venera missions, the environment is so inhospitable that human explorers might never be sent there. In other cases, landers and rovers are used to determine if the location is safe for humans. The Lunar Surveyor missions, for example, tested a theory that the Moon's surface is covered by a thick layer of dust that would swallow up anything that landed on it. The Surveyors revealed that the Moon's surface is solid, and the Apollo lunar landings with the American astronauts proceeded without problems.

When telepresence is used on Earth, the operator is typically in near-instantaneous contact with the robot so the robot's motions can be adjusted in real-time. However, when humans are on Earth and the robot in on another world, the limited speed of the radio signals (traveling at the speed of light) means that there is a time delay between when the operator sends a command and when the robot receives it. Thus, scientists typically develop a sequence of commands to send to the robot and allow it to act autonomously until the next contact period. Rovers usually have internal "fail-safe" modes so if they get themselves into trouble (for example, trying to climb a steep slope, such as the Sojourner rover tried to do several times), they will shut down until the next sequence of commands is received from Earth. Thus, telepresence is much more complicated than simply moving a joystick and seeing how the rover responds on another world.

Scientists look forward to the day when many activities will be completely conducted by telepresence. Some of the possibilities are already apparent. Teleoperated robots are used on Earth to clean up hazardous waste sites. Some Earth-based telescopes are conducting autonomous observations, alerting the operator only when they detect something unusual. The expected increase in technological capabilities will allow future robots to conduct mining operations on asteroids or construct habitats for human occupation on Mars before the astronauts even leave Earth. Increased opportunities for exploration and new ways to improve the lives of humans will be available through the enhanced capabilities of future teleoperated robots. SEE ALSO Asteroid Mining (Volume 4); Mars Missions (Volume 4); Nanotechnology (Volume 4); Scientific Research (Volume 4).

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Terraforming

Terraforming is the process of altering a planet to make it more suitable for life (habitable). Usually this means making the planet suitable for most, if not all, Earth life. However, if there is dormant or hidden life on the planet, terraforming will change conditions so that this life can possibly flourish. In terraforming, there are intermediate stages where the planet has become habitable, but only to organisms that can survive in extreme environments.

Until recently, the topic of terraforming Mars was considered more the subject of science fiction novels rather than serious scientific discussion. But it is now known that we can change the climate of a planet, as we are inadvertently doing it on Earth. In addition, it is thought that billions of years ago Mars did have a climate suitable for life. The main focus of current scientific studies of terraforming is the restoration of Mars to habitable conditions.

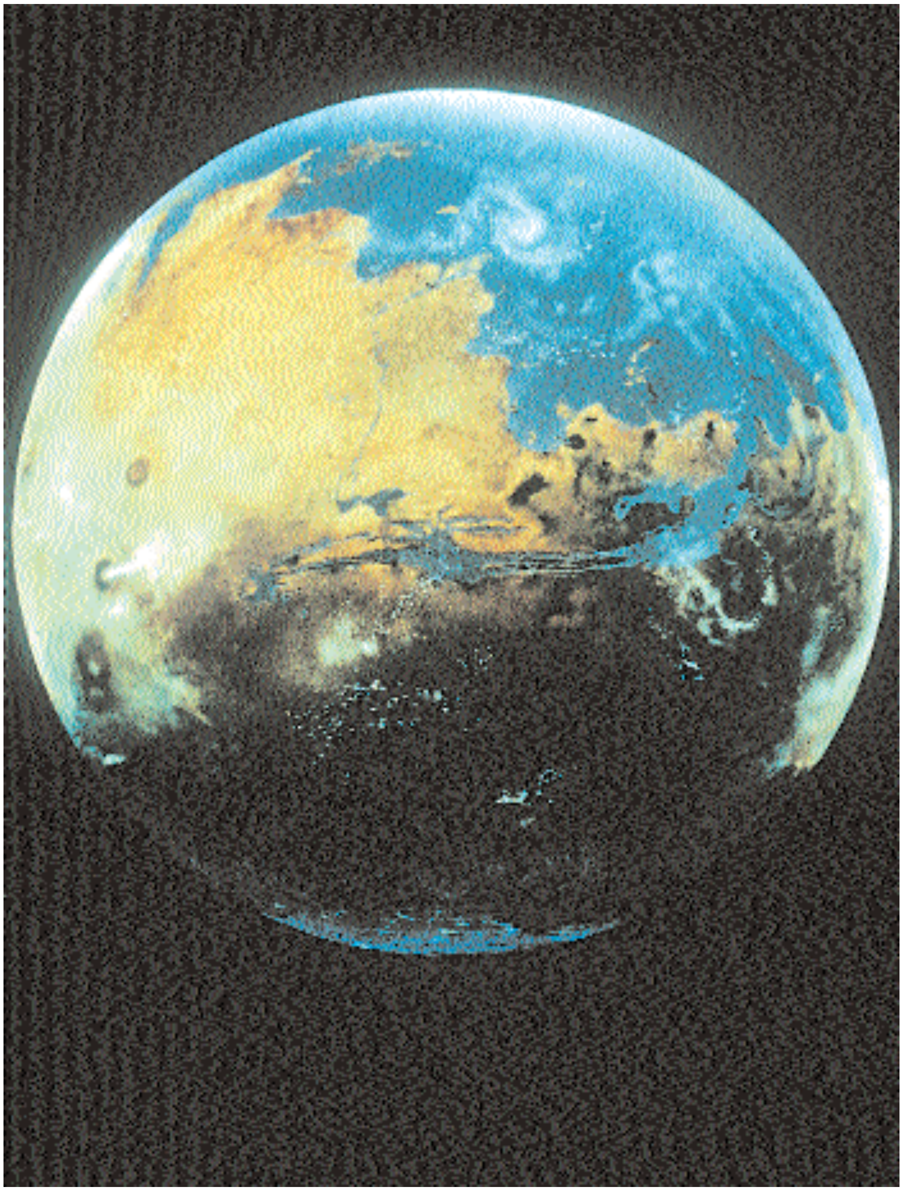
The Restoration of Mars

Mars can be made suitable for life by changing its climate; there is no need to alter its distance from the Sun, its rotation rate, or the tilt of its axis. Exploration of Mars indicates that it already has enough carbon dioxide, nitrogen, and water to build a **biosphere**. The challenge is to warm the planet and release those compounds. Mars is the only one of the inner planets that can be made habitable simply by changing its climate. It is not possible to move Venus or make it spin faster or to add an atmosphere to Mercury or the Moon to make them habitable. Mars is the only practical target for near-term terraforming.

biosphere the interaction of living organisms on a global scale

The Habitability of Mars and Earth

In considering the possibility of restoring habitable conditions to Mars, it is important to define that term. The basic approach to this question is to look at Earth. Clearly, the present environment on Earth is habitable to microorganisms, plants, and animals. But Earth has not always been this way.



Estimates based on the size and shape of the fluvial features on Mars suggest that it has enough water to cover its entire surface with a layer 500 meters thick. This painting shows what the present Mars would look like if that much water was once again on the surface.

For most of Earth's early history, oxygen was not present and carbon dioxide levels were much higher than they are today. This early environment was habitable for microorganisms and would be habitable for most plants but not for animals and humans, which require high oxygen levels and low carbon dioxide levels. On Mars the natural habitable condition is one with high carbon dioxide and only a little oxygen.

In a habitable state, Mars would have a thick atmosphere about one to two times sea-level air pressure on Earth. This atmosphere would be composed primarily of carbon dioxide, with lower levels of nitrogen and small amounts of oxygen produced by sunlight. There may be enough oxygen to create a thin but effective ozone shield, but there will not be enough for humans and animals to breathe. This restored environment would be similar

COMPARING EARTH, MARS, AND VENUS

	Earth	Mars	Venus
Gravity	1	0.38	0.91
Day Length	24h	24h 37min 22.66sec	117 days
Year	365 days	687 days	225 days
Axis Tilt	23°12'	25°12'	2°36'
Ave. Sunlight	345 W/m^2	147 W/m^2	655 W/m^2
Ave. Temperature	+15°C	−60°C	+460°C
Temperature Range	−60°C to +50°C	−145°C to +20°C	−460°C to +460°C
Pressure	1 atm (101.3 kPa)	1/120 atm	95 atm
Atmosphere	N_2, O_2	CO_2	CO_2

to what the Martian environment might have been like 3 to 4 billion years ago, when Mars may have had a biosphere.

Currently Mars is too cold (−60°) and has an atmosphere that is too thin to allow liquid water on the surface; thus, it cannot support life. Therefore, the first step in making Mars habitable is to increase the temperature and the atmospheric pressure enough for liquid water to be stable. The most effective method is the use of super-greenhouse gases known as perfluorocarbons (PFCs). These gases have a strong warming effect even at very low concentrations, as has been seen on Earth. PFCs are not toxic to plants and animals. Unlike chlorofluorocarbons, PFCs do not contain chlorine or bromine, and thus they would not destroy the ozone layer that would form as the atmosphere thickened.

There have been other suggestions of ways to warm Mars, such as placing large orbiting mirrors, sprinkling the poles with dark dust, and crashing asteroids and comets into the surface. Unlike the use of PFCs, none of these methods are practical with today's technology.

regolith upper few meters of a body's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

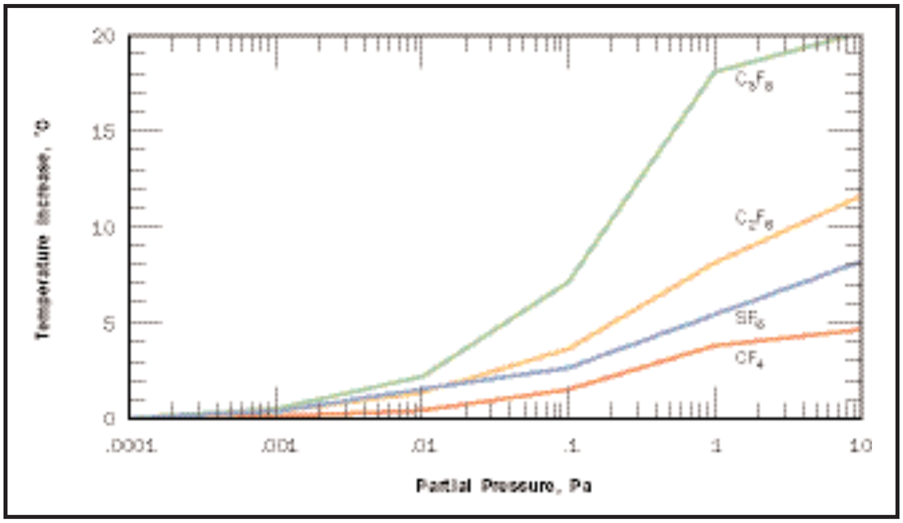
As the temperature on Mars increases, carbon dioxide gas will be released from the **regolith** and the polar cap as it melts (the south polar cap is composed of frozen carbon dioxide and ice). This carbon dioxide will thicken the atmosphere and augment greenhouse warming. This positive feedback between thickening the atmosphere, warming the surface, and releasing carbon dioxide will continue until all the carbon dioxide is in the atmosphere. Calculations indicate that in a concentration of a few parts per million, PFCs can trigger the outgassing of carbon dioxide. At this stage, Mars would be a warm, wet world if the regolith and polar regions have the amount of carbon dioxide and water ice it is thought they have—between 100 and 1000 mbars.

If there is dormant life on Mars, it would expand rapidly into this recreated warm and wet world. The surface would once again be full of Martians. If there is no life on Mars, microorganisms and plants could be introduced from Earth.

Ecological Changes and the Martian Biosphere

The ecological changes on Mars as it warms up will be like hiking down a mountain: from barren frozen rock at the top, through alpine tundra and arctic and alpine grasses, and eventually to trees and forests.

The first Martian pioneers from Earth will be organisms that live in the coldest, driest, most Mars-like environment in the world. These are the



Different types of greenhouse gases can be very efficient at increasing surface temperatures.

cryptoendolithic microbial ecosystems found in Antarctica. In the cold, dry, ice-free regions of Antarctica, **lichens**, **algae**, and bacteria live a few millimeters below the surface of sandstone rocks, where there is a warmer, wetter environment than exists on the surface of the rock. Enough sunlight penetrates through the rock to allow photosynthesis. Similar microorganisms in a rock habitat could survive on Mars when the air temperatures reached −10°C in the daytime for a few weeks during the warmest part of the year.

cryptoendolithic microbial ecosystems microbial ecosystems that live inside sandstone in extreme environments such as Antarctica

lichen fungus that grows symbiotically with algae

algae simple photosynthetic organisms, often aquatic

With further warming and extension of the growing season, alpine plants might survive and cover vast equatorial regions. The first introduction of photosynthetic microbial ecosystems and arctic and alpine tundra will be of biological interest. However, only with the development of ecosystems based on higher plants will the ecological development of Mars become significant in terms of the production of oxygen.

Although plants will be the major biological force on Mars, as they are on Earth, small animals also could play a key role. Insects and soil invertebrates, such as earthworms, would be important in the developing ecosystems. For example, pollination by flying insects would greatly increase the diversity of plants that can be grown on Mars at every stage of the process. Unfortunately, the minimum oxygen requirements and maximum carbon dioxide tolerance of flying insects at a third of Earth gravity remains unknown.

Although life-forms from Earth might be introduced to Mars in a careful sequence, this does not imply that the resulting biosphere will develop as predicted. As life on Mars interacts with itself and the changing environment, it will follow an independent evolutionary path that will be impossible to control. This should be considered a good thing. The resulting biological system is more likely to be stable and globally adapted to the altered environment than would any preconceived ecosystems, and studying such an independent evolutionary path will contribute to scientific knowledge.

By calculating the energy required to change Mars, it is possible to estimate how long the process might take. The results indicate that to warm

Mars and introduce plant life would take about 100 years. It would take another 100,000 years for those plants to produce enough oxygen for humans to breathe. In the meantime humans would have to wear small oxygen masks but not pressurized space suits.

carbonate a class of minerals, such as chalk and limestone, formed by carbon dioxide reacting in water

In the long term Mars will once again decay and lose its atmosphere as the carbon dioxide dissolves in water and is turned into **carbonate**. However, this will take 10 to 100 million years—long enough for a biosphere to develop.

Ethical Issues

Although terraforming a planet is technologically feasible, is it ethically correct? Perhaps the most difficult issue is the possibility that life may already be present on the planet. In terraforming Mars, the first step would be creating a thick carbon dioxide atmosphere that supports a warmer and wetter planet. These conditions closely resemble those on early Mars, when any Martian life-forms would have developed, and therefore are the conditions they are adapted to. Terraforming Mars will make the planet more favorable to any present Mars organisms rather than having the unwanted effect of destroying a different life-form.

Terraforming has as its goal the spreading of life. The process can be seen as part of evolution, in which organisms expand into every available niche either by adapting or by changing the environment. Humans can help this spread of life and contribute in a positive way to the ecological development of the solar system. SEE ALSO Astrobiology (volume 4); Domed Cities (volume 4); Environmental Changes (volume 4); Exploration Programs (volume 2); Living on Other Worlds (volume 4); Mars (volume 2); Mars Bases (volume 4); Scientific Research (volume 4); Social Ethics (volume 4).

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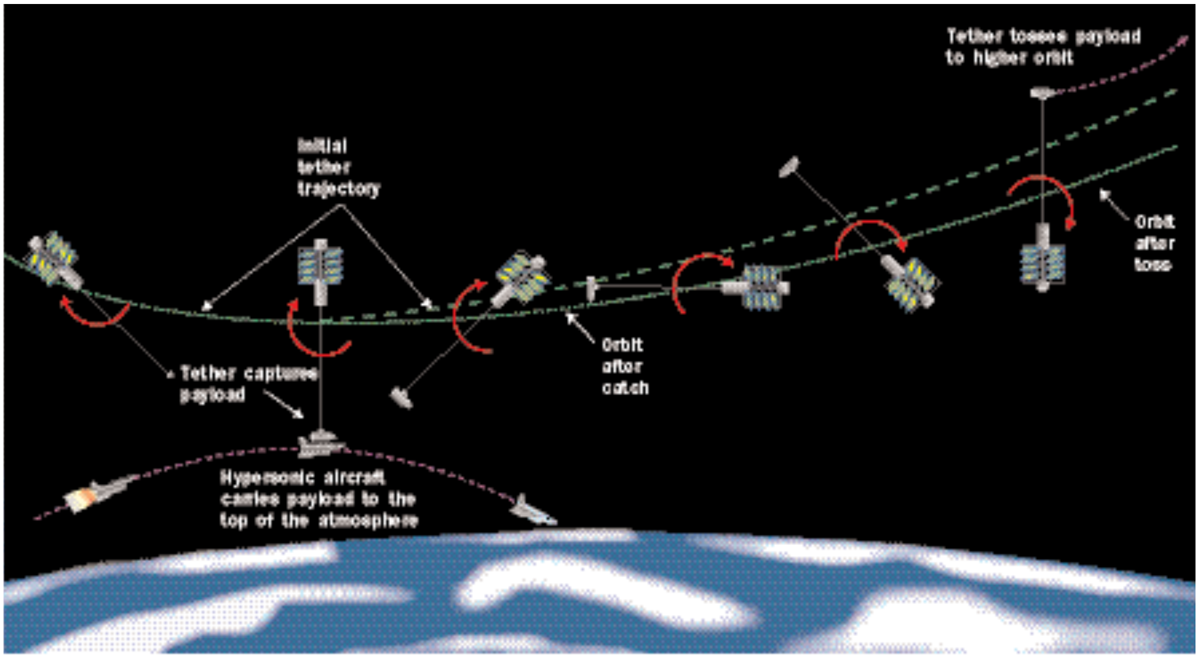
Tethers

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

pyrotechnics fireworks display; the art of building fireworks

Space travel is a tremendously costly enterprise, largely because today's spacecraft use **rockets** to move around, and launching the significant amounts of fuel needed to propel those rockets is very expensive. For humankind to move beyond its current tentative foothold in **low Earth orbit** and begin frequent travel to the Moon, Mars, and other planets, the cost of traveling through space must be substantially reduced. To do this, it may be necessary to rely less on the **pyrotechnics** of rocket technologies and



A concept for a system in which an orbiting tether would pick a payload up from a hypersonic airplane flying at the top of the atmosphere and pull the payload into space.

utilize simpler and less complex technologies. This could entail the use of long strings or wires to move **payloads** around in space without the need to burn large quantities of fuel.

A space tether can be used to move spacecraft through space through two different mechanisms. First, a high-strength string connecting two spacecraft can provide a mechanical link that enables one satellite to "throw" the other into a different orbit, much like casting a stone with a sling. Second, if the tether is made of conductive wire, currents flowing along the wire can interact with Earth's magnetic field to create propulsive forces on the tether. Both momentum-transfer and **electrodynamic** tethers can move spacecraft from one orbit to another without the use of propellant.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

electrodynamic pertaining to the interaction of moving electric charges with magnetic and electric fields

Tether Experiments

A number of tether experiments have been flown in space. In the early days of the space age the Gemini 11 and 12 missions (1966) used short tethers to connect two spacecraft and rotate them around each other to study artificial gravity and other dynamics.

In the 1990s the National Aeronautics and Space Administration (NASA) conducted two series of tether experiments. One series involved a large tether flown on the space shuttle that was called the Tethered Satellite System (TSS). Unfortunately, the TSS missions encountered well-publicized problems. In the 1992 TSS-1 mission, the TSS system attempted to deploy a spherical satellite built by the Italian space agency upwards from the shuttle at the end of a 20-kilometer-long (12 miles) tether made of insulated copper wire. A few hundred meters into deployment the spool mechanism jammed, ending the experiment.

In 1996 NASA repeated the experiment. As the tether approached its full length, the rapid motion of the orbiting tether through Earth's magnetic field generated a current of over 3,500 volts along the tether. The TSS

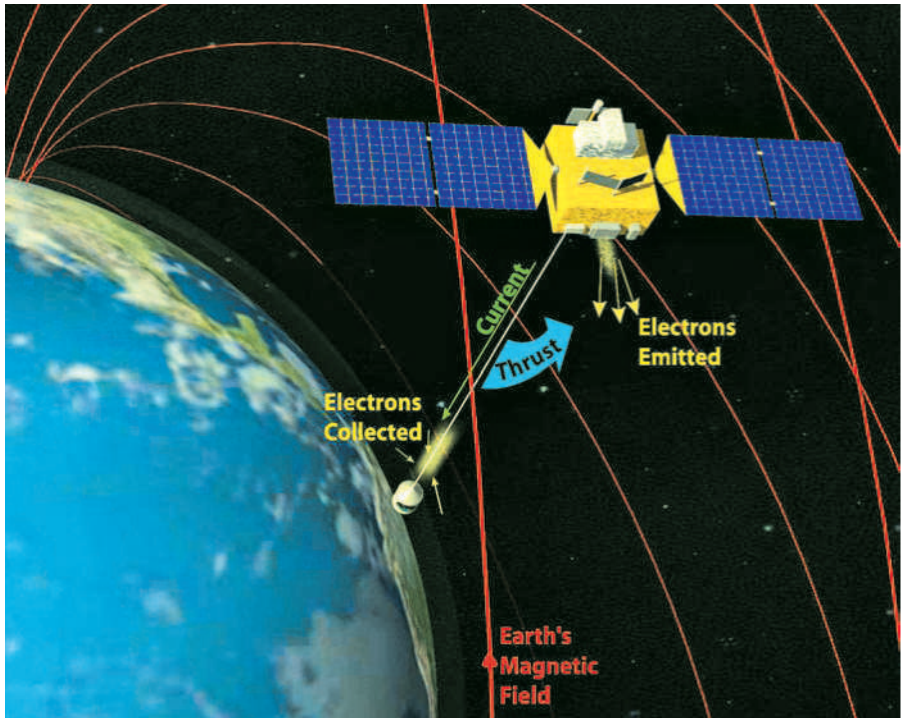


Illustration of how an electrodynamic tether can boost the orbit of a spacecraft.

electrons negatively charged subatomic particles

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

system included devices that emitted **electrons** or ions at both ends of the tether, enabling the tether system to make electrical contact with the **ionosphere**. This allowed the induced voltage to drive a current along the tether, demonstrating that an electrodynamic tether could generate power by converting the shuttle's orbital energy into electrical energy.

A flaw in the insulation allowed an arc to jump from the tether to the deployment boom. The arc burned through the tether, causing it to part and effectively ending the electrodynamic tether part of the experiment. The break, however, showed that tethers could be used to move spacecraft to higher orbits. When the TSS tether was severed, the Italian satellite at the end of the tether was tossed 140 kilometers (87 miles) above the shuttle.

Despite the difficulties encountered in the TSS experiments, enthusiasm for tether missions remains high, largely because of the many successes of the second series of NASA tether experiments, which were based on a much smaller and less expensive system called the Small Expendable-Tether Deployer System (SEDS). Four highly successful SEDS tether experiments have been carried out as piggyback missions on upper-stage vehicles launching larger satellites. The SEDS-1 mission used a tether to drop a payload back down to Earth. The experiment showed that a spool of string could perform the same job that a rocket does. This technique could be used to drop scientific payloads from the International Space Station down to Earth. The 1993 Plasma Motor Generator mission used a modified SEDS system to deploy a 500-meter (1,640-foot) conducting wire to study electrodynamic interactions with the ionosphere. The SEDS-2 mission deployed a 20-kilometer-long (12.4 miles) tether below an upper-stage rocket and left it hanging to see how long it would survive in space. After only four days a micrometeorite or piece of space debris cut the tether, which was only about 0.8 millimeters (0.0315 inches) in diameter. This experiment showed that in order for tethers to be useful for long-duration missions in space, they must be designed to withstand cuts by micrometeorites and space debris.

Future Uses of Tethers

One way to solve this problem was demonstrated by the Tethered Physics and Survivability experiment, which was conducted by the Naval Research Laboratory. That experiment used the SEDS system to deploy a tether constructed as a hollow braid that had ordinary knitting yarn stuffed in the middle to puff it out. Launched on June 20, 1996, the 4-kilometer-long (2.5 miles), 2.5-millimeter-diameter (0.098 inches) tether has been orbiting in space uncut for more than five years.

Another method of ensuring that tethers can survive impacts with space debris may be to fabricate them as long, spiderweb-like nets rather than as single-line cables. Tethers Unlimited is developing a flight experiment to demonstrate this and other technologies.

Tethers also may provide a cost-effective means for removing spacecraft and space trash from orbit. In late 2001 NASA planned to fly the ProSEDS experiment to demonstrate that a conducting tether can be used to lower the orbit of a spacecraft by dragging against Earth's magnetic field.

In the future, long rotating tethers may be used to toss payloads through space. Tethers Unlimited has developed a design for a Cislunar Tether Transport System that could repeatedly transport payloads to the Moon and back, and other researchers have developed designs for tether systems to take payloads to Mars and back. In addition, tethers may provide a way to lower the cost of boosting payloads into orbit. In one concept a small **hypersonic** airplane could be used to carry a payload halfway into orbit, where a rotating tether facility already in orbit could pick it up and toss it into orbit.

hypersonic capable of speeds over five times the speed of sound

Although a number of technical challenges have to be addressed before tethers can provide routine transport around and beyond Earth orbit, tethers have the potential to reduce the cost of space travel greatly and may play a key role in the development of space. SEE ALSO Accessing Space (volume 1). Getting to Space Cheaply (volume 1); Payloads (volume 3); Space Elevators (volume 4).

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Time Travel

In 1898 H. G. Wells wrote his most famous novel, *The Time Machine.* In this novel, a young Victorian invented a device that allowed him to travel into the future or the past. He travels 800,000 years into the future and finds a society very different from the one he was accustomed to, inhabited by

In *Back to the Future* (1985), Marty McFly inadvertently finds himself in the 1950s, his "modern" car an oddity in a rural field.

the Eloi and the Morlocks. The Eloi appear to live an idyllic life, but the time traveler discovers that there is a horrible price they must pay.

Writers such as Wells used fiction to comment on their own society. However, serious paradoxes raised by time travel have led many to contend that it is impossible. For example, what if a time traveler accidentally killed his own father, long before he was born? Isaac Newton thought of time as an arrow, traveling in a straight line at constant speed. But Albert Einstein theorized that time was much more variable. To Einstein, time could slow down and speed up in strong gravitational fields or when an object was traveling at high speed. The faster we travel through space, the slower we travel through time, at least to a stationary observer. Einstein's equations of **general relativity** allow several varieties of time travel. For example, in a rotating universe, moving against the direction of rotation would be moving backwards in time. Our expanding universe does not have this property.

general relativity a branch of science first described by Albert Einstein showing the relationship between gravity and acceleration

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

event horizon the imaginary spherical shell surrounding a black hole that marks the boundary where no light or any other information can escape

A more interesting time travel possibility is presented by rapidly rotating, massive **black holes**. Such a black hole does not have an **event horizon**, but appears to be a ring. Moving through the center of the ring might lead to a different place and time—a wormhole through space. Nevertheless, no physical process currently known by scientists can produce a black hole with enough rotational speed for this to happen. Even if it did occur, such an object might be unstable and it might collapse if anything did pass through its center.

Stephen Hawking once suggested that time travel must be impossible, because if it were possible, we should have had visitors from the future. Since we have never seen a tourist from the future, time travel must be impossible. However, others have suggested that this argument breaks down if tourists from the future are simply not interested in us, or that time travel might be possible but impractical because of the enormous amounts of energy required.

If time travel is possible after all, how do we deal with the paradoxes? One way is to postulate the existence of alternate realities. Quantum mechanics teaches us that a given system can exist in two different states, and we do not know which one until we examine the system. So, if we were to travel back in time and prevent, say, the assassination of U.S. President John F. Kennedy, we would have created a parallel universe. We would have changed the past for someone else, but not us. SEE ALSO Black Holes (volume 2); Einstein, Albert (volume 2); Kennedy, John F. (volume 3); Science Fiction (volume 4); Wormholes (volume 4).

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Traffic Control

In the early twenty-first century, there are approximately 5000 commercial and private airplanes in the air at any one moment. The task of the U.S. Air Traffic Control System is to ensure the safe operation of these commercial and private aircraft. Air traffic controllers coordinate the movements of these planes, keep them at safe distances from each other, direct them during take-off and landing from airports, reroute them around bad weather, and ensure that air traffic flows smoothly. Other nations around the world maintain and operate similar air traffic control systems.

As space travel becomes a more common activity, it may become essential to institute a similar traffic control system for spacecraft. However, a more urgent problem is presented by the number of individual objects that are in orbit around Earth. The Space Surveillance Network (SSN) is currently tracking around 7,000 artificial objects circling Earth. The risk of collision with an object in space increases rapidly as the number of objects increases. A bit of space debris as small as a paint chip can do severe damage if it collides with a satellite because the relative **velocity** between the two objects can be as high as 25,000 kilometers per hour. The National Aeronautics and Space Administration (NASA) has calculated that the probability of a collision between a space station–sized satellite and a piece of orbital debris is 46 percent over the lifetime of the spacecraft unless avoidance techniques are used.

velocity speed and direction of a moving object; a vector quantity

A space traffic control system would therefore have two separate missions. The current role of tracking and cataloging functioning and

In 1999, NASA's "Future Flight Central" opened at Ames Research Center. It is a full-scale virtual airport control tower designed to test ways to monitor potential traffic problems.

transponders bandwidth-specific transmitter-receiver units

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

nonfunctioning orbital objects currently performed by SSN would need to be transferred to the new space traffic control system. This mission would also include a system for predicting and warning satellite operators of potential collisions between different spacecraft or between spacecraft and debris.

The future role of the space traffic control system would also include the monitoring of all space traffic and determination of the best orbits for the insertion of new satellites into Earth orbit. Moreover, it would guide and monitor the greatly increased numbers of both cargo- and passenger-carrying space vehicles anticipated in future decades. Such a system would require full utilization of both current and advanced technology. New satellites and spacecraft would carry **transponders** similar to the devices carried by modern aircraft. These would transmit identifying information back to the space traffic control **radar** system. Older satellites without transponders and nonfunctioning space debris would be tracked by more sophisticated equipment.

In order for the new system to function efficiently, it must have complete access to all of the information currently maintained in the SSN and the North American Aerospace Defense Command databases. Of greater importance, however, will be making the program international. Currently, each nation provides its own air traffic control system and aircraft flying over international boundaries are "handed off" from one system to another as the aircraft crosses the boundary. While the United States has taken the lead in monitoring and tracking space debris and functioning satellites, other countries must fully participate in any space traffic control system. It must be a truly international effort, supported by firm treaties between the nations with launch capabilities. At present, the United States, the Russian Federation, the European Space Agency, China, and Japan are all capable of launching **payloads** into any Earth orbits. These countries must all cooperate in the design and implementation of a space traffic control system. SEE ALSO NAVIGATION (VOLUME 3); SPACE DEBRIS (VOLUME 2); TRACKING OF SPACECRAFT (VOLUME 3).

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TransHab

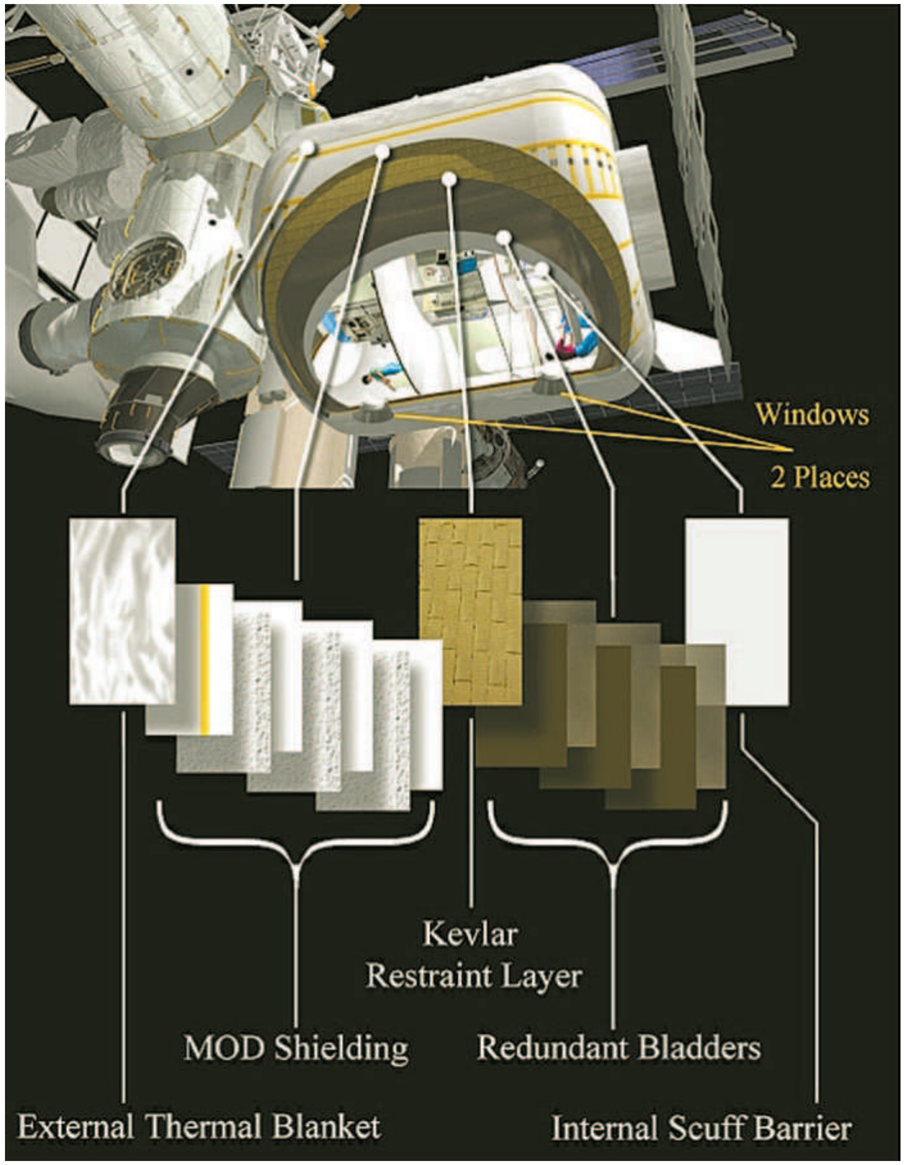
TransHab (short for "Transit Habitat") is the first space inflatable module designed by the National Aeronautics and Space Administration (NASA). It was conceived as a technology capable of supporting a crew of six on an extended space journey, such as a six-month trip to Mars. During its development in 1997–2001 at NASA's Johnson Space Center in Houston, Texas, TransHab was considered for use on International Space Station "Alpha" as a habitation module for two reasons: first, because of its superior ability to support crew needs, and second, to test it for possible use on a human mission to Mars.

History

TransHab was first conceived in 1997 by a team of engineers and architects at the Johnson Space Center. A space human factors group was asked to join the design team in developing the best size and layout for the spacecraft. Based in part on psychological, social, and operational lessons learned from earlier American and Russian missions, the team recommended a three-level internal layout with crew quarters isolated at the center; mechanical systems grouped together in a separate "room"; and exercise and hygiene situated on a different level from the public functions of kitchen, dining and conferencing. The total volume is over 342 cubic meters.

All spacecraft flown up until now have been of an exoskeletal type—that is, its hard outer shell acts both as a pressure container and as its main channel for structural loading. This includes the rest of Alpha, which is currently under construction in low Earth orbit at about 250 miles above the Earth.

By contrast, TransHab is the first endoskeletal space habitat, consisting of a dual system: a light, reconfigurable central structure and a deployable pressure shell. The shell is so resilient because it is made of several layers, TransHab represents a major breakthrough in that it solves the "problem" of inflatables and at the same time invents a whole new way of building for space and Earth.



each with its own specific purpose. Principal among these is the restraint layer, which is interwoven to distribute tremendous loads evenly and efficiently around its torus, much in the same way as the reeds in a round basket are woven to spread weight and give the basket strength. Each strap is made of Kevlar®, an aramid-fiber material, which has a very high strength-to-weight ratio and great impact resistance, and is often used today in the making of bulletproof vests. Woven together into the vehicle's main shell, these straps when inflated form a system that is capable of withstanding up to 4 atmospheres of pressure differential (over 54 psi) between interior and exterior.

Inside the restraint layer, multiple bladders of heavy, flexible plastic are mounted to hold in the air. Although only one bladder is necessary to do the job, the requirements for safety in spacecraft design are so high that TransHab's designers put in three bladder layers to protect the vehicle in case one of them failed. On the outside of the restraint layer, a shield of impact-resistant layers separated by open-cell foam is mounted to defend TransHab against the tiny meteor-like particles that are often encountered in space, traveling at velocities up to 7 kilometers per second. The outermost layer of the shell is made of a glass fiber cloth that resists abrasion by the charged particles in Earth's **ionosphere**.

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

Why Was TransHab Considered for the International Space Station?

TransHab is designed around human requirements, not just engineering solutions to the challenges of spaceflight. It is roomy and offers enough stowage space to take care of a crew for over six months, and it houses all the crew activities from sleeping to exercise. This reduces clutter and activity elsewhere on the International Space Station, enhancing the environment for the scientific experiments that are the station's primary purpose.

For the Human Exploration of Mars

TransHab could also play an important part of the human exploration of Mars or other bodies in the solar system. Without an inflatable module such as TransHab, the cost of getting a crew safely to a remote destination such as Mars could be much higher, and if the alternative is a constricted, conventional spacecraft, the crew would be much more likely to experience stress before the most challenging part of their mission begins on Mars. This makes TransHab a central part of NASA's Mars Design Reference Mission (DRM), as the crew habitat for the journey between planets. At the beginning of the DRM, TransHab is launched in a space shuttle bay, deflated, and packaged tight; once in orbit it can be unfolded, inflated, and deployed. At that time, elements that served structural functions during launch are reconfigured to serve as walls, partitions, and furnishings.

All of this is possible because it is specifically designed for use in a **microgravity** environment, so its pieces are lighter than other modules. Once ready to go, TransHab would be attached to the propulsion and guidance systems that take it and its crew on the six-month trip to the Red Planet. When they reach Mars, the crew would "park" TransHab in orbit and take a transfer ship to the surface, where their surface habitat is already in place and waiting for them. At the end of their 425-day scientific expedition on Mars, the crew would then launch back up to orbit and reboard TransHab for the journey home. SEE ALSO Habitats (Volume 3); Human Missions to Mars (Volume 3); International Space Station (Volumes 1 and 3); Long-Duration Spaceflight (Volume 3); Mars Missions (Volume 4); Human Factors (Volume 3).

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

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U

Utopia

"Utopia" is a term that English statesman and author Thomas More coined in the early sixteenth century in his novel of the same name. It is derived from two Greek words: *Eutopia* (meaning "good place") and *Outopia* (meaning "no place"). Utopia is therefore a good place that does not exist. A space utopia, one could claim, is a good place that can exist only in space.

The word "utopia" conjures up the vision of an ideal society, where people are physically and morally free, where they work not because of need but out of pleasure, where love knows no laws, and where everyone is an artist. A space utopia is the same paradise set elsewhere and served with a generous dose of science fiction.

Space utopias resonate mostly in the United States, because of its history as an immigrant nation with an open frontier; its tolerance for small, like-minded, isolated communities; its preference for the individual as opposed to the government; and its faith in technology to solve human problems.

A good example of space utopia is the human-made space habitat first described by Princeton University physicist Gerard K. O'Neill in his book *The High Frontier* (1977). Situated at L-5, an equilibrium point between Earth and the Moon, and made of lunar material, this hypothetical habitat is entirely controlled by its creators, including the gravity, terrain, landscape, and weather. Energy is obtained from the Sun, while air, water, and materials are constantly recycled. The few thousand inhabitants in these settlements lead happy and productive lives, dedicated to learning, service, production, commerce, science, and exploration. Their society combines control over the environment, the beauty of self-made nature, the shared plenty of a consumer economy, and the intimacy of village life. There is little crime and no racial, ethnic, religious, or economic strife. Government is democratic and limited, imposing few legal, fiscal, or moral restraints on its citizens, thereby enabling them to pursue their individual happiness.

The likelihood of the successful existence of space utopias is diminished as the inherent difficulties of utopias on Earth are compounded by the rigors of the space environment. Social and biological scientists, humanists, and theologians argue that a large-scale utopian society is against human nature, if for no other reason than it ignores the human drive for power. Social scientists argue that the demise of small-scale utopian communities is caused by their inability to sufficiently isolate themselves from the rest of society and to survive the transition to new group leadership. Faced with fading communities, American Mennonites emigrated to the jungles of Central America, and few cults in the United States have survived their charismatic leaders. While many utopian cults transformed into established religions and institutions with bureaucratic organization independent of their founders, there are examples of those that could not and, instead, have found violent death (People's Temple followers, led by the Reverend Jim Jones, in Guyana, 1978; Branch Davidians, led by David Koresh, in Texas, 1993; and Heaven's Gate followers, led by Marshall Applewhite, in California, 1997).

The harsh and unforgiving environment of space precludes the existence of human groups without strict authority structures, at least within our solar system. The International Space Station operates under a rigorous chain of command sanctioned by international law. Space utopian societies may have to wait for routine travel between solar systems and the availability of uninhabited Earthlike planets. SEE ALSO COMMUNITIES IN SPACE (VOLUME 4); O'NEILL, GERARD K. (VOLUME 4); O'NEILL COLONIES (VOLUME 4); SETTLEMENTS (VOLUME 4); SOCIAL ETHICS (VOLUME 4).

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Vehicles

Space vehicles encompass different categories of spacecraft, including **satellites**, **rockets**, space **capsules**, **space stations**, and colonies. In general, satellites are considered any object launched by a rocket for the purpose of orbiting Earth or another celestial body. A rocket, on the other hand, is a vehicle or device, especially designed to travel through space, propelled by one or more engines.

satellites any objects launched by a rocket for the purpose of orbiting the Earth or another celestial body

rockets vehicles (or devices) especially designed to travel through space, propelled by one or more engines

A Brief History of Space Vehicles

The Soviet Union launched the first successful satellite, Sputnik 1 in October 1957. America's first satellite, Explorer 1, followed Sputnik by three months, in January 1958. Soon after satellites orbited the Earth, space capsules were launched containing closed compartments designed to hold and

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

space stations large orbiting outposts equipped to support human crews and designed to remain in orbit around Earth for an extended period

protect humans and/or equipment. Less than three years after Sputnik 1, both the United States and Soviet Union put capsules into space with humans aboard. In 1961 cosmonaut Yuri Gagarin became the first person in space aboard a Vostok space capsule. A month later, American astronaut Alan Shepard in the Mercury capsule Freedom 7 made a 14.8-minute suborbital flight, becoming the first U.S. astronaut in space.

While the American space program focused first on the Apollo missions to the Moon and then turned to development of the space shuttle (the first reusable launch vehicle) and low Earth orbit operations, the Soviet Union established a series of space stations in Earth orbit. Space stations are large spacecraft equipped to support a crew and remain in orbit for an extended period of time to serve as a base for launching exploratory expeditions, conducting scientific research, repairing satellites, and performing other space-related activities. The Soviets' first space station, Salyut 1, was launched in 1971. Later, the Soviet Union and Russia orbited the Mir space station. America's first space station, and the only one that it deployed during the first four decades of human spaceflight, was the 100-ton Skylab launched in 1973. Today, the United States, Russia and other international partners are constructing the International Space Station, Alpha.

The Future of Space Vehicles

A major imperative for the future is to reduce the cost of getting to orbit. To this end significant funds have already been invested in technology development towards a single-stage-to-orbit reusable space vehicle to replace the shuttle. Problems with the X-33 scaled prototype led to a recognition that development of such a vehicle is still years away. The U.S. government has committed to a series of shuttle upgrades to keep the fleet flying and to improve safety and capability. A likely intermediate stage is development of a two-stage-to-orbit reusable vehicle, possibly building on shuttle components with fly-back boosters. (The shuttle discards its solid rocket boosters minutes after launch. The casings are reclaimed from the sea and towed back to land to be reused. A booster that could fly back to the space center runway on automatic pilot after fulfilling its role in boosting the spacecraft launch would be a significant advance.)

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

antimatter matter composed of antiparticles, such as positrons and antiprotons

libration points one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

Looking to the far horizon, space elevators, launch systems driven by a massive catapult system (the so-called slingatron), or sophisticated magnets, could revolutionize the way **payloads** are launched to space. New forms of nuclear propulsion, plasma propulsion, **antimatter** systems, vastly improved solar sail techniques, faster-than-light travel, or the exploitation of zero point energy for transportation through space could move humankind into a new space age that leaves traditional chemical propulsion behind.

The establishment of permanent space colonies has fascinated people for decades. Permanent settlements have been proposed for the Moon and Mars, as well as stable positions in space equidistant from both Earth and Moon called the Lagrangian **libration points**. Space visionaries advocated a space colony at L5 early in the space age. More recently NASA scientists have considered placing a space station at L2. In the future, space transportation vehicles serving humans and space habitats will become more spacious and more conducive to long journeys or permanent habitation.

Eventually, space settlers, like the immigrants who came to America, might consider their settlement "home" and become increasingly self-sufficient by growing their own food and using solar energy to generate electricity and manufacture goods. SEE ALSO CAPSULES (VOLUME 3); GETTING TO SPACE CHEAPLY (VOLUME 1); LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); LUNAR BASES (VOLUME 4); MARS BASES (VOLUME 4); REUSABLE LAUNCH VEHICLES (VOLUME 4); SATELLITES, TYPES OF (VOLUME 4); SETTLEMENTS (VOLUME 4); SPACE ELEVATORS (VOLUME 4); SPACE SHUTTLE (VOLUME 3); SPACE STATIONS OF THE FUTURE (VOLUME 4).

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Wormholes

W

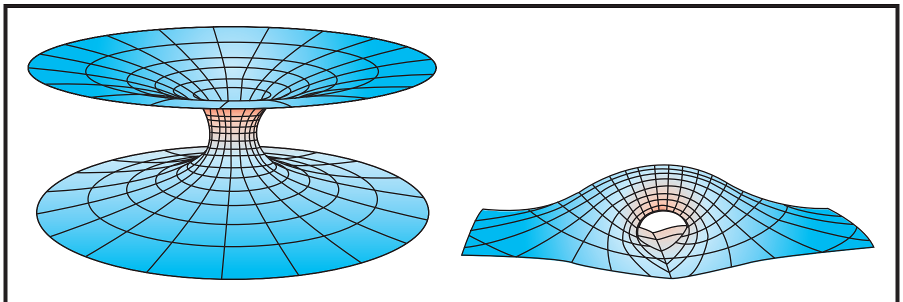
Space-time wormholes are hypothetical objects in German-born Jewish physicist Albert Einstein's general theory of relativity, where intense gravitational fields warp space and time to provide shortcuts from one part of our universe to another (or worse, perhaps, a route from our universe to some other universe). Physicists have not found solid experimental evidence that wormholes exist, but there are reasonably convincing theoretical arguments that strongly suggest that wormholes should be part of the theory of **quantum gravity**.

quantum gravity an attempt to replace the inherently incompatible theories of quantum physics and Einstein gravity with some deeper theory that would have features of both, but be identical to neither

As theoretical objects, wormholes were invented and named in the late 1950s by American physicist John Archibald Wheeler, an early pioneer in the quest for quantum gravity. Since then they have become a standard tool in science fiction (such as in the television series *Star Trek* and *Farscape* and the novel *Einstein's Bridge*), but they have also attracted a lot of serious scientific attention. Although physicists cannot conduct any experiments yet, wormholes can be used in "thought experiments" to see how solid and reliable certain theories are.

Science fiction stories make wormhole travel look relatively straightforward, if not exactly easy. The physicists' conception is more conservative and less encouraging: Naturally occurring wormholes, if they exist at all, are likely to be extremely small, about 10 septillion (10^{25}) times smaller than a typical atom. They are expected to be part of a quantum-mechanical "space-time foam" that is expected to arise at extremely short distances. Wormholes of this size are not useful for human travel, or even for sending signals.

Wormholes theoretically provide passageways between two points in our own universe, or between universes.



Creating a large wormhole, or artificially enlarging a small naturally occurring wormhole, would require the manipulation of large quantities of matter—planet loads of mass. A wormhole 1 meter (about 1 yard) across would require the manipulation of objects with the mass of the planet Jupiter and the squeezing of them into a region about a meter wide. Worse, because the gravitational field of a wormhole is in some sense repulsive (one would not want a **black hole** to form), one would need to manipulate large quantities of what is called "exotic matter," which is basically negative energy matter with less energy than the energy of an equal volume of **vacuum**.

black hole object so massive for its size that its gravitational pull prevents everything, even light, from escaping

vacuum a space where air and all other molecules and atoms of matter have been removed

Needless to say, we do not currently have the technology needed to do this, nor is there any realistic hope of acquiring such technology in the foreseeable future. We cannot even manipulate positive masses the size of Jupiter, nor have we ever found large quantities of negative mass lying around anywhere. So realistically, the prospects for space travel using wormholes is close to zero. This will not stop physicists from investigating the subject, but one should try to not be overly enthusiastic about the chances.

Because wormholes connect distant places, and the laws of **space-time** physics seem to treat space and time on an almost equal footing, it has also been suggested that wormholes should be able connect distant times: If you find a wormhole, it would seem at first glance to be relatively easy to turn it into a time machine. Now this does scare the physics community; allowing time travel into physics is, to say the least, awkward. There is an idea called "chronology protection," formulated by English physicist Stephen Hawking, to the effect that **quantum physics** may "keep the universe safe for historians" by automatically destroying any wormhole that gets too close to forming a time machine. As Hawking put it: "there is considerable evidence in favour of [chronology protection] based on the fact that we have not been invaded by hordes of tourists from the future." SEE ALSO Cosmology (Volume 2); Einstein, Albert (Volume 2); Zero-Point Energy (Volume 4).

space-time in relativity, the four-dimensional space through which objects move and in which events happen

quantum physics branch of physics that uses quantum mechanics to explain physical systems

Matt Visser

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Zero-Point Energy

Z

Quantum physics predicts the existence of an underlying sea of zero-point energy at every spot in the universe. This is different from the **cosmic microwave background** and is also referred to as the electromagnetic **quantum vacuum**, since it is the lowest energy state of otherwise empty space. This energy is so enormous that most physicists believe that even though zero-point energy seems to be an inescapable consequence of elementary quantum theory, it cannot be physically real. However, a minority of physicists accept it as real energy that we cannot directly sense because it is the same everywhere, even inside our bodies and measuring devices. From this perspective, the ordinary world of matter and energy is like a foam atop the quantum vacuum sea. It does not matter to a ship how deep the ocean is below it. If zero-point energy is real, there is the possibility that it can be tapped as a source of energy or be harnessed to generate a propulsive force for space travel.

quantum physics branch of physics that uses quantum mechanics to explain physical systems

cosmic microwave background ubiquitous, diffuse, uniform, thermal radiation created during the earliest hot phases of the universe

quantum vacuum consistent with the Heisenberg uncertainty principle, vacuum is not empty but is filled with zero-point energy and particle-antiparticle pairs constantly being created and then mutually annhilating each other

New Propulsion for Space Travel

The propeller or the jet engine of an aircraft pushes air backwards to propel the aircraft forward. A ship or boat propeller does the same thing with water. On Earth there is always air or water available to push against. But a rocket in space has nothing to push against, and so it needs to carry propellant to eject in place of air or water. As the propellant shoots out the back, the rocket reacts by moving forward. The fundamental problem is that a deep-space rocket would have to start out with all the propellant it would ever need. This quickly results in the need to carry more and more propellant just to propel the propellant. The breakthrough needed for deep-space travel is to overcome the need to carry propellant at all. How can one generate a propulsive force without carrying and ejecting propellant?

One possibility may involve a type of Casimir force. The Casimir force is an attraction between parallel metallic plates that has now been well measured. It can be attributed to a minutely tiny imbalance in the zero-point energy between the plates and the zero-point energy outside the plates. This is not currently useful for propulsion since it just pulls the plates together. If, however, some asymmetric variation of the Casimir force could be found, one could use it to sail through space as if propelled by a kind of quantum fluctuation wind. This is pure speculation at present.

The other requirement for space travel is energy. A thought experiment published by physicist Robert Forward in 1984 demonstrated how the Casimir force could in principle be used to extract energy from the quantum vacuum. Theoretical studies in the early 1990s verified that this was not contradictory to the laws of thermodynamics (because the zero-point energy is different from a thermal reservoir of heat). Unfortunately, the Forward process cannot be cycled to yield a continuous extraction of energy. A

Casimir engine would be one whose cylinders could fire only once, after which the engine becomes useless.

The Heisenberg Uncertainty Principle

The basis of zero-point energy is the Heisenberg uncertainty principle, one of the fundamental laws of quantum physics. According to this principle, the more precisely one measures the position of a moving particle, such as an electron, the less exact the best possible measurement of its momentum (mass times velocity) will be, and vice versa. The least possible uncertainty of position times momentum is specified by Planck's constant, h. A parallel uncertainty exists between measurements involving time and energy. This minimum uncertainty is not due to any correctable flaws in measurement but rather reflects an intrinsic quantum fuzziness in the very nature of energy and matter.

A useful calculational tool in physics is the ideal harmonic oscillator: a hypothetical mass on a perfect spring moving back and forth. The Heisenberg uncertainty principle dictates that such an ideal harmonic oscillator—one small enough to be subject to quantum laws—can never come entirely to rest, because that would be a state of exactly zero energy, which is forbidden. In this case the average minimum energy is one-half h times the frequency, hf/2.

The Origin of Zero-Point Energy

X rays high-energy radiation just beyond the ultraviolet portion of the spectrum

polarization state degree to which a beam of electromagnetic radiation has all of the vibrations in the same plane or direction

quantum foam notion that there is a smallest distance scale at which space itself is not a continuous medium, but breaks up into a seething foam of wormholes and tiny black holes far smaller than a proton

The zero-point energy is electromagnetic in nature and is like ordinary radio waves, light, **X rays**, gamma rays, and so forth. Classically, electromagnetic radiation can be pictured as waves flowing through space at the speed of light. The waves are not waves of anything substantive but are ripples in a state of a theoretically defined field. However, these waves do carry energy, and each wave has a specific direction, frequency, and **polarization state**. This is called a "propagating mode of the electromagnetic field."

Each mode is subject to the Heisenberg uncertainty principle. This means that each mode is equivalent to a harmonic oscillator. From this analogy, every mode of the field must have hf/2 as its average minimum energy. This is a tiny amount of energy, but the number of modes is enormous and indeed increases as the square of the frequency. The product of the tiny energy per mode times the huge spatial density of modes yields a very high theoretical zero-point energy density per cubic centimeter.

From this line of reasoning, quantum physics predicts that all of space must be filled with electromagnetic zero-point fluctuations (also called the zero-point field), creating a universal sea of zero-point energy. The density of this energy depends critically on where in frequency the zero-point fluctuations cease. Since space itself is thought to break up into a kind of **quantum foam** at a tiny distance scale called the Planck scale (10^{-33} centimeters), it is argued that the zero-point fluctuations must cease at a corresponding Planck frequency (10^{43} hertz). If this is the case, the zero-point energy density would be 110 orders of magnitude greater than the radiant energy at the center of the Sun.

Inertia, Gravitation, and Zero-Point Energy

Theoretical work from the 1990s suggests a tantalizing connection between inertia and zero-point energy. When a passenger in an airplane feels pushed against his seat as the airplane accelerates down the runway, or when a driver feels pushed to the left when her car makes a sharp turn to the right, what is doing the pushing? Since the time of English physicist and mathematician Isaac Newton (1642–1727), this pushing feeling has been attributed to an innate property of matter called inertia. In 1994 a process was discovered whereby the zero-point fluctuations could be the source of the push one feels when changing speed or direction, both being forms of acceleration. The zero-point fluctuations could be the underlying cause of inertia. If that is the case, then people are actually sensing the zero-point energy with every move they make. The zero-point energy would be the origin of inertia, hence the cause of mass.

The principle of equivalence would require an analogous connection for gravitation. German-born American physicist Albert Einstein's general theory of relativity successfully accounts for the motions of freely falling objects on geodesics (the shortest distance between two points in curved **space-time**), but it does not provide a mechanism for generating a reaction force for objects when they are forced to deviate from geodesic tracks. A theoretical study sponsored by the National Aeronautics and Space Administration has demonstrated that an object undergoing acceleration or one held fixed in a gravitational field would both experience the same kind of asymmetric pattern in the zero-point radiation field, the asymmetry yielding the inertia reaction force or weight, respectively. The weight one measures on a scale would be due to zero-point energy.

space-time in relativity, the four-dimensional space through which objects move and in which events happen

The possibility that electromagnetic zero-point energy may be involved in the production of inertial and gravitational forces opens the possibility that both inertia and gravitation might someday be controlled and manipulated. Imagine being accelerated from zero to light speed in a fraction of a second without experiencing any devastating **G forces**. Such a science fiction–like possibility could someday become real and have a profound impact on propulsion and space travel. SEE ALSO Accessing Space (volume 1); Power, Methods of Generating (volume 4).

G force the force an astronaut or pilot experiences when undergoing large accelerations

Bernard Haisch

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Zubrin, Robert

American Aerospace Engineer
1952–

Robert Maynard Zubrin is an aerospace engineer credited for revolutionizing plans for the human exploration of Mars. After an early career as a teacher, Zubrin went to graduate school in the mid-1980s, earning a doctorate in nuclear engineering from the University of Washington.

As an engineer for the aerospace firm Martin Marietta (now Lockheed Martin) starting in the late 1980s, Zubrin worked on projects ranging from a nuclear rocket engine to a spaceplane. His best-known work at the company, however, was the development of "Mars Direct," a new architecture for human missions to Mars that would rely on the resources available on Mars to reduce their cost. Mars Direct attracted the attention of the National Aeronautics and Space Administration, which incorporated aspects of the proposal into its Mars mission plans.

Zubrin also coauthored a popular book about Mars Direct, *The Case for Mars* (1996). Zubrin used the success of the book as a springboard in 1998 for creating the Mars Society, a membership organization that promotes the human exploration of Mars. Zubrin serves as president of the society, which has supported a number of research projects designed to further technology needed for future Mars missions. Zubrin also founded Pioneer Astronautics, a small aerospace firm in Colorado he created after leaving Lockheed Martin in 1996. SEE ALSO Human Missions to Mars (volume 3); Mars (volume 2); Mars Bases (volume 4); Mars Direct (volume 4).

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Glossary

ablation removal of the outer layers of an object by erosion, melting, or vaporization

abort-to-orbit emergency procedure planned for the space shuttle and other spacecraft if the spacecraft reaches a lower than planned orbit

accretion the growth of a star or planet through the accumulation of material from a companion star or the surrounding interstellar matter

adaptive optics the use of computers to adjust the shape of a telescope's optical system to compensate for gravity or temperature variations

aeroballistic describes the combined aerodynamics and ballistics of an object, such as a spacecraft, in flight

aerobraking the technique of using a planet's atmosphere to slow down an incoming spacecraft; its use requires the spacecraft to have a heat shield, because the friction that slows the craft is turned into intense heat

aerodynamic heating heating of the exterior skin of a spacecraft, aircraft, or other object moving at high speed through the atmosphere

Agena a multipurpose rocket designed to perform ascent, precision orbit injection, and missions from low Earth orbit to interplanetary space; also served as a docking target for the Gemini spacecraft

algae simple photosynthetic organisms, often aquatic

alpha proton X-ray analytical instrument that bombards a sample with alpha particles (consisting of two protons and two neutrons); the X rays are generated through the interaction of the alpha particles and the sample

altimeter an instrument designed to measure altitude above sea level

amplitude the height of a wave or other oscillation; the range or extent of a process or phenomenon

angular momentum the angular equivalent of linear momentum; the product of angular velocity and moment of inertia (moment of inertia $=$ mass $\times$ radius^2)

angular velocity the rotational speed of an object, usually measured in radians per second

anisotropy a quantity that is different when measured in different directions or along different axes

annular ring-like

anomalies phenomena that are different from what is expected

anorthosite a light-colored rock composed mainly of the mineral feldspar (an aluminum silicate); commonly occurs in the crusts of Earth and the Moon

anthropocentrism valuing humans above all else

antimatter matter composed of antiparticles, such as positrons and antiprotons

antipodal at the opposite pole; two points on a planet that are diametrically opposite

aperture an opening, door, or hatch

aphelion the point in an object's orbit that is farthest from the Sun

Apollo American program to land men on the Moon; Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

asthenosphere the weaker portion of a planet's interior just below the rocky crust

astrometry the measurement of the positions of stars on the sky

astronomical unit the average distance between Earth and the Sun (152 million kilometers [93 million miles])

atmospheric probe a separate piece of a spacecraft that is launched from it and separately enters the atmosphere of a planet on a one-way trip, making measurements until it hits a surface, burns up, or otherwise ends its mission

atmospheric refraction the bending of sunlight or other light caused by the varying optical density of the atmosphere

atomic nucleus the protons and neutrons that make up the core of an atom

atrophy condition that involves withering, shrinking, or wasting away

auroras atmospheric phenomena consisting of glowing bands or sheets of light in the sky caused by high-speed charged particles striking atoms in Earth's upper atmosphere

avionics electronic equipment designed for use on aircraft, spacecraft, and missiles

azimuth horizontal angular distance from true north measured clockwise from true north (e.g., if North = 0 degrees; East = 90 degrees; South = 180 degrees; West = 270 degrees)

ballast heavy substance used to increase the stability of a vehicle

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

basalt a dark, volcanic rock with abundant iron and magnesium and relatively low silica common on all of the terrestrial planets

base load the minimum amount of energy needed for a power grid

beacon signal generator a radio transmitter emitting signals for guidance or for showing location

berth space the human accommodations needed by a space station, cargo ship, or other vessel

Big Bang name given by astronomers to the event marking the beginning of the universe when all matter and energy came into being

biocentric notion that all living organisms have intrinsic value

biogenic resulting from the actions of living organisms; or, necessary for life

bioregenerative referring to a life support system in which biological processes are used; physiochemical and/or nonregenerative processes may also be used

biosignatures the unique traces left in the geological record by living organisms

biosphere the interaction of living organisms on a global scale

bipolar outflow jets of material (gas and dust) flowing away from a central object (e.g., a protostar) in opposite directions

bitumen a thick, almost solid form of hydrocarbons, often mixed with other minerals

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

bone mineral density the mass of minerals, mostly calcium, in a given volume of bone

breccia mixed rock composed of fragments of different rock types; formed by the shock and heat of meteorite impacts

bright rays lines of lighter material visible on the surface of a body and caused by relatively recent impacts

brown dwarf star-like object less massive than 0.08 times the mass of the Sun, which cannot undergo thermonuclear process to generate its own luminosity

calderas the bowl-shaped crater at the top of a volcano caused by the collapse of the central part of the volcano

Callisto one of the four large moons of Jupiter; named for one of the Greek nymphs

Caloris basin the largest (1,300 kilometers [806 miles] in diameter) well-preserved impact basin on Mercury viewed by Mariner 10

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

carbon-fiber composites combinations of carbon fibers with other materials such as resins or ceramics; carbon fiber composites are strong and lightweight

carbonaceous meteorites the rarest kind of meteorites, they contain a high percentage of carbon and carbon-rich compounds

carbonate a class of minerals, such as chalk and limestone, formed by carbon dioxide reacting in water

cartographic relating to the making of maps

Cassini mission a robotic spacecraft mission to the planet Saturn scheduled to arrive in July 2004 when the Huygens probe will be dropped into Titan's atmosphere while the Cassini spacecraft studies the planet

catalyst a chemical compound that accelerates a chemical reaction without itself being used up; any process that acts to accelerate change in a system

catalyze to change by the use of a catalyst

cell culture a means of growing mammalian (including human) cells in the research laboratory under defined experimental conditions

cellular array the three-dimensional placement of cells within a tissue

centrifugal directed away from the center through spinning

centrifuge a device that uses centrifugal force caused by spinning to simulate gravity

Cepheid variables a class of variable stars whose luminosity is related to their period. Their periods can range from a few hours to about 100 days and the longer the period, the brighter the star

Čerenkov light light emitted by a charged particle moving through a medium, such as air or water, at a velocity greater than the phase velocity of light in that medium; usually a faint, eerie, bluish, optical glow

chassis frame on which a vehicle is constructed

chondrite meteorites a type of meteorite that contains spherical clumps of loosely consolidated minerals

cinder field an area dominated by volcanic rock, especially the cinders ejected from explosive volcanoes

circadian rhythm activities and bodily functions that recur every twenty-four hours, such as sleeping and eating

Clarke orbit geostationary orbit; named after science fiction writer Arthur C. Clarke, who first realized the usefulness of this type of orbit for communication and weather satellites

coagulate to cause to come together into a coherent mass

comet matrix material the substances that form the nucleus of a comet; dust grains embedded in frozen methane, ammonia, carbon dioxide, and water

cometary outgassing vaporization of the frozen gases that form a comet nucleus as the comet approaches the Sun and warms

communications infrastructure the physical structures that support a network of telephone, Internet, mobile phones, and other communication systems

convection the movement of heated fluid caused by a variation in density; hot fluid rises while cool fluid sinks

convection currents mechanism by which thermal energy moves because its density differs from that of surrounding material. Convection current is the movement pattern of thermal energy transferring within a medium

convective processes processes that are driven by the movement of heated fluids resulting from a variation in density

coronal holes large, dark holes seen when the Sun is viewed in X-ray or ultraviolet wavelengths; solar wind emanates from the coronal holes

coronal mass ejections large quantities of solar plasma and magnetic field launched from the Sun into space

cosmic microwave background ubiquitous, diffuse, uniform, thermal radiation created during the earliest hot phases of the universe

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

cosmocentric ethic an ethical position that establishes the universe as the priority in a value system or appeals to something characteristic of the universe that provides justification of value

cover glass a sheet of glass used to cover the solid state device in a solar cell

crash-landers or hard-lander; a spacecraft that collides with the planet, making no—or little—attempt to slow down; after collision, the spacecraft ceases to function because of the (intentional) catastrophic failure

crawler transporter large, tracked vehicles used to move the assembled Apollo/Saturn from the VAB to the launch pad

cryogenic related to extremely low temperatures; the temperature of liquid nitrogen or lower

cryptocometary another name for carbonaceous asteroids—asteroids that contain a high percentage of carbon compounds mixed with frozen gases

cryptoendolithic microbial microbial ecosystems that live inside sandstone in extreme environments such as Antarctica

crystal lattice the arrangement of atoms inside a crystal

crystallography the study of the internal structure of crystals

dark matter matter that interacts with ordinary matter by gravity but does not emit electromagnetic radiation; its composition is unknown

density-separation jigs a form of gravity separation of materials with different densities that uses a pulsating fluid

desiccation the process of drying up

detruents microorganisms that act as decomposers in a controlled environmental life support system

diffuse spread out; not concentrated

DNA deoxyribonucleic acid; the molecule used by all living things on Earth to transmit genetic information

docking system mechanical and electronic devices that work jointly to bring together and physically link two spacecraft in space

doped semiconductor such as silicon with an addition of small amounts of an impurity such as phosphorous to generate more charge carriers (such as electrons)

dormant comet a comet whose volatile gases have all been vaporized, leaving behind only the heavy materials

downlink the radio dish and receiver through which a satellite or spacecraft transmits information back to Earth

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

dunites rock type composed almost entirely of the mineral olivine, crystallized from magma beneath the Moon's surface

dynamic isotope power the decay of isotopes such as plutonium-238, and polonium-210 produces heat, which can be transformed into electricity by radioisotopic thermoelectric generators

Earth-Moon LaGrange five points in space relative to Earth and the Moon where the gravitational forces on an object balance; two points, 60 degrees from the Moon in orbit, are candidate points for a permanent space settlement due to their gravitational stability

eccentric the term that describes how oval the orbit of a planet is

ecliptic the plane of Earth's orbit

EH condrites a rare form of meteorite containing a high concentration of the mineral enstatite (a type of pyroxene) and over 30 percent iron

ejecta the pieces of material thrown off by a star when it explodes; or, material thrown out of an impact crater during its formation

ejector ramjet engine design that uses a small rocket mounted in front of the ramjet to provide a flow of heated air, allowing the ramjet to provide thrust when stationary

electrodynamic pertaining to the interaction of moving electric charges with magnetic and electric fields

electrolytes a substance that when dissolved in water creates an electrically conducting solution

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

electron a negatively charged subatomic particle

electron volts units of energy equal to the energy gained by an electron when it passes through a potential difference of 1 volt in a vacuum

electrostatic separation separation of substances by the use of electrically charged plates

elliptical having an oval shape

encapsulation enclosing within a capsule

endocrine system in the body that creates and secretes substances called hormones into the blood

equatorial orbit an orbit parallel to a body's geographic equator

equilibruim point the point where forces are in balance

Europa one of the large satellites of Jupiter

eV an electron volt is the energy gained by an electron when moved across a potential of one volt. Ordinary molecules, such as air, have an energy of about $3x10^{-2}$ eV

event horizon the imaginary spherical shell surrounding a black hole that marks the boundary where no light or any other information can escape

excavation a hole formed by mining or digging

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

extrasolar planets planets orbiting stars other than the Sun

extravehicular activity a space walk conducted outside a spacecraft cabin, with the crew member protected from the environment by a pressurized space suit

extremophiles microorganisms that can survive in extreme environments such as high salinity or near boiling water

extruded forced through an opening

failsafe a system designed to be failure resistant through robust construction and redundant functions

fairing a structure designed to provide low aerodynamic drag for an aircraft or spacecraft in flight

fault a fracture in rock in the upper crust of a planet along which there has been movement

feedstock the raw materials introduced into an industrial process from which a finished product is made

feldspathic rock containing a high proportion of the mineral feldspar

fiber-optic cable a thin strand of ultrapure glass that carries information in the form of light, with the light turned on and off rapidly to represent the information sent

fission act of splitting a heavy atomic nucleus into two lighter ones, releasing tremendous energy

flares intense, sudden releases of energy

flybys flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

fracture any break in rock, from small "joints" that divide rocks into planar blocks (such as that seen in road cuts) to vast breaks in the crusts of unspecified movement

freefall the motion of a body acted on by no forces other than gravity, usually in orbit around Earth or another celestial body

free radical a molecule with a high degree of chemical reactivity due to the presence of an unpaired electron

frequencies the number of oscillations or vibrations per second of an electromagnetic wave or any wave

fuel cells cells that react a fuel (such as hydrogen) and an oxidizer (such as oxygen) together; the chemical energy of the initial reactants is released by the fuel cell in the form of electricity

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

fusion fuel fuel suitable for use in a nuclear fusion reactor

G force the force an astronaut or pilot experiences when undergoing large accelerations

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

Galilean satellite one of the four large moons of Jupiter first discovered by Galileo

Galileo mission succesful robot exploration of the outer solar system; this mission used gravity assists from Venus and Earth to reach Jupiter, where it dropped a probe into the atmosphere and studied the planet for nearly seven years

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

Ganymede one of the four large moons of Jupiter; the largest moon in the solar system

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

general relativity a branch of science first described by Albert Einstein showing the relationship between gravity and acceleration

geocentric a model that places Earth at the center of the universe

geodetic survey determination of the exact position of points on Earth's surface and measurement of the size and shape of Earth and of Earth's gravitational and magnetic fields

geomagnetic field Earth's magnetic field; under the influence of solar wind, the magnetic field is compressed in the Sunward direction and stretched out in the downwind direction, creating the magnetosphere, a complex, teardrop-shaped cavity around Earth

geospatial relating to measurement of Earth's surface as well as positions on its surface

geostationary remaining above a fixed point above Earth's equator

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

gimbal motors motors that direct the nozzle of a rocket engine to provide steering

global change a change, such as average ocean temperature, affecting the entire planet

global positioning systems a system of satellites and receivers that provide direct determination of the geographical location of the receiver

globular clusters roughly spherical collections of hundreds of thousands of old stars found in galactic haloes

grand unified theory (GUT) states that, at a high enough energy level (about 10^{25} eV), the electromagnetic force, strong force, and weak force all merge into a single force

gravitational assist the technique of flying by a planet to use its energy to "catapult" a spacecraft on its way—this saves fuel and thus mass and cost of a mission; gravitational assists typically make the total mission duration longer, but they also make things possible that otherwise would not be possible

gravitational contraction the collapse of a cloud of gas and dust due to the mutual gravitational attraction of the parts of the cloud; a possible source of excess heat radiated by some Jovian planets

gravitational lenses two or more images of a distant object formed by the bending of light around an intervening massive object

gravity assist using the gravity of a planet during a close encounter to add energy to the motion of a spacecraft

gravity gradient the difference in the acceleration of gravity at different points on Earth and at different distances from Earth

gravity waves waves that propagate through space and are caused by the movement of large massive bodies, such as black holes and exploding stars

greenhouse effect process by which short wavelength energy (e.g., visible light) penetrates an object's atmosphere and is absorbed by the surface, which reradiates this energy as longer wavelength infrared (thermal) energy; this energy is blocked from escaping to space by molecules (e.g., H_2O and CO_2) in the atmosphere; and as a result, the surface warms

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

hard-lander spacecraft that collides with the planet or satellite, making no attempt to slow its descent; also called crash-landers

heliosphere the volume of space extending outward from the Sun that is dominated by solar wind; it ends where the solar wind transitions into the interstellar medium, somewhere between 40 and 100 astronomical units from the Sun

helium-3 a stable isotope of helium whose nucleus contains two protons and one neutron

hertz unit of frequency equal to one cycle per second

high-power klystron tubes a type of electron tube used to generate high frequency electromagnetic waves

hilly and lineated terrain the broken-up surface of Mercury at the antipode of the Caloris impact basin

hydrazine a dangerous and corrosive compound of nitrogen and hydrogen commonly used in high powered rockets and jet engines

hydroponics growing plants using water and nutrients in solution instead of soil as the root medium

hydrothermal relating to high temperature water

hyperbaric chamber compartment where air pressure can be carefully controlled; used to gradually acclimate divers, astronauts, and others to changes in pressure and air composition

hypergolic fuels and oxidizers that ignite on contact with each other and need no ignition source

hypersonic capable of speeds over five times the speed of sound

hyperspectral imaging technique in remote sensing that uses at least sixteen contiguous bands of high spectral resolution over a region of the electromagnetic spectrum; used in NASA spacecraft Lewis' payload

ilmenite an important ore of titanium

Imbrium Basin impact largest and latest of the giant impact events that formed the mare-filled basins on the lunar near side

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

impact winter the period following a large asteroidal or cometary impact when the Sun is dimmed by stratospheric dust and the climate becomes cold worldwide

impact-melt molten material produced by the shock and heat transfer from an impacting asteroid or meteorite

in situ in the natural or original location

incandescence glowing due to high temperature

indurated rocks rocks that have been hardened by natural processes

information age the era of our time when many businesses and persons are involved in creating, transmitting, sharing, using, and selling information, particularly through the use of computers

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

infrared radiation radiation whose wavelength is slightly longer than the wavelength of light

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

intercrater plains the oldest plains on Mercury that occur in the highlands and that formed during the period of heavy meteoroid bombardment

interferometers devices that use two or more telescopes to observe the same object at the same time in the same wavelength to increase angular resolution

interplanetary trajectories the solar orbits followed by spacecraft moving from one planet in the solar system to another

interstellar between the stars

interstellar medium the gas and dust found in the space between the stars

ion propulsion a propulsion system that uses charged particles accelerated by electric fields to provide thrust

ionization removing one or more electrons from an atom or molecule

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

isotopic ratios the naturally occurring ratios between different isotopes of an element

jettison to eject, throw overboard, or get rid of

Jovian relating to the planet Jupiter

Kevlar® a tough aramid fiber resistant to penetration

kinetic energy the energy an object has due to its motion

KREEP acronym for material rich in potassium (K), rare earth elements (REE), and phosphorus (P)

L-4 the gravitationally stable Lagrange point 60 degrees ahead of the orbiting planet

L-5 the gravitationally stable Lagrange point 60 degrees behind the orbiting planet

Lagrangian point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

laser-pulsing firing periodic pulses from a powerful laser at a surface and measuring the length of time for return in order to determine topography

libration point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

lichen fungus that grows symbiotically with algae

light year the distance that light in a vacuum would travel in one year, or about 9.5 trillion kilometers (5.9 trillion miles)

lithosphere the rocky outer crust of a body

littoral the region along a coast or beach between high and low tides

lobate scarps a long sinuous cliff

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

lunar maria the large, dark, lava-filled impact basins on the Moon thought by early astronomers to resemble seas

Lunar Orbiter a series of five unmanned missions in 1966 and 1967 that photographed much of the Moon at medium to high resolution from orbit

macromolecules large molecules such as proteins or DNA containing thousands or millions of individual atoms

magnetohydrodynamic waves a low frequency oscillation in a plasma in the presence of a magnetic field

magnetometer an instrument used to measure the strength and direction of a magnetic field

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

majority carriers the more abundant charge carriers in semiconductors; the less abundant are called minority carriers; for n-type semiconductors, electrons are the majority carriers

malady a disorder or disease of the body

many-bodied problem in celestial mechanics, the problem of finding solutions to the equations for more than two orbiting bodies

mare dark-colored plains of solidified lava that mainly fill the large impact basins and other low-lying regions on the Moon

Mercury the first American piloted spacecraft, which carried a single astronaut into space; six Mercury missions took place between 1961 and 1963

mesons any of a family of subatomic particle that have masses between electrons and protons and that respond to the strong nuclear force; produced in the upper atmosphere by cosmic rays

meteor the physical manifestation of a meteoroid interacting with Earth's atmosphere; this includes visible light and radio frequency generation, and an ionized trail from which radar signals can be reflected. Also called a "shooting star"

meteorites any part of a meteoroid that survives passage through Earth's atmosphere

meteoroid a piece of interplanetary material smaller than an asteroid or comet

meteorology the study of atmospheric phenomena or weather

meteorology satellites satellites designed to take measurements of the atmosphere for determining weather and climate change

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

micrometeoroid flux the total mass of micrometeoroids falling into an atmosphere or on a surface per unit of time

micrometeoroid any meteoroid ranging in size from a speck of dust to a pebble

microwave link a connection between two radio towers that each transmit and receive microwave (radio) signals as a method of carrying information (similar to radio communications)

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

missing matter the mass of the universe that cannot be accounted for but is necessary to produce a universe whose overall curvature is "flat"

monolithic massive, solid, and uniform; an asteroid that is formed of one kind of material fused or melted into a single mass

multi-bandgap photovoltaic photovoltaic cells designed to respond to several different wavelengths of electromagnetic radiation

multispectral referring to several different parts of the electromagnetic spectrum, such as visible, infrared, and radar

muons the decay product of the mesons produced by cosmic rays; muons are about 100 times more massive than electrons but are still considered leptons that do not respond to the strong nuclear force

near-Earth asteroids asteroids whose orbits cross the orbit of Earth; collisions between Earth and near Earth asteroids happen a few times every million years

nebulae clouds of interstellar gas and/or dust

neutron a subatomic particle with no electrical charge

neutron star the dense core of matter composed almost entirely of neutrons that remain after a supernova explosion has ended the life of a massive star

New Millennium a NASA program to identify, develop and validate key instrument and spacecraft technologies that can lower cost and increase performance of science missions in the twenty-first century

Next Generation Space Telescope the telescope scheduled to be launched in 2009 that will replace the Hubble Space Telescope

nuclear black holes black holes that are in the centers of galaxies; they range in mass from a thousand to a billion times the mass of the Sun

nuclear fusion the combining of low-mass atoms to create heavier ones; the heavier atom's mass is slightly less than the sum of the mass of its constituents, with the remaining mass converted to energy

nucleon a proton or a neutron; one of the two particles found in a nucleus

occultations a phenomena that occurs when one astronomical object passes in front of another

optical interferometry a branch of optical physics that uses the wavelength of visible light to measure very small changes within the environment

optical-interferometry based the use of two or more telescopes observing the same object at the same time at the same visible wavelength to increase angular resolution

optical radar a method of determining the speed of moving bodies by sending a pulse of light and measuring how long it takes for the reflected light to return to the sender

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

orbital dynamics the mathematical study of the nature of the forces governing the movement of one object in the gravitational field of another object

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

orthogonal composed of right angles or relating to right angles

oscillation energy that varies between alternate extremes with a definable period

osteoporosis the loss of bone density; can occur after extended stays in space

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

paleolake depression that shows geologic evidence of having contained a lake at some previous time

Paleozoic relating to the first appearance of animal life on Earth

parabolic trajectory trajectory followed by an object with velocity equal to escape velocity

parking orbit placing a spacecraft temporarily into Earth orbit, with the engines shut down, until it has been checked out or is in the correct location for the main burn that sends it away from Earth

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

payload bay the area in the shuttle or other spacecraft designed to carry cargo

payload fairing structure surrounding a payload; it is designed to reduce drag

payload operations experiments or procedures involving cargo or "payload" carried into orbit

payload specialists scientists or engineers selected by a company or a government employer for their expertise in conducting a specific experiment or commercial venture on a space shuttle mission

perihelion the point in an object's orbit that is closest to the Sun

period of heavy meteoroid the earliest period in solar system history (more than 3.8 billion years ago) when the rate of meteoroid impact was very high compared to the present

perturbations term used in orbital mechanics to refer to changes in orbits due to "perturbing" forces, such as gravity

phased array a radar antenna design that allows rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

phased-array antennas radar antenna designs that allow rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

photolithography printing that uses a photographic process to create the printing plates

photometer instrument to measure intensity of light

photosynthesis a process performed by plants and algae whereby light is transformed into energy and sugars

photovoltaic pertaining to the direct generation of electricity from electromagnetic radiation (light)

photovoltaic arrays sets of solar panels grouped together in big sheets; these arrays collect light from the Sun and use it to make electricity to power the equipment and machines

photovoltaic cells cells consisting of a thin wafer of a semiconductor material that incorporates a p-n junction, which converts incident light into electrical power; a number of photovoltaic cells connected in series makes a solar array

plagioclase most common mineral of the light-colored lunar highlands

planetesimals objects in the early solar system that were the size of large asteroids or small moons, large enough to begin to gravitationally influence each other

pn single junction in a transistor or other solid state device, the boundary between the two different kinds of semiconductor material

point of presence an access point to the Internet with a unique Internet Protocol (IP) address; Internet service providers (ISP) like AOL generally have multiple POPs on the Internet

polar orbits orbits that carry a satellite over the poles of a planet

polarization state degree to which a beam of electromagnetic radiation has all of the vibrations in the same plane or direction

porous allowing the passage of a fluid or gas through holes or passages in the substance

power law energy spectrum spectrum in which the distribution of energies appears to follow a power law

primary the body (planet) about which a satellite orbits

primordial swamp warm, wet conditions postulated to have occurred early in Earth's history as life was beginning to develop

procurement the process of obtaining

progenitor star the star that existed before a dramatic change, such as a supernova, occurred

prograde having the same general sense of motion or rotation as the rest of the solar system, that is, counterclockwise as seen from above Earth's north pole

prominences inactive "clouds" of solar material held above the solar surface by magnetic fields

propagate to cause to move, to multiply, or to extend to a broader area

proton a positively charged subatomic particle

pseudoscience a system of theories that assumes the form of science but fails to give reproducible results under conditions of controlled experiments

pyroclastic pertaining to clastic (broken) rock material expelled from a volcanic vent

pyrotechnics fireworks display; the art of building fireworks

quantum foam the notion that there is a smallest distance scale at which space itself is not a continuous medium, but breaks up into a seething foam of wormholes and tiny black holes far smaller than a proton

quantum gravity an attempt to replace the inherently incompatible theories of quantum physics and Einstein gravity with some deeper theory that would have features of both, but be identical to neither

quantum physics branch of physics that uses quantum mechanics to explain physical systems

quantum vacuum consistent with the Heisenberg uncertainty principle, vacuum is not empty but is filled with zero-point energy and particle-antiparticle pairs constantly being created and then mutually annihilating each other

quasars luminous objects that appear star-like but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

quiescent inactive

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

radar altimetry using radar signals bounced off the surface of a planet to map its variations in elevation

radar images images made with radar illumination instead of visible light that show differences in radar brightness of the surface material or differences in brightness associated with surface slopes

radiation belts two wide bands of charged particles trapped in a planet's magnetic field

radio lobes active galaxies show two regions of radio emission above and below the plane of the galaxy, and are thought to originate from powerful jets being emitted from the accretion disk surrounding the massive black hole at the center of active galaxies

radiogenic isotope techniques use of the ratio between various isotopes produced by radioactive decay to determine age or place of origin of an object in geology, archaeology, and other areas

radioisotope a naturally or artificially produced radioactive isotope of an element

radioisotope thermoelectric device using solid state electronics and the heat produced by radioactive decay to generate electricity

range safety destruct systems system of procedures and equipment designed to safely abort a mission when a spacecraft malfunctions, and destroy the rocket in such a way as to create no risk of injury or property damage

Ranger series of spacecraft sent to the Moon to investigate lunar landing sites; designed to hard-land on the lunar surface after sending back television pictures of the lunar surface; Rangers 7, 8, and 9 (1964–1965) returned data

rarefaction decreased pressure and density in a material caused by the passage of a sound wave

reconnaissance a survey or preliminary exploration of a region of interest

reflex motion the orbital motion of one body, such as a star, in reaction to the gravitational tug of a second orbiting body, such as a planet

regolith upper few meters of a body's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

relative zero velocity two objects having the same speed and direction of movement, usually so that spacecraft can rendezvous

relativistic time dilation effect predicted by the theory of relativity that causes clocks on objects in strong gravitational fields or moving near the speed of light to run slower when viewed by a stationary observer

remote manipulator system a system, such as the external Canada2 arm on the International Space Station, designed to be operated from a remote location inside the space station

remote sensing the act of observing from orbit what may be seen or sensed below on Earth

retrograde having the opposite general sense of motion or rotation as the rest of the solar system, clockwise as seen from above Earth's north pole

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

reusables launches that can be used many times before discarding

rift valley a linear depression in the surface, several hundred to thousand kilometers long, along which part of the surface has been stretched, faulted, and dropped down along many normal faults

rille lava channels in regions of maria, typically beginning at a volcanic vent and extending downslope into a smooth mare surface

rocket vehicle or device that is especially designed to travel through space, and is propelled by one or more engines

"rocky" planets nickname given to inner or solid-surface planets of the solar system, including Mercury, Venus, Mars, and Earth

rover vehicle used to move about on a surface

rutile a red, brown, or black mineral, primarily titanium dioxide, used as a gemstone and also a commercially important ore of titanium

satellite any object launched by a rocket for the purpose of orbiting the Earth or another celestial body

scoria fragments of lava resembling cinders

secondary crater crater formed by the impact of blocks of rock blasted out of the initial crater formed by an asteroid or large meteorite

sedentary lifestyle a lifestyle characterized by little movement or exercise

sedimentation process of depositing sediments, which result in a thick accumulation of rock debris eroded from high areas and deposited in low areas

semiconductor one of the groups of elements with properties intermediate between the metals and nonmetals

semimajor axis one half of the major axis of an ellipse, equal to the average distance of a planet from the Sun

shepherding small satellites exerting their gravitational influence to cause or maintain structure in the rings of the outer planets

shield volcanoes volcanoes that form broad, low-relief cones, characterized by lava that flows freely

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

sine wave a wave whose amplitude smoothly varies with time; a wave form that can be mathematically described by a sine function

smooth plains the youngest plains on Mercury with a relatively low impact crater abundance

soft-landers spacecraft that uses braking by engines or other techniques (e.g., parachutes, airbags) such that its landing is gentle enough that the spacecraft and its instruments are not damaged, and observations at the surface can be made

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

solar corona the thin outer atmosphere of the Sun that gradually transitions into the solar wind

solar flares explosions on the Sun that release bursts of electromagnetic radiation, such as light, ultraviolet waves, and X rays, along with high speed protons and other particles

solar nebula the cloud of gas and dust out of which the solar system formed

solar prominence cool material with temperatures typical of the solar photosphere or chromosphere suspended in the corona above the visible surface layers

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

sounding rocket a vehicle designed to fly straight up and then parachute back to Earth, usually designed to take measurements of the upper atmosphere

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period; to date, only Earth-orbiting space stations have been launched

space-time in relativity, the four-dimensional space through which objects move and in which events happen

spacecraft bus the primary structure and subsystems of a spacecraft

spacewalking moving around outside a spaceship or space station, also known as extravehicular activity

special theory of relativity the fundamental idea of Einstein's theories, which demonstrated that measurements of certain physical quantities such as mass, length, and time depended on the relative motion of the object and observer

specific power amount of electric power generated by a solar cell per unit mass; for example watts per kilogram

spectra representations of the brightness of objects as a function of the wavelength of the emitted radiation

spectral lines the unique pattern of radiation at discrete wavelengths that many materials produce

spectrograph an instrument that can permanently record a spectra

spectrographic studies studies of the nature of matter and composition of substances by examining the light they emit

spectrometers an instrument with a scale for measuring the wavelength of light

spherules tiny glass spheres found in and among lunar rocks

spot beam technology narrow, pencil-like satellite beam that focuses highly radiated energy on a limited area of Earth's surface (about 100 to 500 miles in diameter) using steerable or directed antennas

stratigraphy the study of rock layers known as strata, especially the age and distribution of various kinds of sedimentary rocks

stratosphere a middle portion of a planet's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

subduction the process by which one edge of a crustal plate is forced to move under another plate

sublimate to pass directly from a solid phase to a gas phase

suborbital trajectory the trajectory of a rocket or ballistic missile that has insufficient energy to reach orbit

subsolar point the point on a planet that receives direct rays from the Sun

substrate the surface, such as glass, metallic foil, or plastic sheet, on which a thin film of photovoltaic material is deposited

sunspots dark, cooler areas on the solar surface consisting of transient, concentrated magnetic fields

supercarbonaceous term given to P- and D-type meteorites that are richer in carbon than any other meteorites and are thought to come from the primitive asteroids in the outer part of the asteroid belt

supernova an explosion ending the life of a massive star

supernovae ejecta the mix of gas enriched by heavy metals that is launched into space by a supernova explosion

superstring theory the best candidate for a "theory of everything" unifying quantum mechanics and gravity, proposes that all particles are oscillations in tiny loops of matter only 10^{-35} meters long and moving in a space of ten dimensions

superstrings supersymmetric strings are tiny, one dimensional objects that are about 10^{-33} cm long, in a 10-dimensional spacetime. Their different vibration modes and shapes account for the elementary particles we see in our 4-dimensional spacetime

Surveyor a series of spacecraft designed to soft-land robotic laboratories to analyze and photograph the lunar surface; Surveyors 1, 3, and 5–7 landed between May 1966 and January 1968

synchrotron radiation the radiation from electrons moving at almost the speed of light inside giant magnetic accelerators of particles, called synchrotrons, either on Earth or in space

synthesis the act of combining different things so as to form new and different products or ideas

technology transfer the acquisition by one country or firm of the capability to develop a particular technology through its interactions with the existing technological capability of another country or firm, rather than through its own research efforts

tectonism process of deformation in a planetary surface as a result of geological forces acting on the crust; includes faulting, folding, uplift, and downwarping of the surface and crust

telescience the act of operation and monitoring of research equipment located in space by a scientist or engineer from their offices or laboratories on Earth

terrestrial planet a small rocky planet with high density orbiting close to the Sun; Mercury, Venus, Earth, and Mars

thermodynamically referring to the behavior of energy

thermostabilized designed to maintain a constant temperature

thrust fault a fault where the block on one side of the fault plane has been thrust up and over the opposite block by horizontal compressive forces

toxicological related to the study of the nature and effects on humans of poisons and the treatment of victims of poisoning

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

transonic barrier the aerodynamic behavior of an aircraft moving near the speed of sound changes dramatically and, for early pioneers of transonic flight, dangerously, leading some to hypothesize there was a "sound barrier" where drag became infinite

transpiration process whereby water evaporates from the surface of leaves, allowing the plant to lose heat and to draw water up through the roots

transponder bandwidth-specific transmitter-receiver units

troctolite rock type composed of the minerals plagioclase and olivine, crystallized from magma

tunnelborer a mining machine designed to dig a tunnel using rotating cutting disks

Tycho event the impact of a large meteoroid into the lunar surface as recently as 100 million years ago, leaving a distinct set of bright rays across the lunar surface including a ray through the Apollo 17 landing site

ultramafic lavas dark, heavy lavas with a high percentage of magnesium and iron; usually found as boulders mixed in other lava rocks

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

ultraviolet radiation electromagnetic radiation with a shorter wavelength and higher energy than light

uncompressed density the lower density a planet would have if it did not have the force of gravity compressing it

Universal time current time in Greenwich, England, which is recognized as the standard time that Earth's time zones are based

vacuum an environment where air and all other molecules and atoms of matter have been removed

vacuum conditions the almost complete lack of atmosphere found on the surface of the Moon and in space

Van Allen radiation belts two belts of high energy charged particles captured from the solar wind by Earth's magnetic field

variable star a star whose light output varies over time

vector sum sum of two vector quantities taking both size and direction into consideration

velocity speed and direction of a moving object; a vector quantity

virtual-reality simulations a simulation used in training by pilots and astronauts to safely reproduce various conditions that can occur on board a real aircraft or spacecraft

visible spectrum the part of the electromagnetic spectrum with wavelengths between 400 nanometers and 700 nanometers; the part of the electromagnetic spectrum to which human eyes are sensitive

volatile ices (e.g., H_2O and CO_2) that are solids inside a comet nucleus but turn into gases when heated by sunlight

volatile materials materials that easily pass into the vapor phase when heated

wavelength the distance from crest to crest on a wave at an instant in time

X ray form of high-energy radiation just beyond the ultraviolet portion of the spectrum

X-ray diffraction analysis a method to determine the three-dimensional structure of molecules

Cumulative Index

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