space sciences

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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 (~1.495×10^8 km).
[2] R indicates planet rotation is retrograde (i.e., opposite to the planet's orbit).
[3] Earth's mass is approximately 5.976×10^{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)	$\frac{1}{8}$ 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

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)

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* 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 $31\frac{1}{2}$ 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.

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 Penemünde.
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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VOLUME 4: OUR FUTURE IN SPACE

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Animals

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.

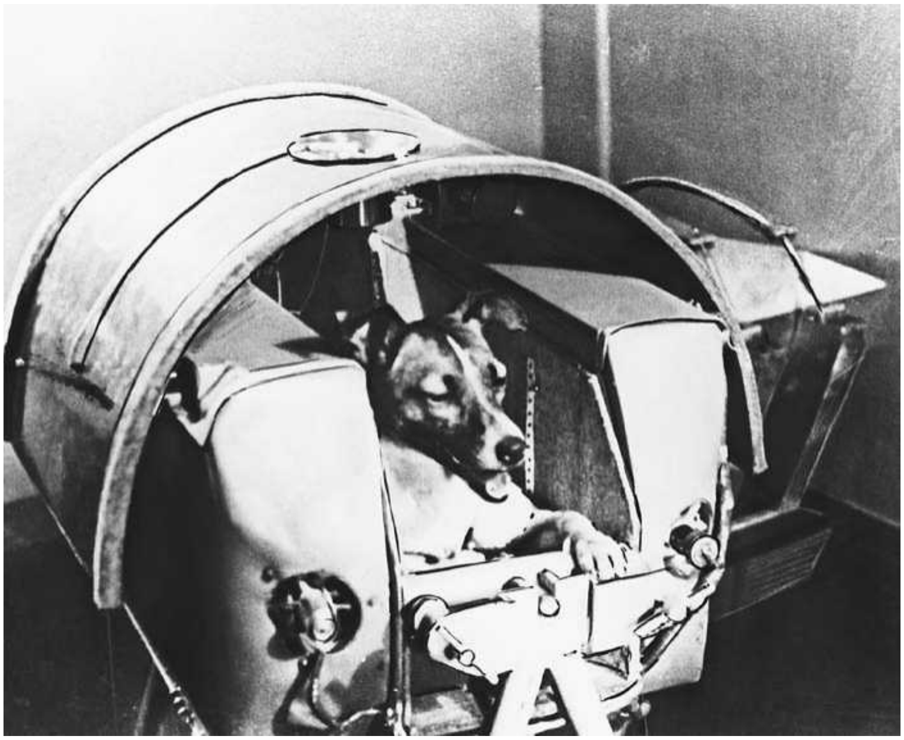
rocket vehicle (or device) especially designed to travel through space, propelled by one or more engines

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.

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

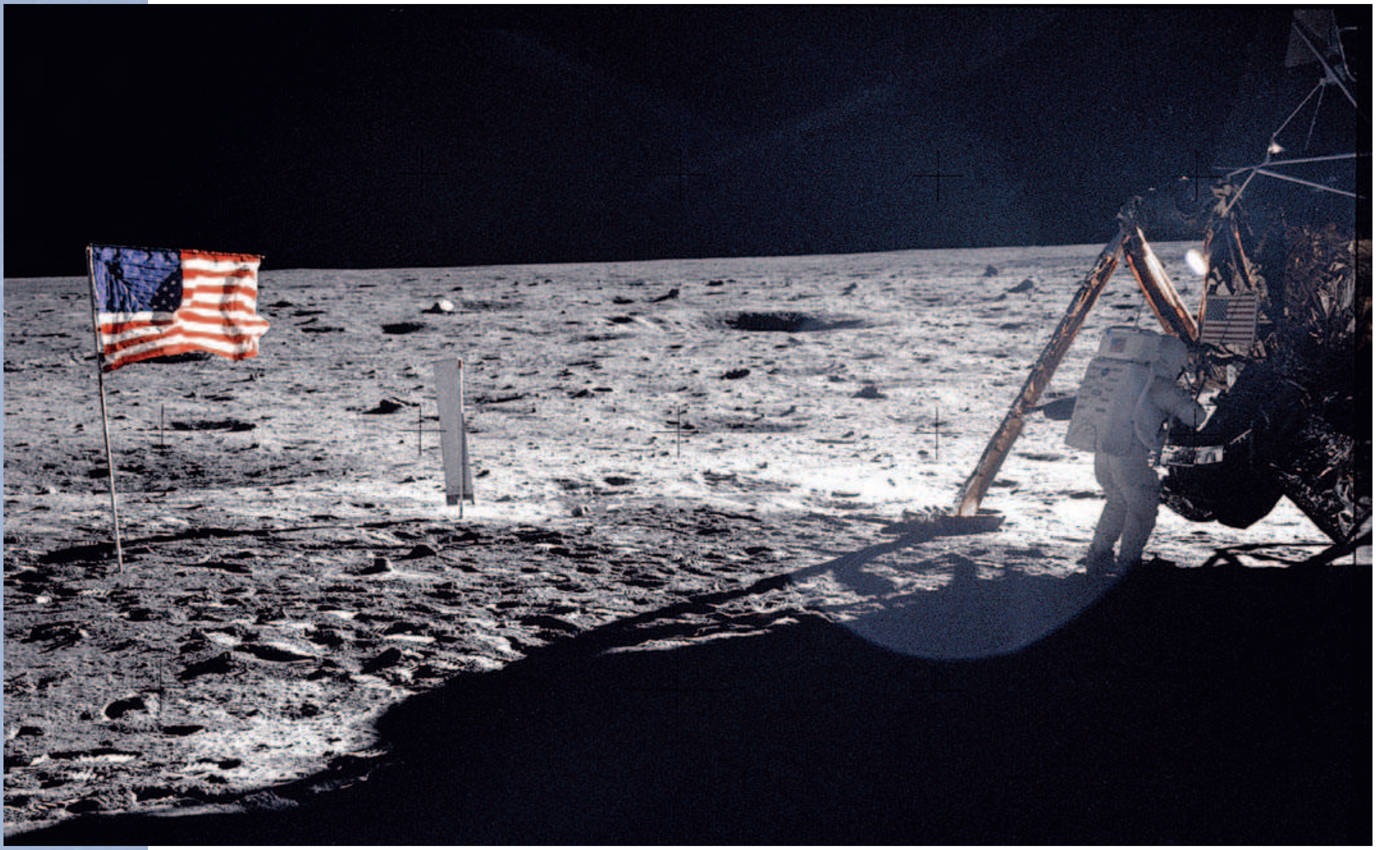
Mercury the first American-piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963.

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

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).

Randy L. Korotev

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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

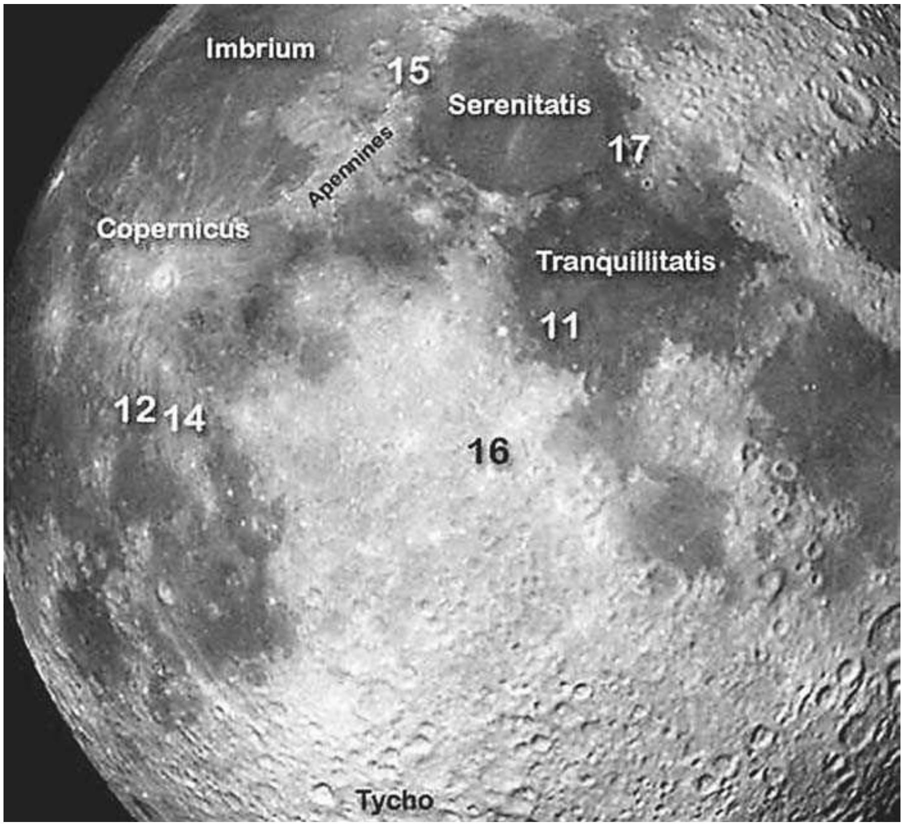
The Apollo 12 (Surveyor 3) site was selected because it appeared to contain basalts of a different type and age. The site lay on one of the **bright rays** from the crater Copernicus, offering the chance to sample some of the ray material. The mission included two EVAs on foot and the setup of the first 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

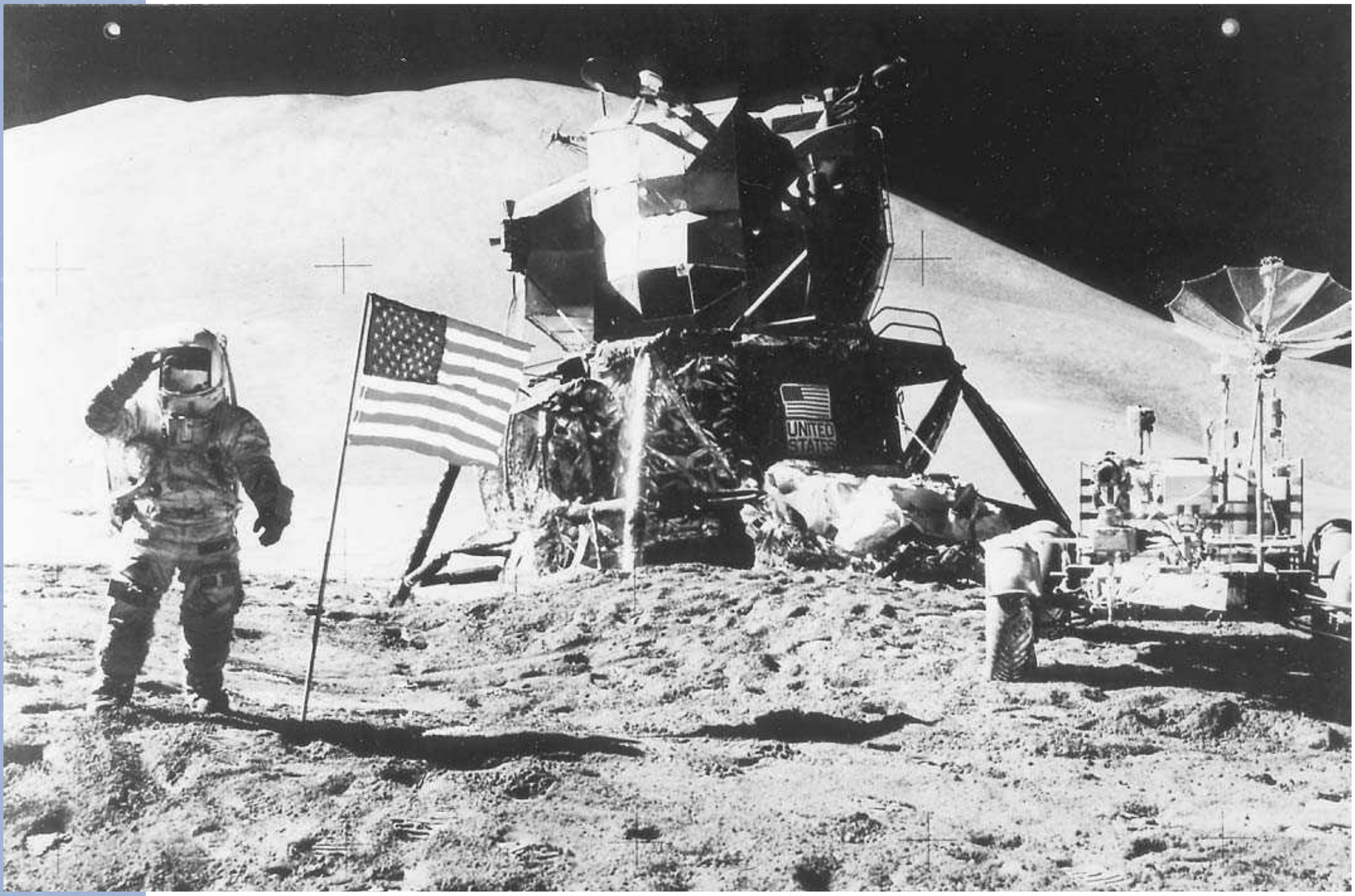
anorthosite a light-colored rock composed mainly of the mineral feldspar (an aluminum silicate); commonly occurs in the crusts of Earth and the Moon

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

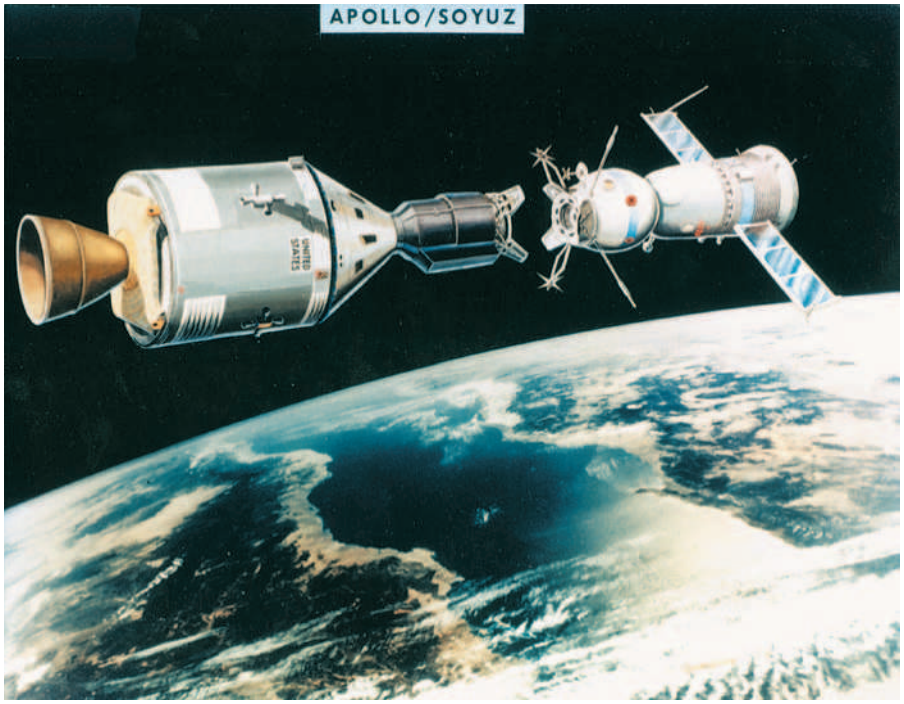
On January 30, 1973, NASA introduced astronauts Thomas Stafford, Donald Slayton, and Vance Brand as its prime ASTP crew. In May, the Soviets tapped Alexei Leonov and Valeri Kubasov as its ASTP prime cosmonauts. The crews trained together in Houston, Texas, and in Moscow and learned each other's language. 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

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.

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

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).

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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).

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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

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.

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

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.

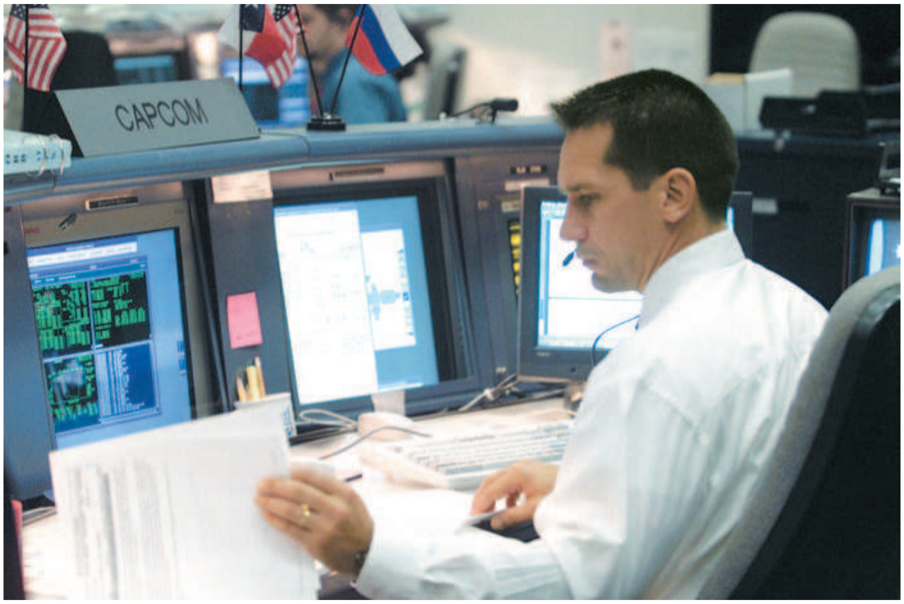
Due to high-risk time-critical decisions, the astronaut corps believed that only astronauts should talk to the astronaut in the capsule. Since the men trained together, the astronaut capcom might recognize the significance of each crew members' tone of voice or speech pattern, which a non-astronaut might 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).

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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.

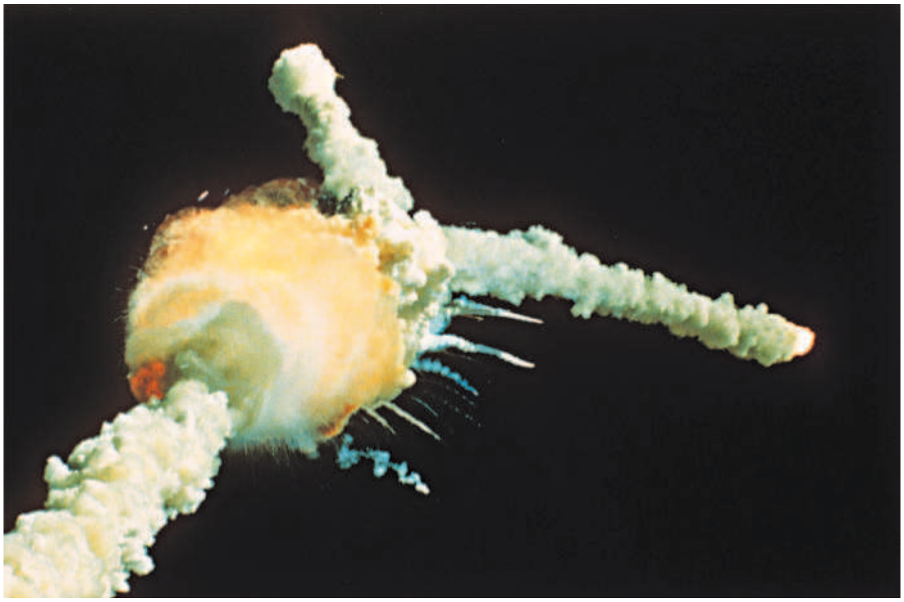
Early History

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).

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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

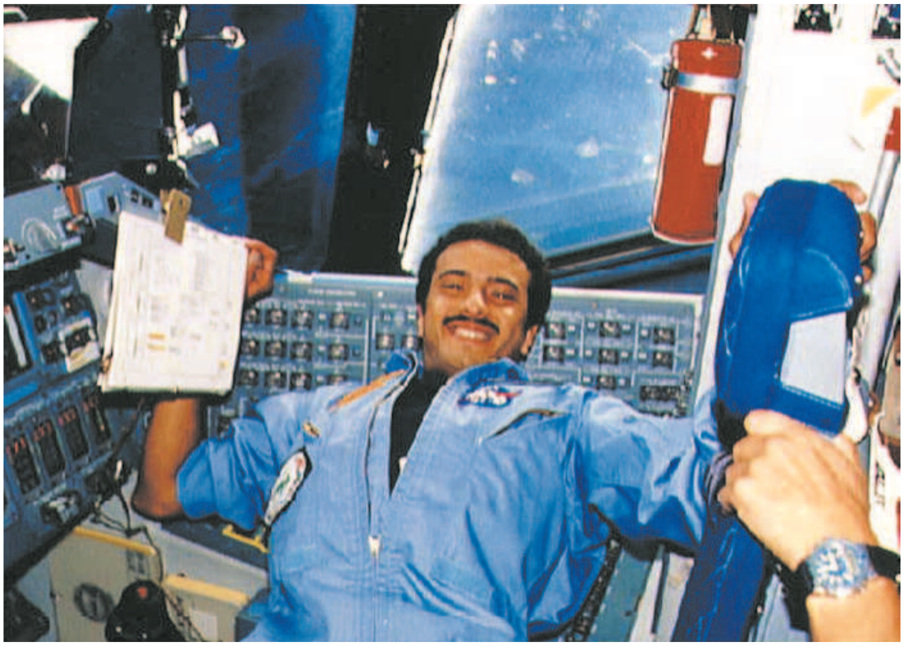
The first guest astronaut invited into the shuttle's crew cabin was a U.S. senator, Jake Garn of Utah, who chaired a NASA oversight committee. Garn, flying as a "congressional observer," made a seven-day flight in April 1985. While his crewmates dispatched two satellites into orbit and conducted science 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).

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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.

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.

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.

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**

WHAT ARE THE LAWS OF THERMODYNAMICS?

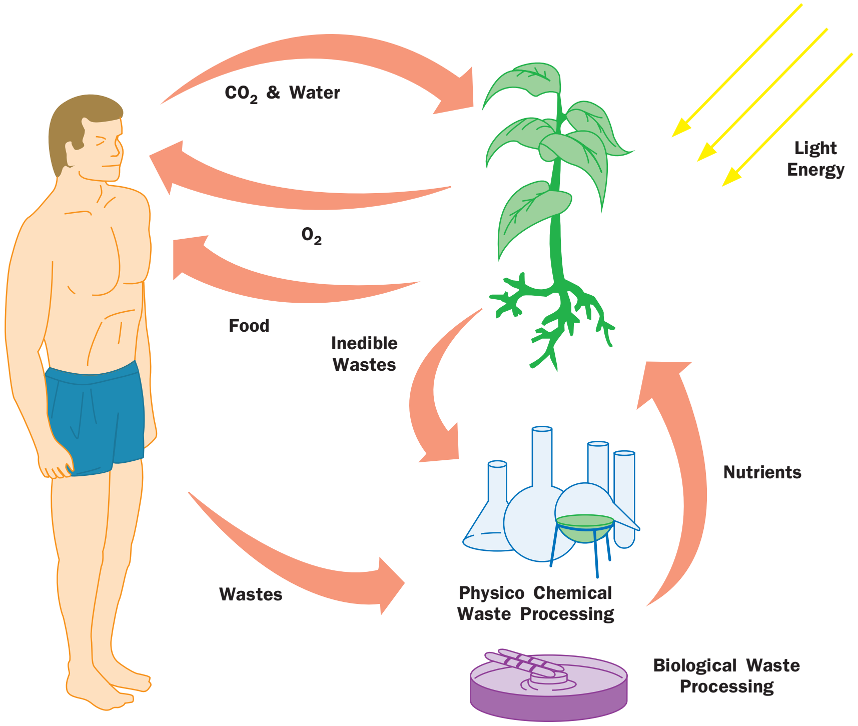
The term "thermodynamics" refers to the behavior of energy. The first law of thermodyamics states that energy can be transferred from one form into another form but is never created or destroyed. The second law states that no process involving energy transformation can occur unless there is degradation of energy from a concentrated form into a dispersed form.

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

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

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.

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 system provides service to a wide range of orbiting spacecraft, both those with crews and those without. Spacecraft supported by this

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

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

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.

Early Spaceflight Computers

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

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.

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).

Craig Samuels

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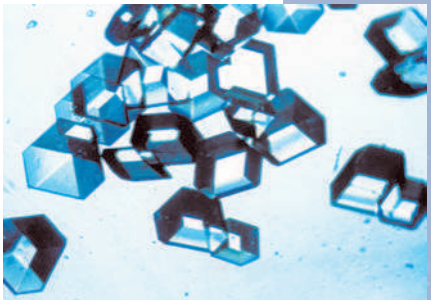
Crystal Growth

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.



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.

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

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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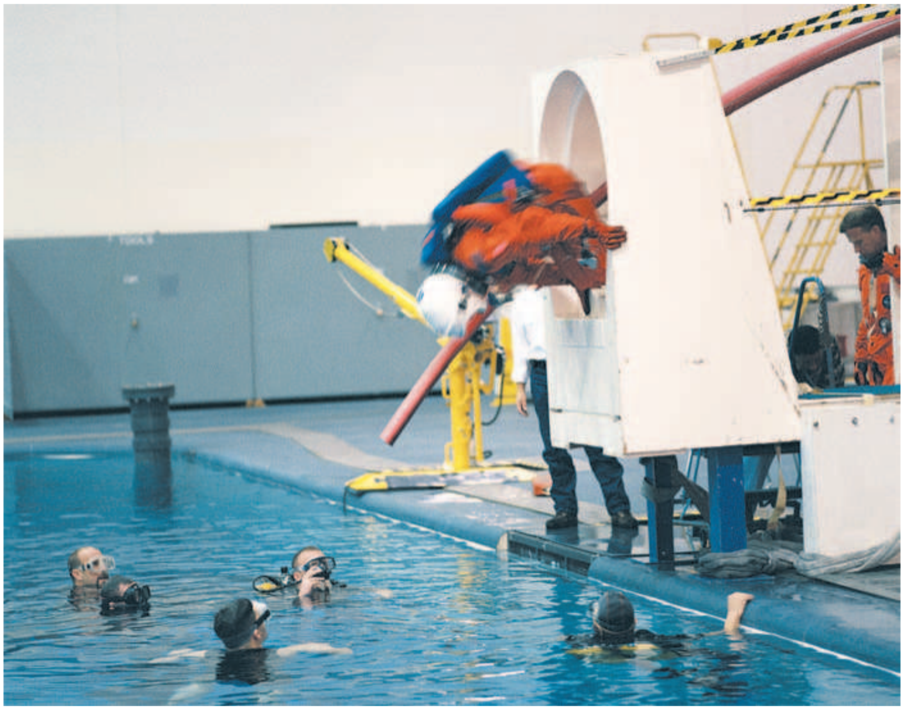
Docking ***See Apollo-Soyuz (Volume 3); International Space Station (Volume 3); Mir (Volume 3); Rendezvous (Volume 3); Space Shuttle (Volume 3).***

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).

Irene Brown

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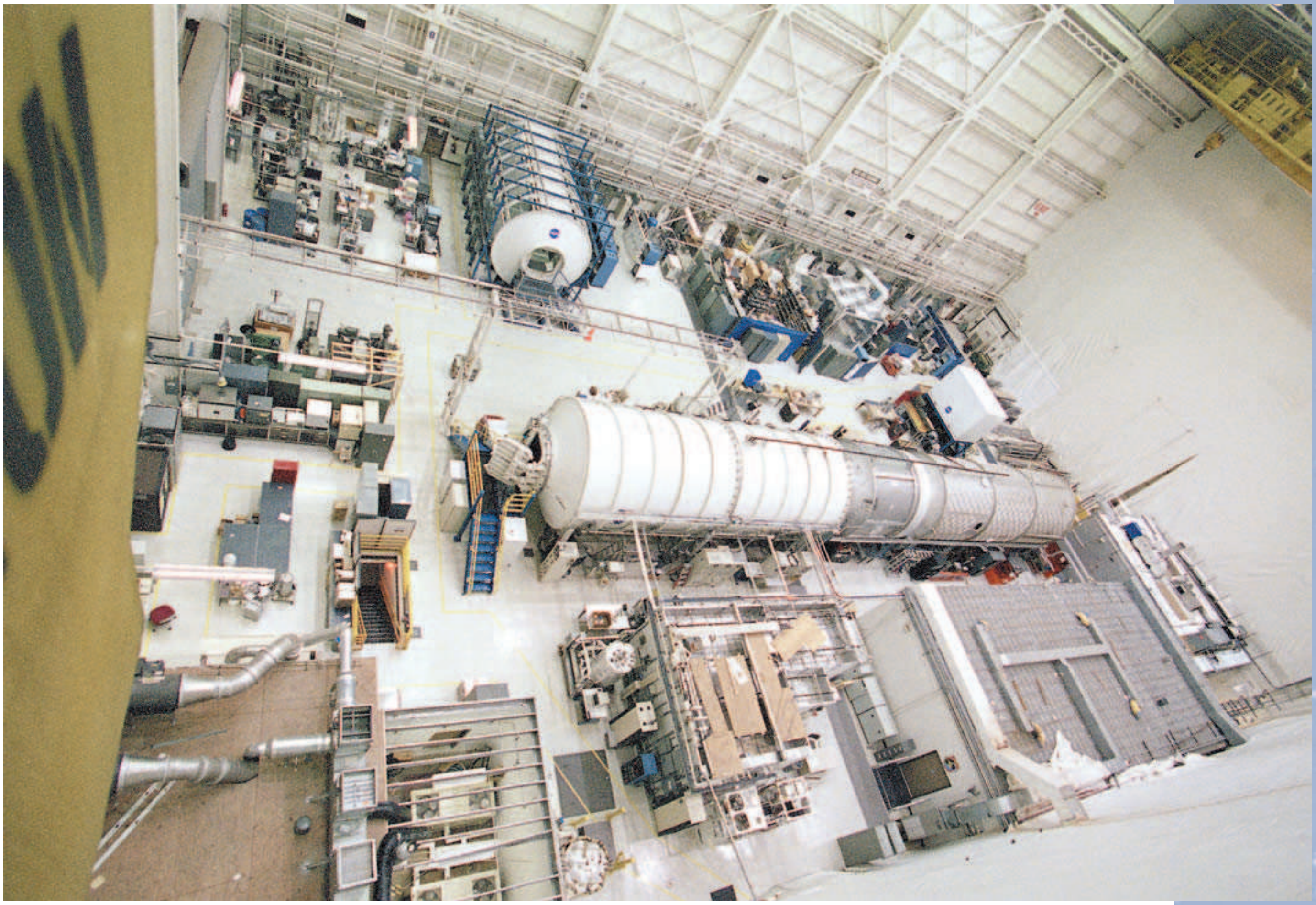
Environmental Controls

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).

Julie L. McDowell

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International Space Station Life Support Systems. NASA Marshall Space Flight Center. <http://www.msfc.nasa.gov/NEWMSFC/eclss.html>.

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, super-cold 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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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).

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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.

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).

centrifugal directed away from the center through spinning

John F. Kross

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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.

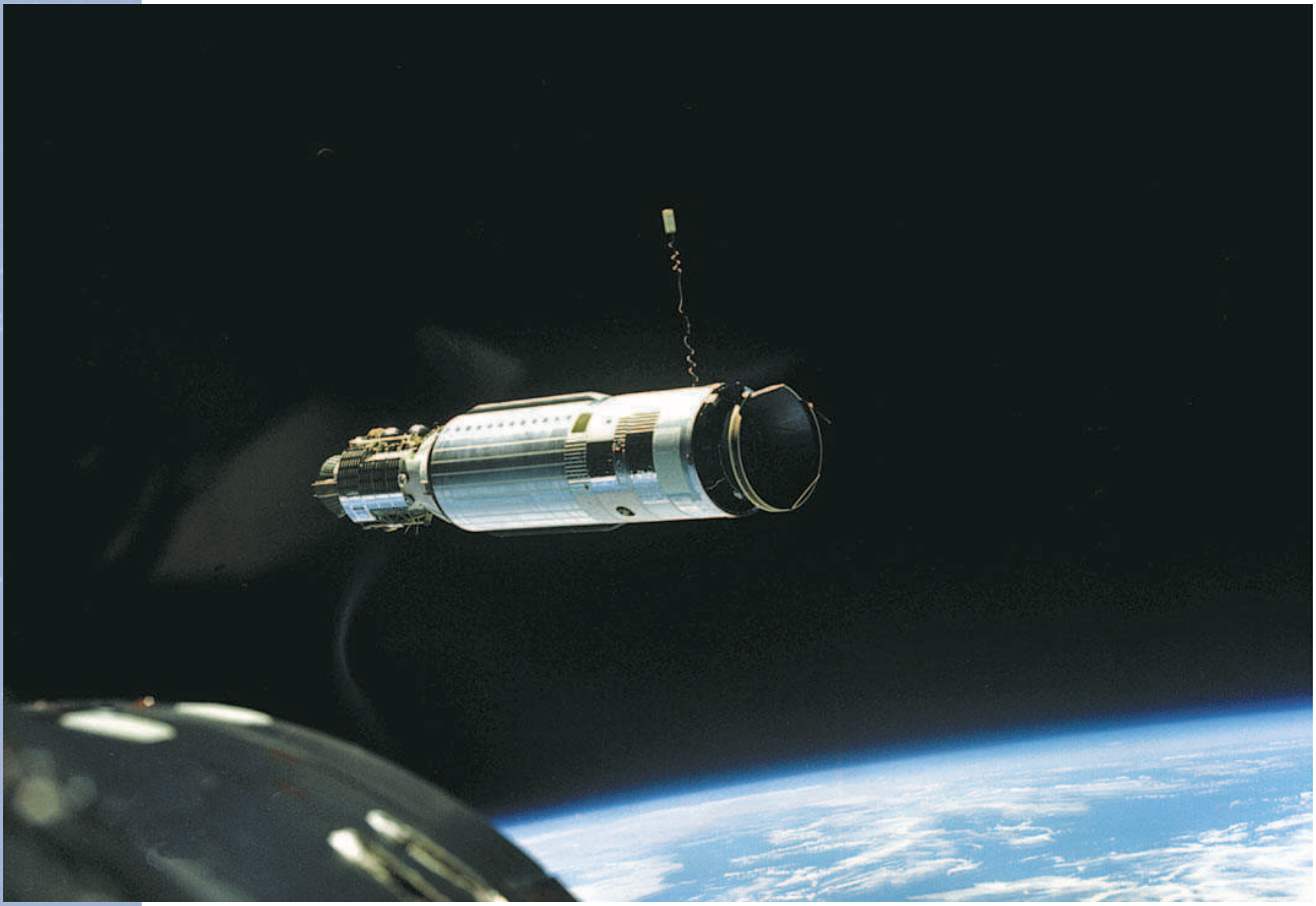
Edward H. White was the first U.S. astronaut to complete extravehicular activity.

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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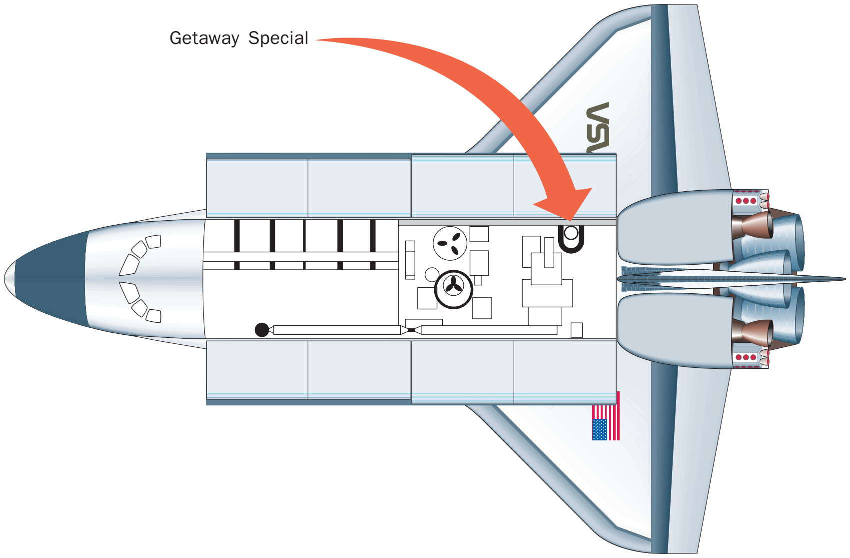
Getaway Specials

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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Glenn, John

American Astronaut and Senator
1921–

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.

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.

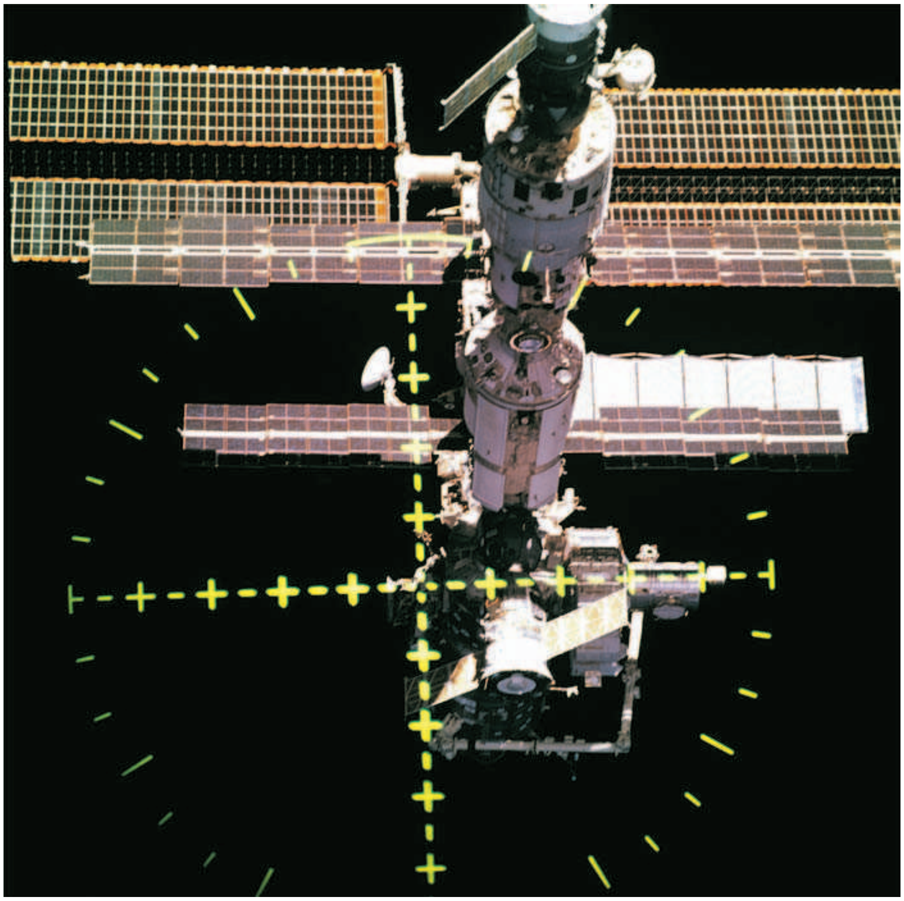
interstellar between the stars

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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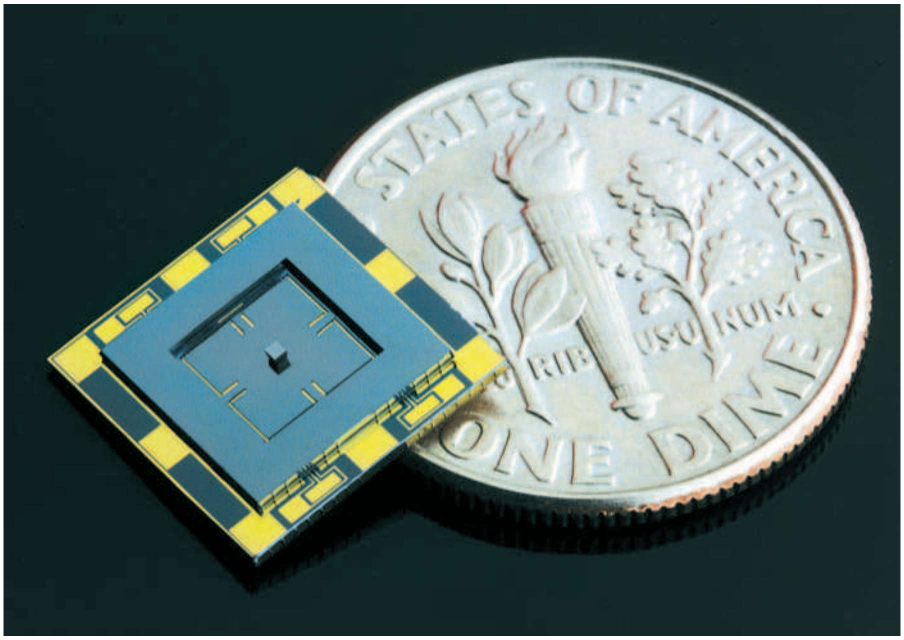
Gyroscopes

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 × 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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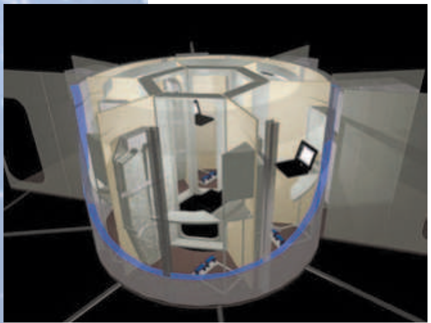
Habitats

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.

The First Space Stations



This computer-generated close up of the TransHab Module crew quarters is an example of the living space available in such a module.

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

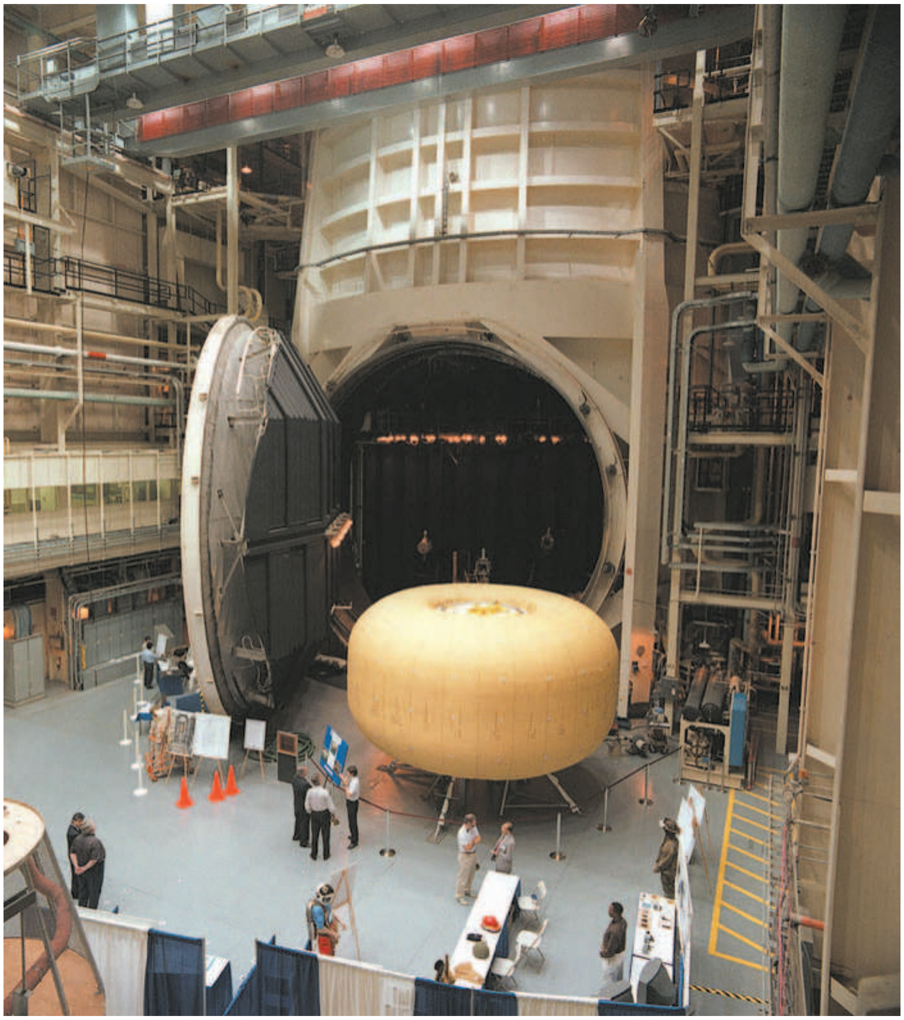
payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

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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NASA web site on TransHab. <http://spaceflight.nasa.gov/station/assembly/elements/transhab/>.

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.

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).

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

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.

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

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

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.

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.

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.

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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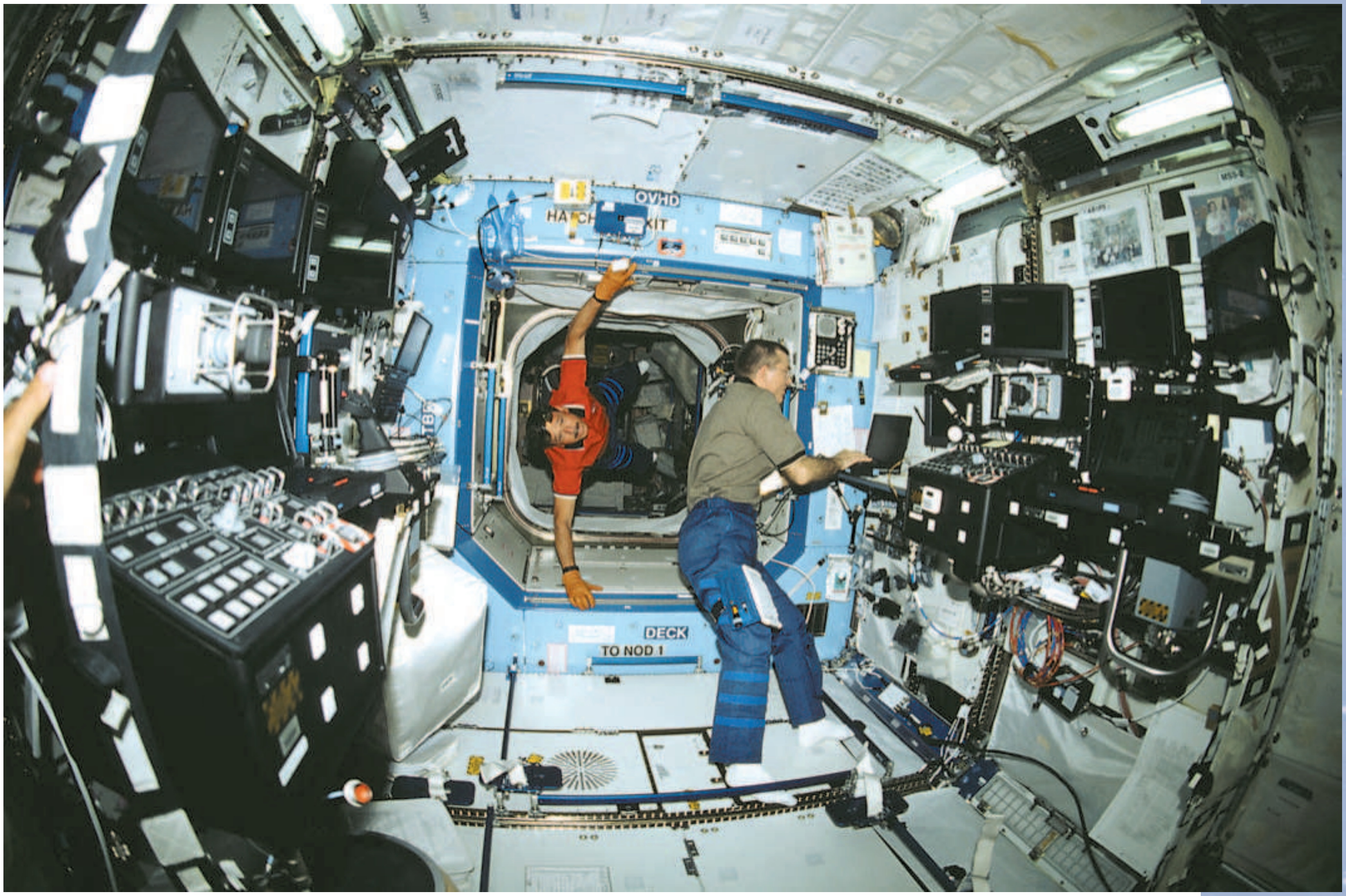
Human Factors

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).

Theodore T. Foley II and Sudhakar Rajulu

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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

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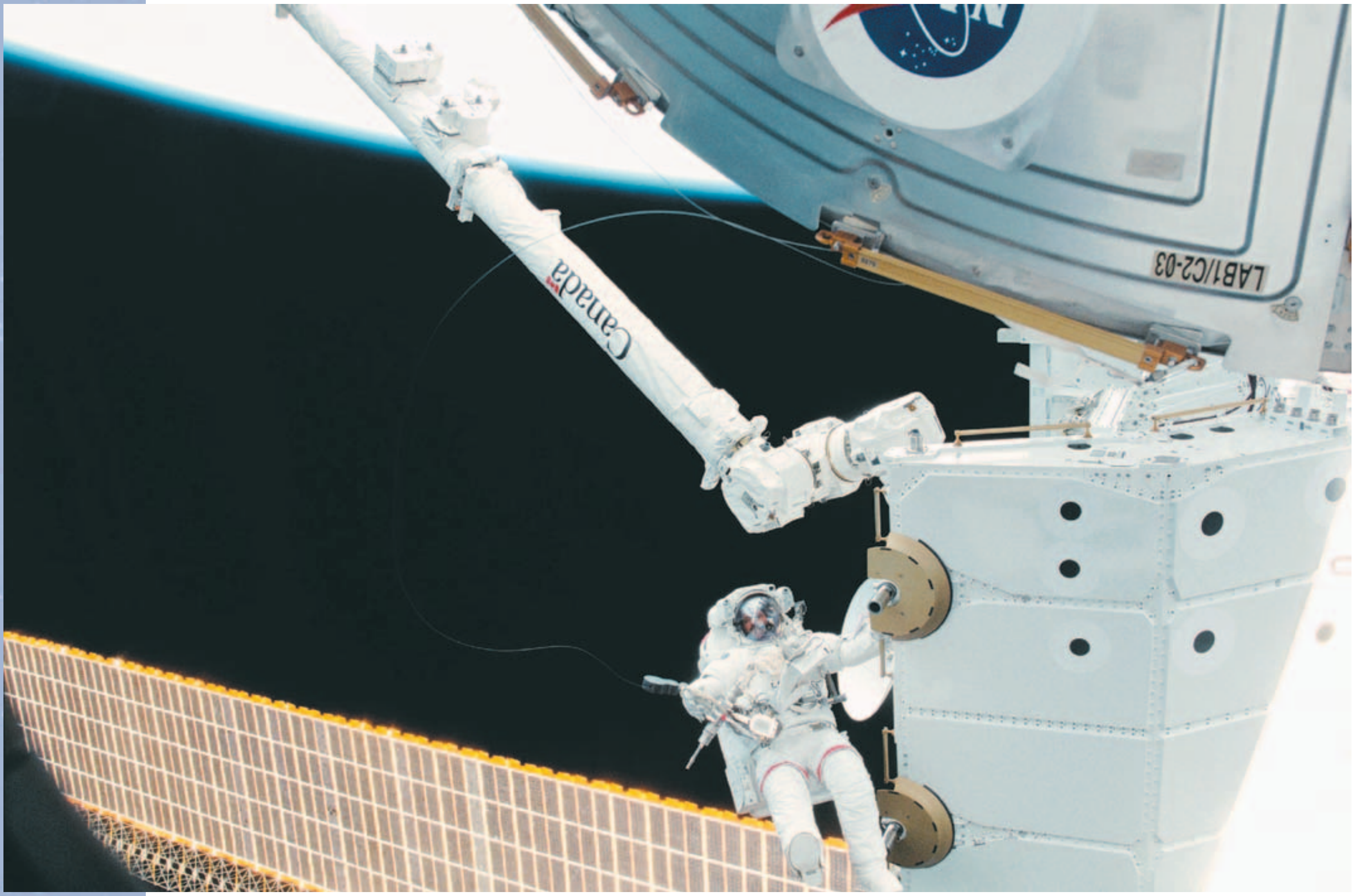
Humans versus Robots

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

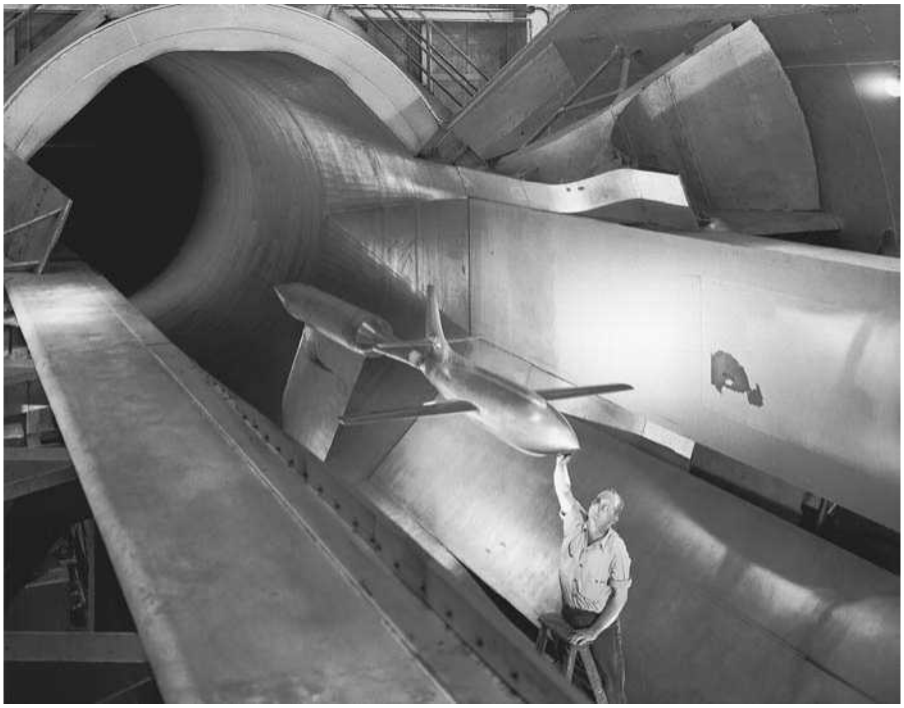
High-speed aircraft design began with **rocket**-powered craft. Many rocket-powered aircraft built in the 1940s and 1950s carried the X, or experimental, designation, beginning with the bullet-shaped Bell X-1, which on

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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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

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

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.

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

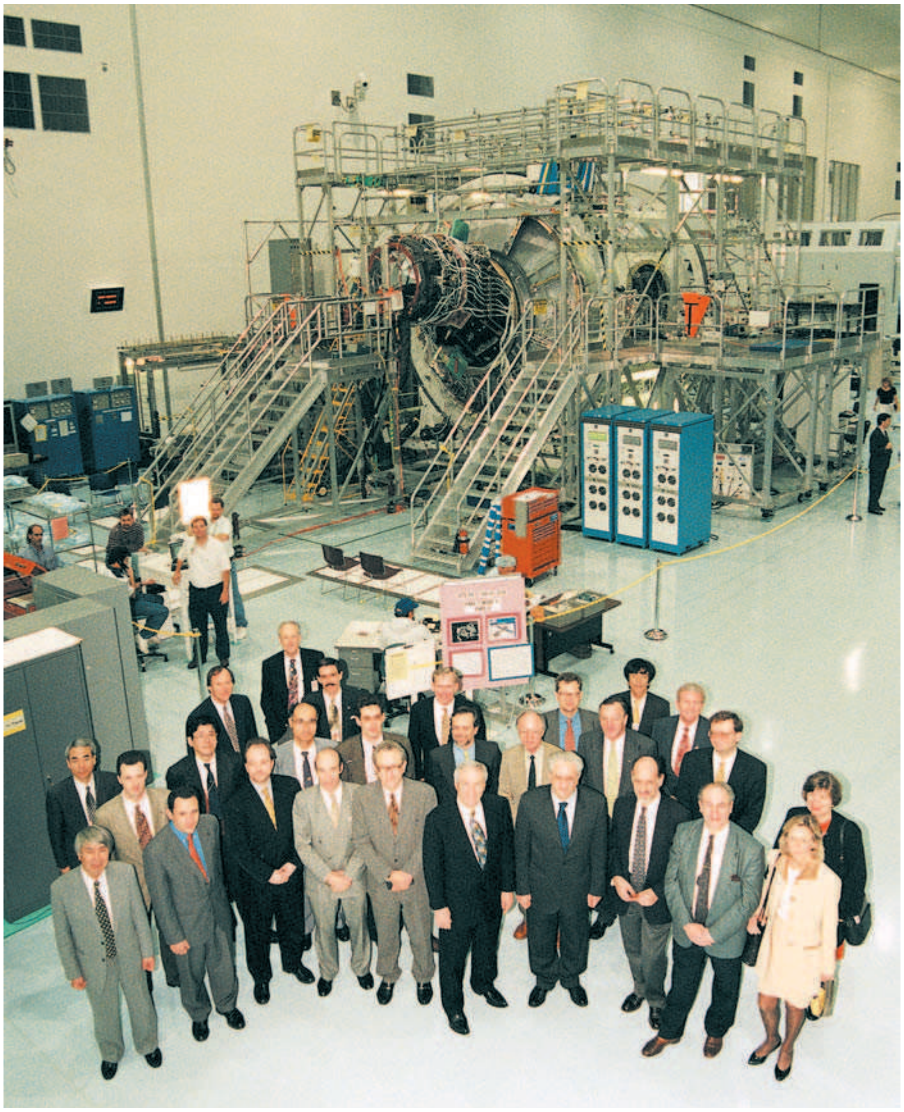
U.S. mission specialist C. Michael Foale (left) and Claude Nicollier, a European Space Agency astronaut, participate in the second of three space walks to repair the Hubble Space Telescope.

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.)

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

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.

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

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

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.

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

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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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.

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

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 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.

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

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. Colocated 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°.

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).

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

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Wallops Flight Facility. <http://www.wff.nasa.gov/>.

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

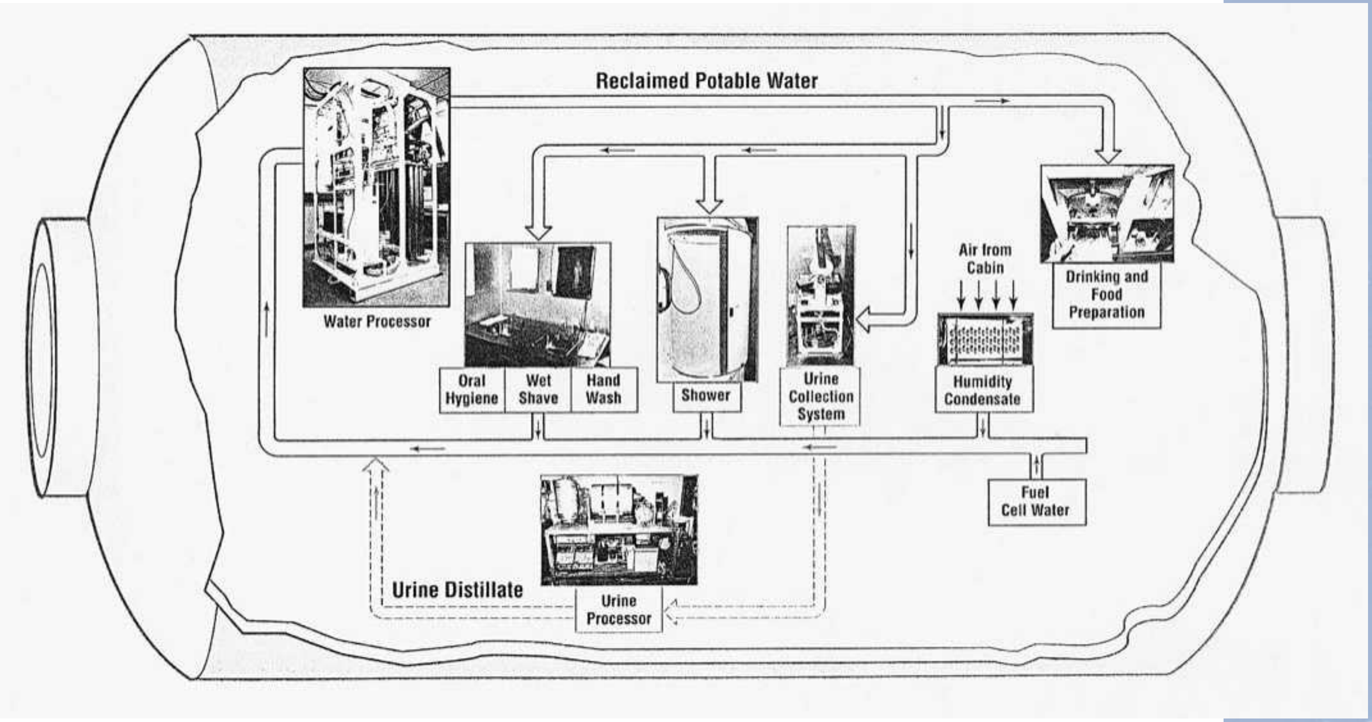

Diagram showing the flow of water recovery and management in the International Space Station (ISS).

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

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.

jettison to eject, throw overboard, or get rid of

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

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.

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

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

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.

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

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.

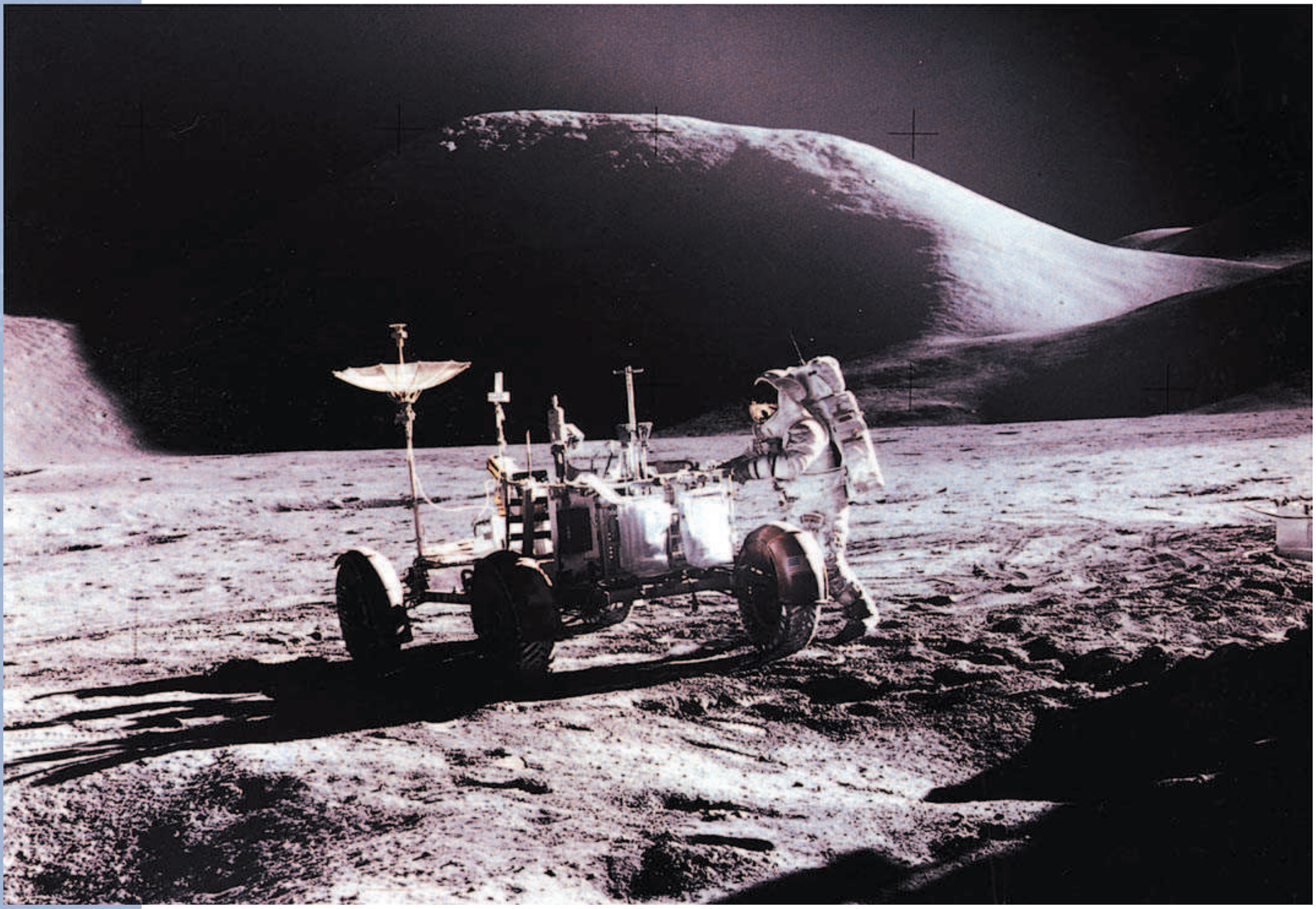
chassis frame on which a vehicle is constructed

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).

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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.✶

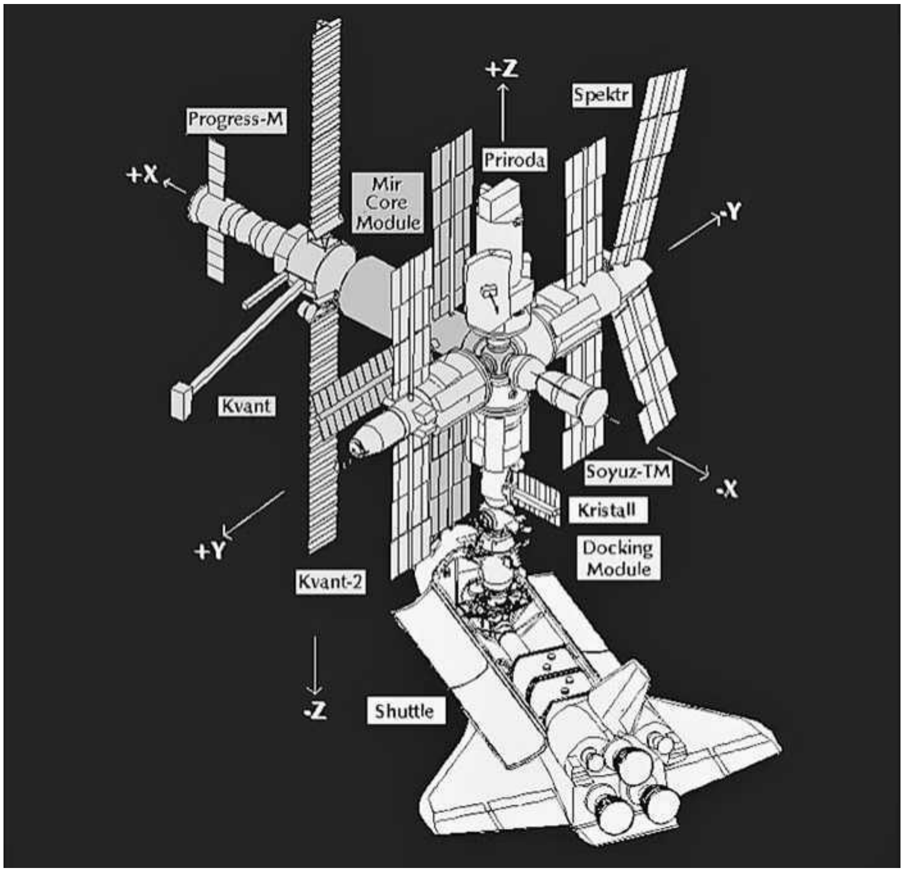
Problems Plague Mir

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 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
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.

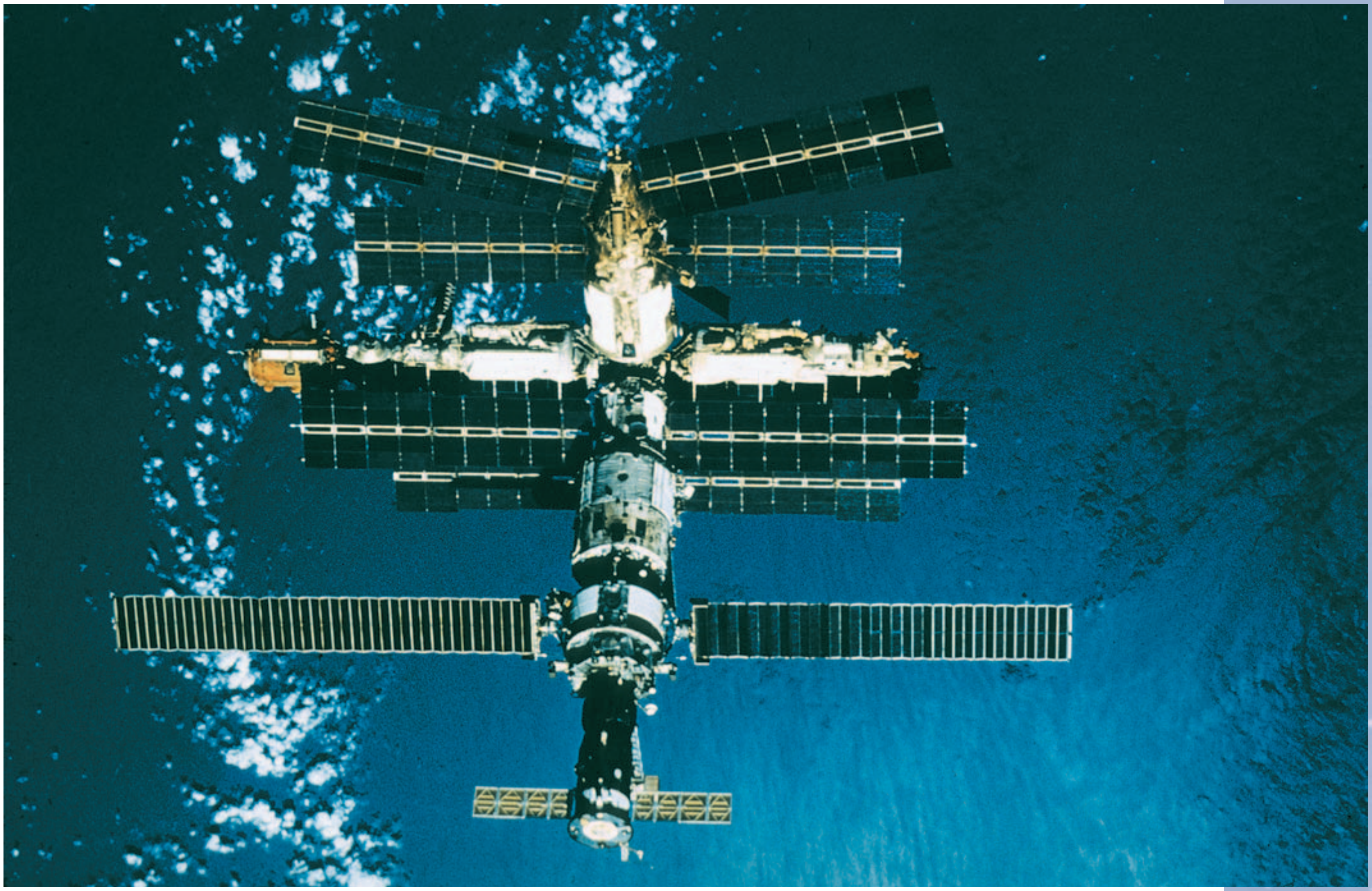


On January 14, 1994, cosmonauts ignored weight limitations on the Soyuz craft and caused a collision with the station. On February 23, 1997, a fire ignited onboard. Luckily, no one was harmed and the fire was extinguished. Less than six months later, on June 25, 1997, Soyuz craft again collided with 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).

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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.

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.

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

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).

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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

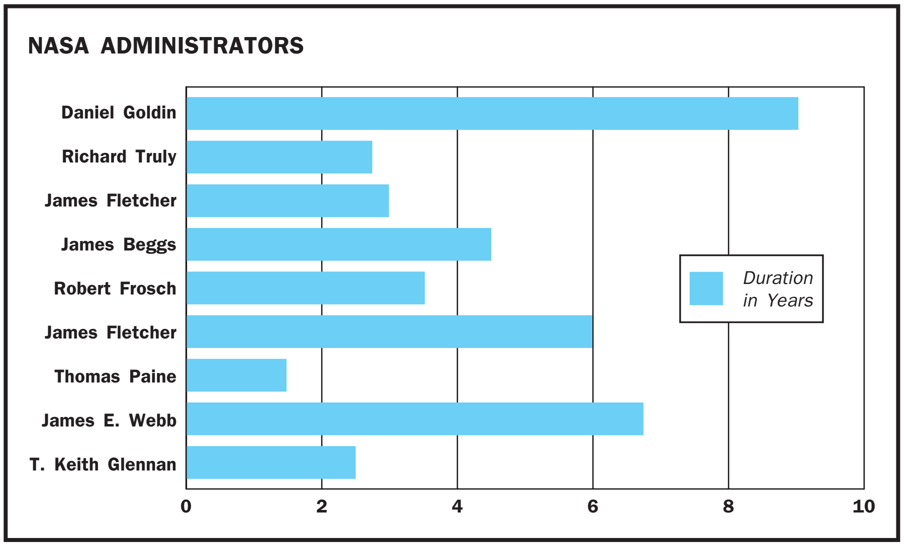
of all but one of the planets in the solar system, the development of **remote sensing** and communications satellites, and dramatic advances in aeronautical research. NASA technology has been adapted for many non-aerospace uses by the private sector, and NASA remains a leading force in scientific research. 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).

Lori Garver

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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

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Oxygen Atmosphere in Spacecraft

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

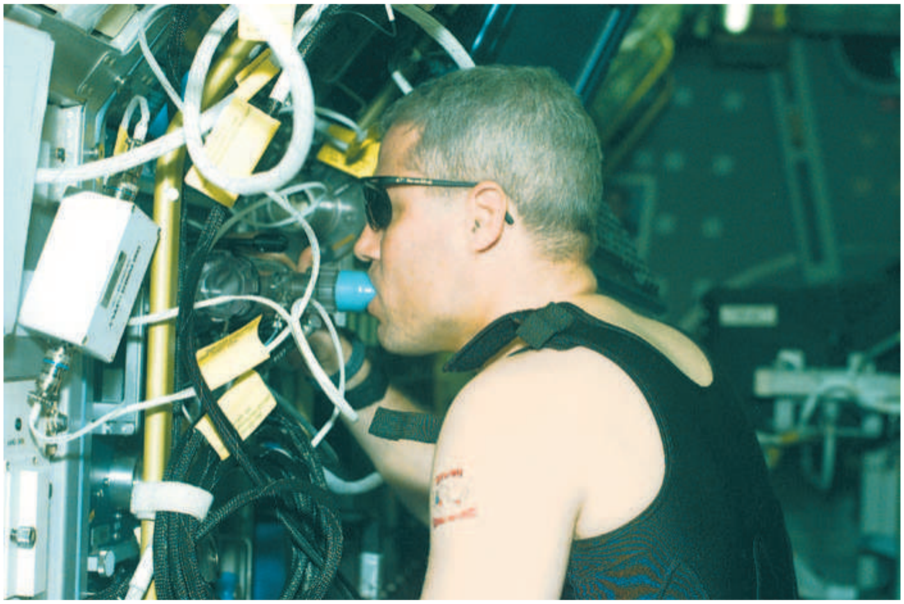
Payload specialists are persons who have been designated by the National Aeronautics and Space Administration (NASA) or its commercial or international partners to serve as crewmembers in association with a specific **payload** and/or to accomplish a specific mission objective. Payload specialists include 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).

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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

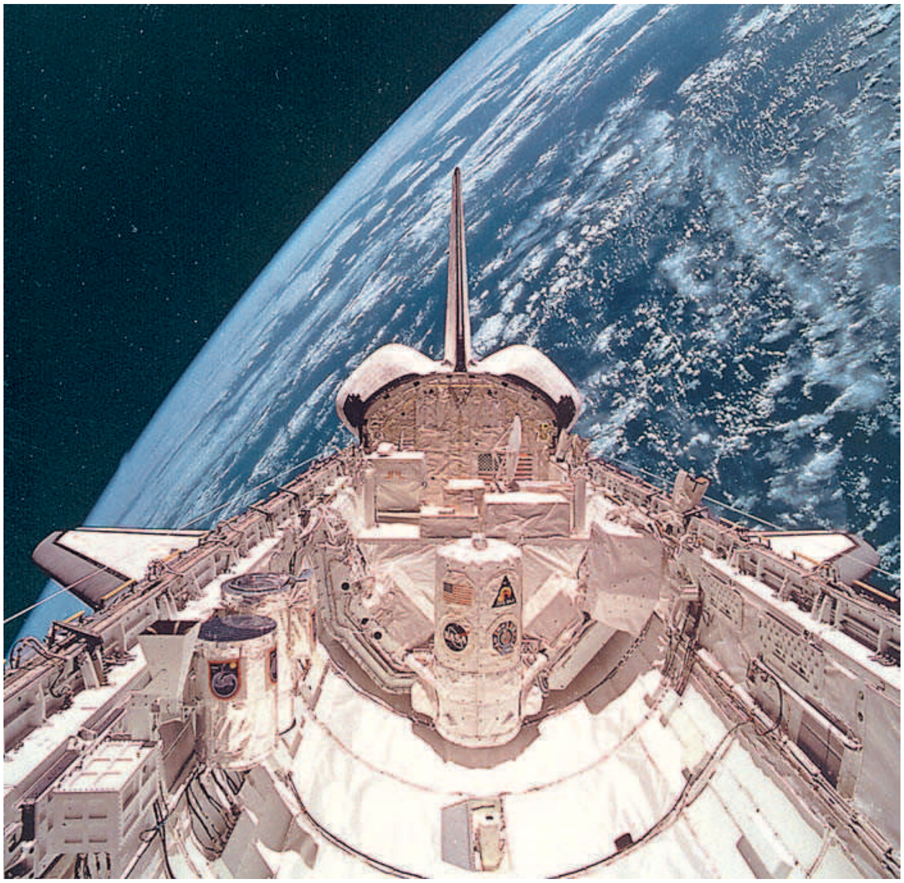
infrared portion of the electromagnetic spectrum with wavelengths slightly longer than visible light

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).

Rick Fleeter

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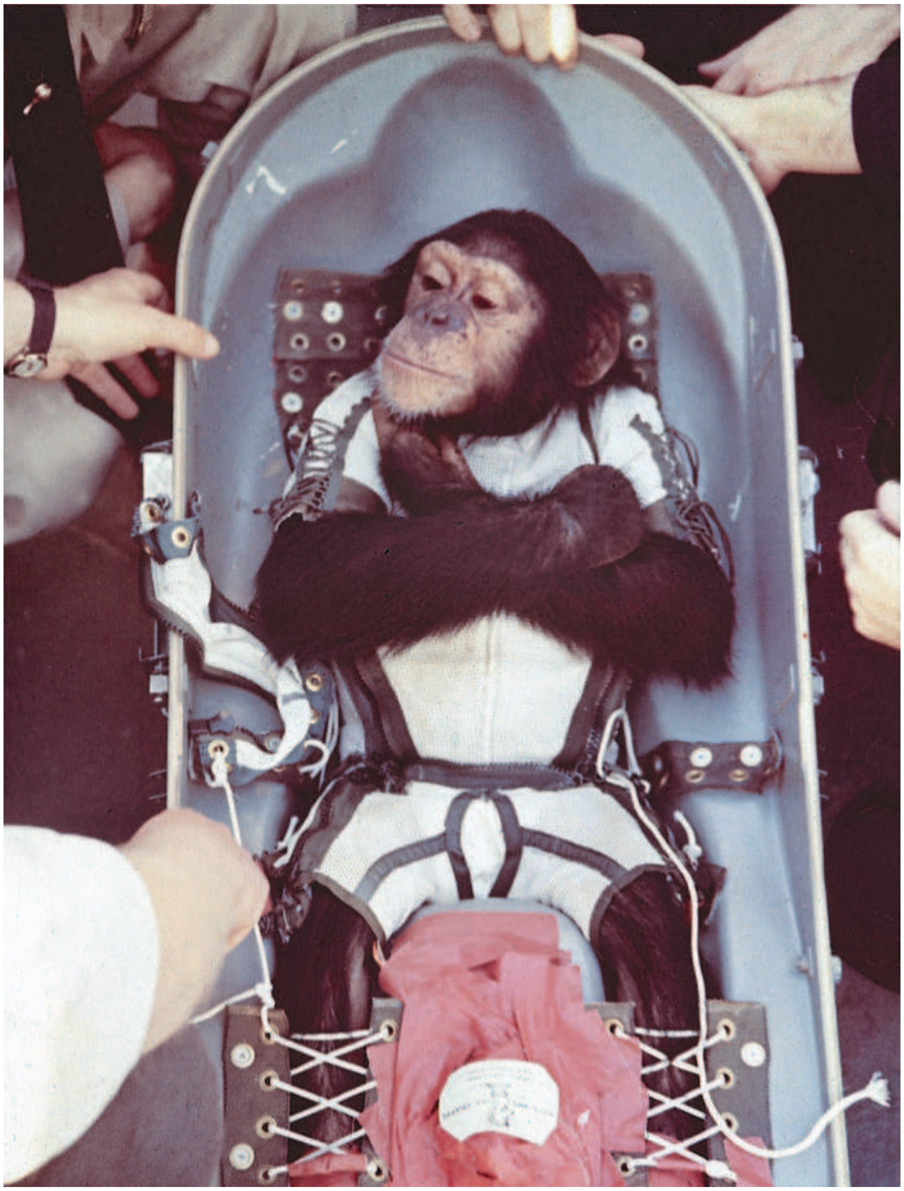
Primates, Non-Human

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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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

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

Internet Resources

Kennedy Space Center. <http://www.ksc.nasa.gov/shuttle/>.

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).

Chad Boutin

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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

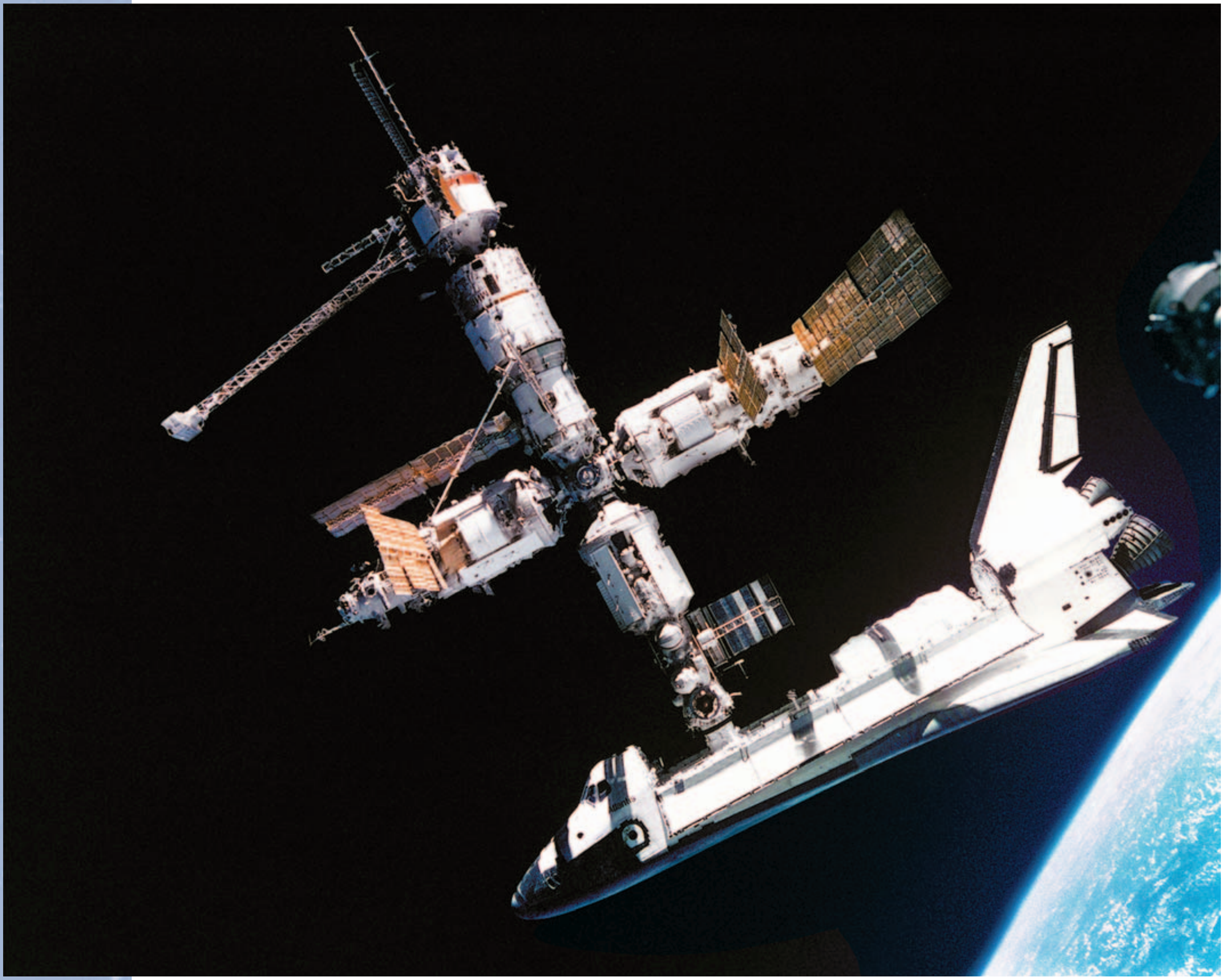
semimajor axis one half of the major axis of an ellipse, equal to the average distance of a planet from the Sun

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).

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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,

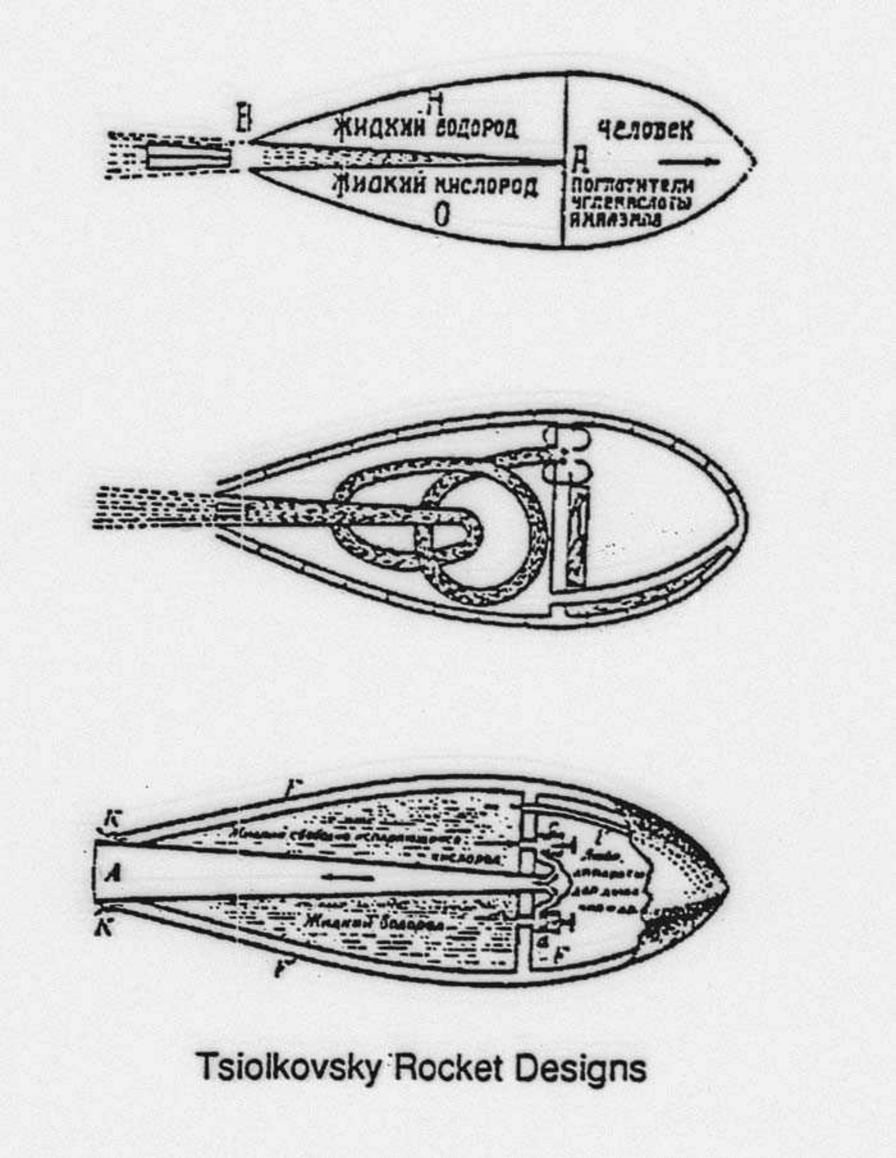

Illustration of three different early rocket designs created by Russian scientist and theorist Konstantin Tsiolkovsky. In the 1920s, Tsiolkovsky solved the mathematical problems that would allow staged rockets to break free of the Earth's atmosphere and continue into space.

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).

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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).

Linda D. Voss

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Skylab

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.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

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.

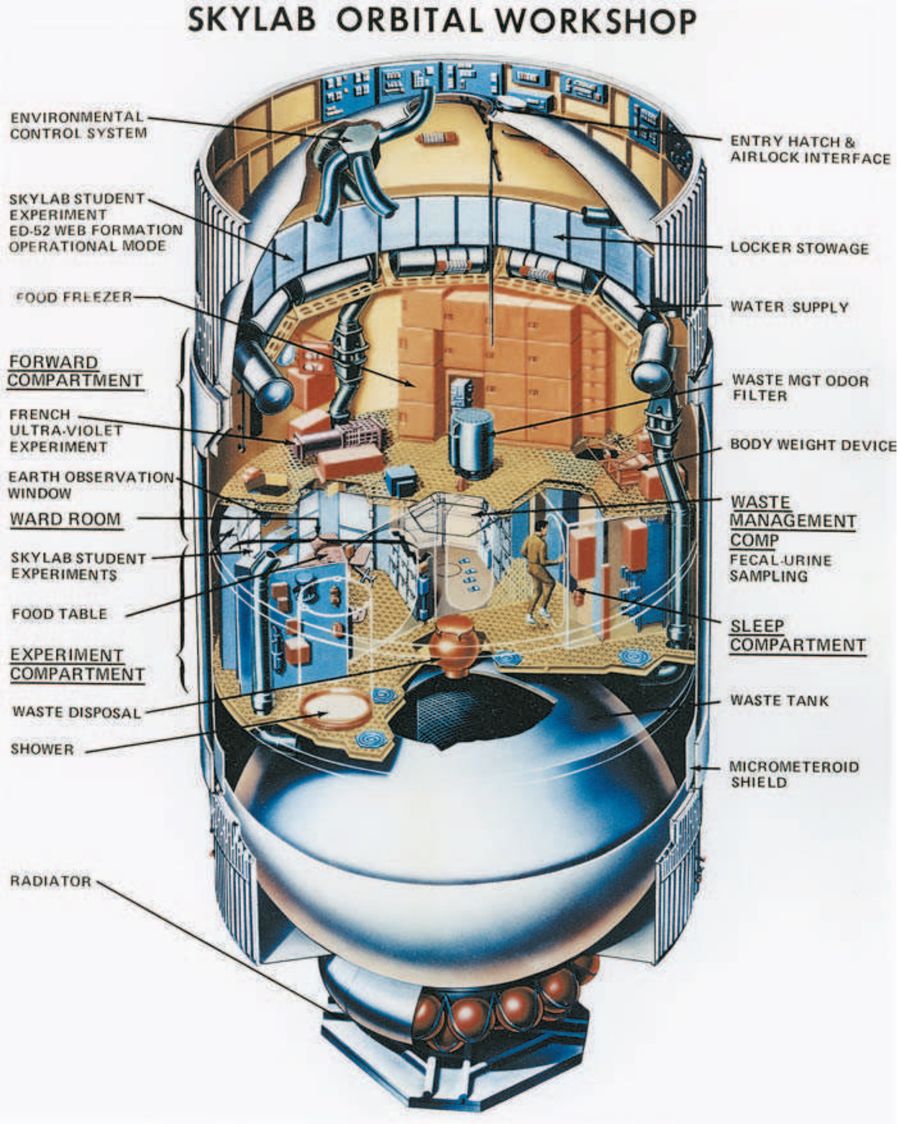
Designed for long-duration missions, the Skylab program was intended to prove that humans could live and work in space for extended periods, to expand knowledge of solar astronomy and earth science, and to provide information that could be used in the development of future space stations. In addition 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.

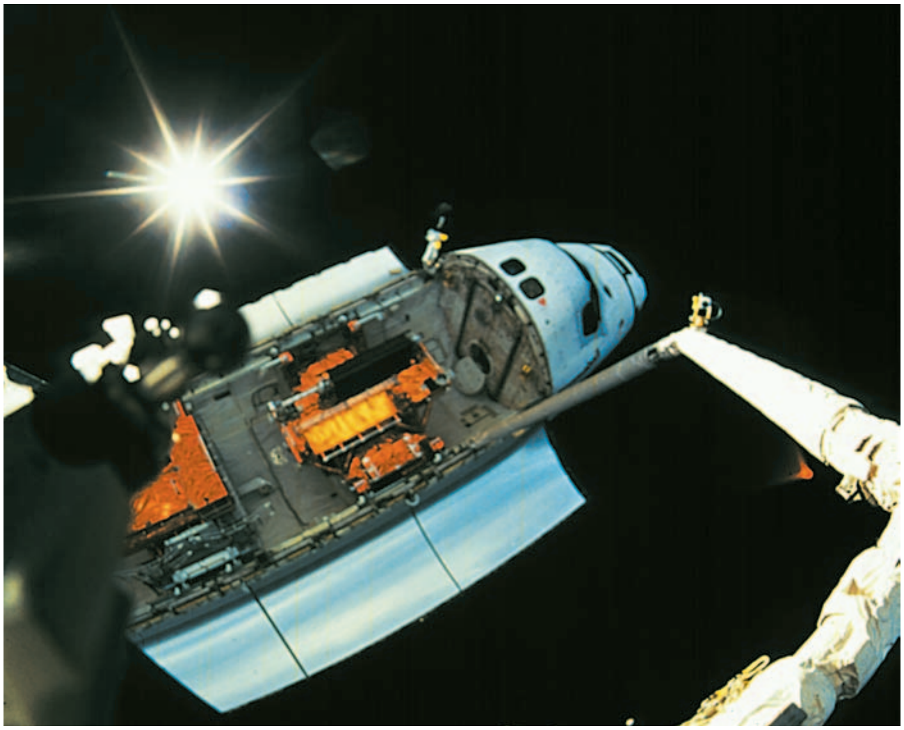
The Space Shuttle's Mission

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 spinoff 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.

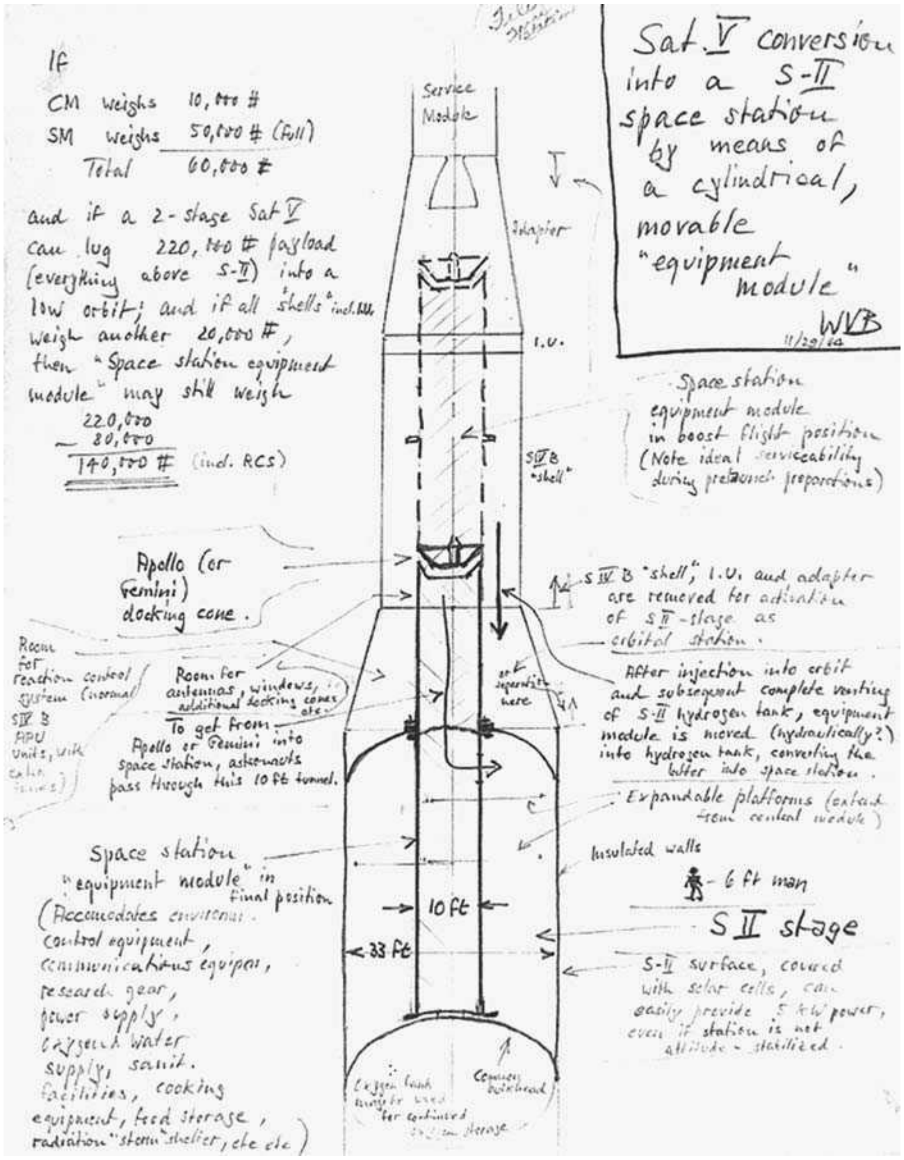
space stations large orbital outposts equipped to support a human crew and designed to remain in orbit for an extended period

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).

David S. F. Portree

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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

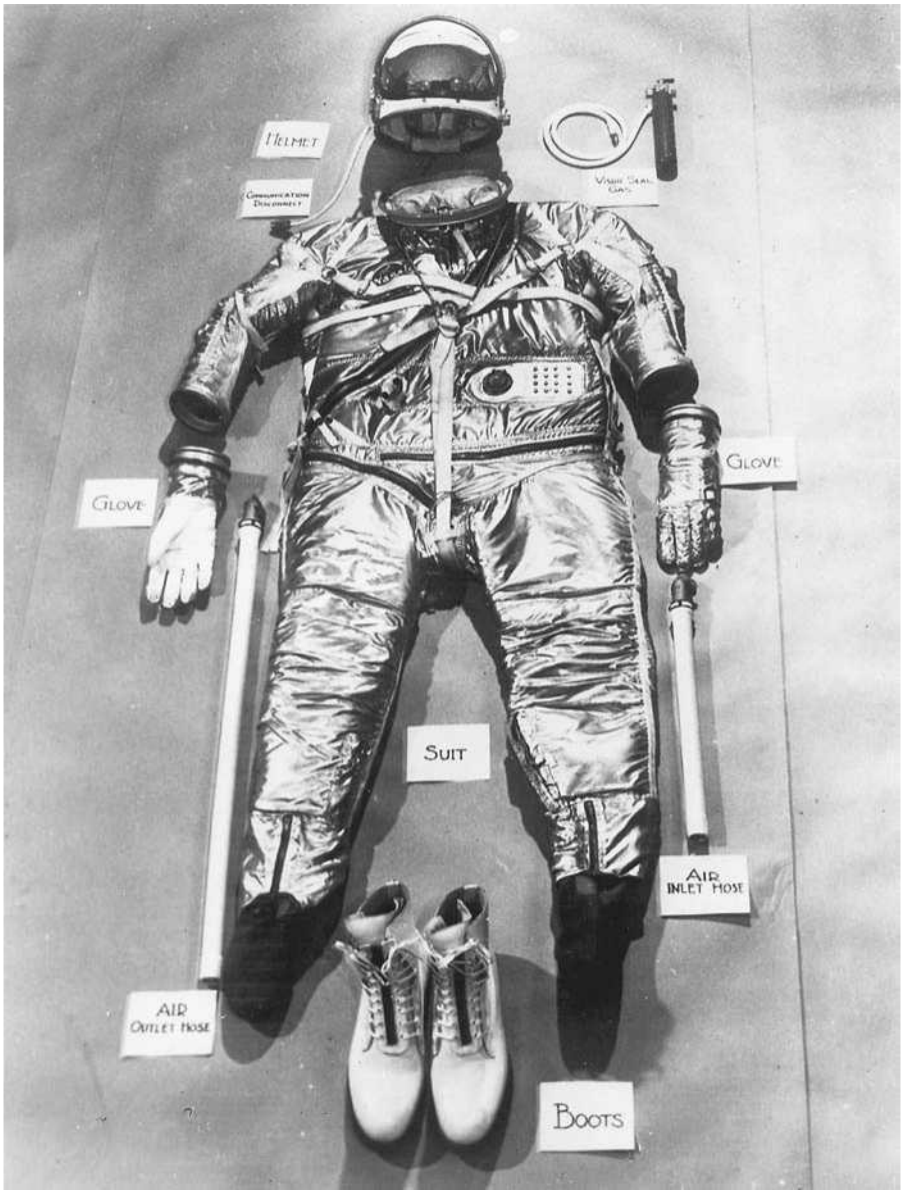
In 1933 Wiley Post, while flying air races, discovered that he could not fly in the jet stream unless he had a pressurized enclosed cabin or wore a pressurized suit. After Post contacted the B. F. Goodrich Company, engineer Russell Colley's group designed a suit that could hold 1.1 kilograms (2.4 pounds) 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).

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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.

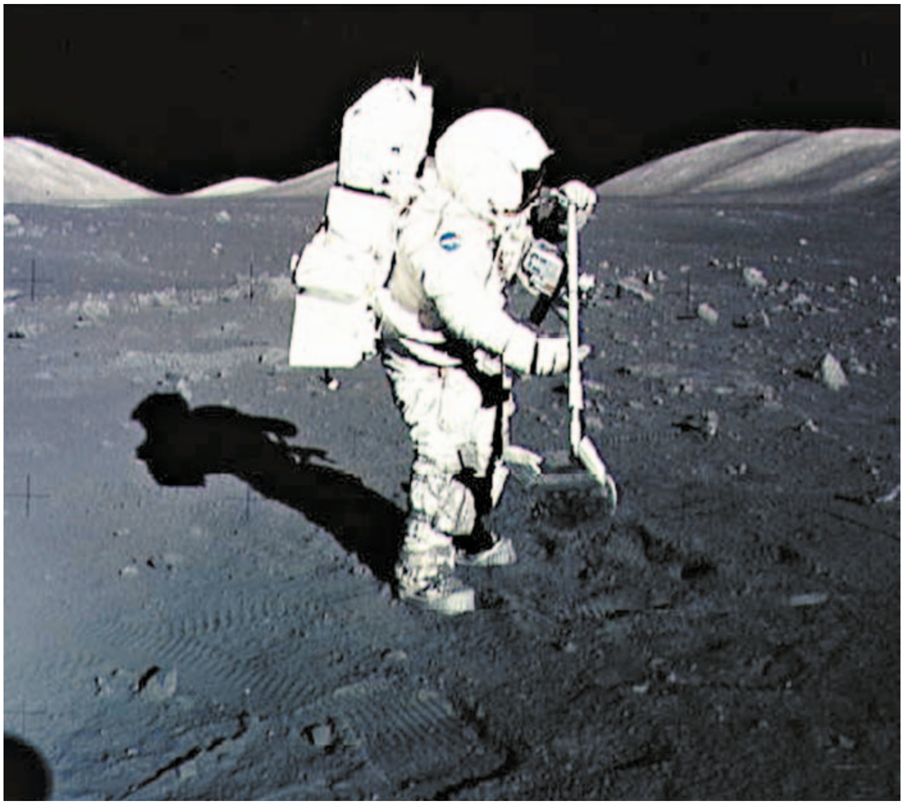
The drill core, used on the last Apollo missions, acquired regolith up to 3 meters in depth with good preservation of **stratigraphy**. These samples contained a very useful record of the cosmic ray history on the Moon. The drill motor provided a rotary/percussive action to penetrate the regolith and 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

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.

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

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.

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

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.

aperture an opening, door, or hatch

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

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).

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

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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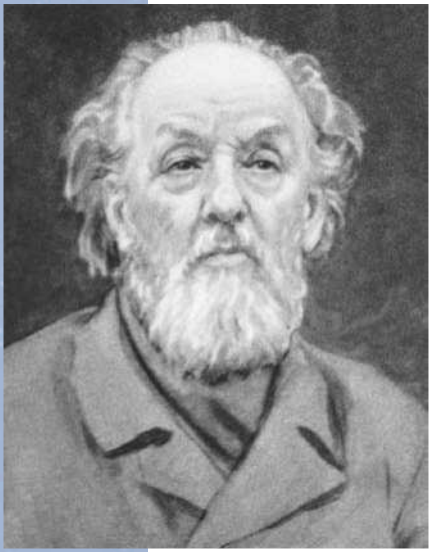

Konstantin Tsiolkovsky was a pioneer in space and rocket research.

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period

Tsiolkovsky, Konstantin

Russian Physicist and Rocket Pioneer

1857–1935

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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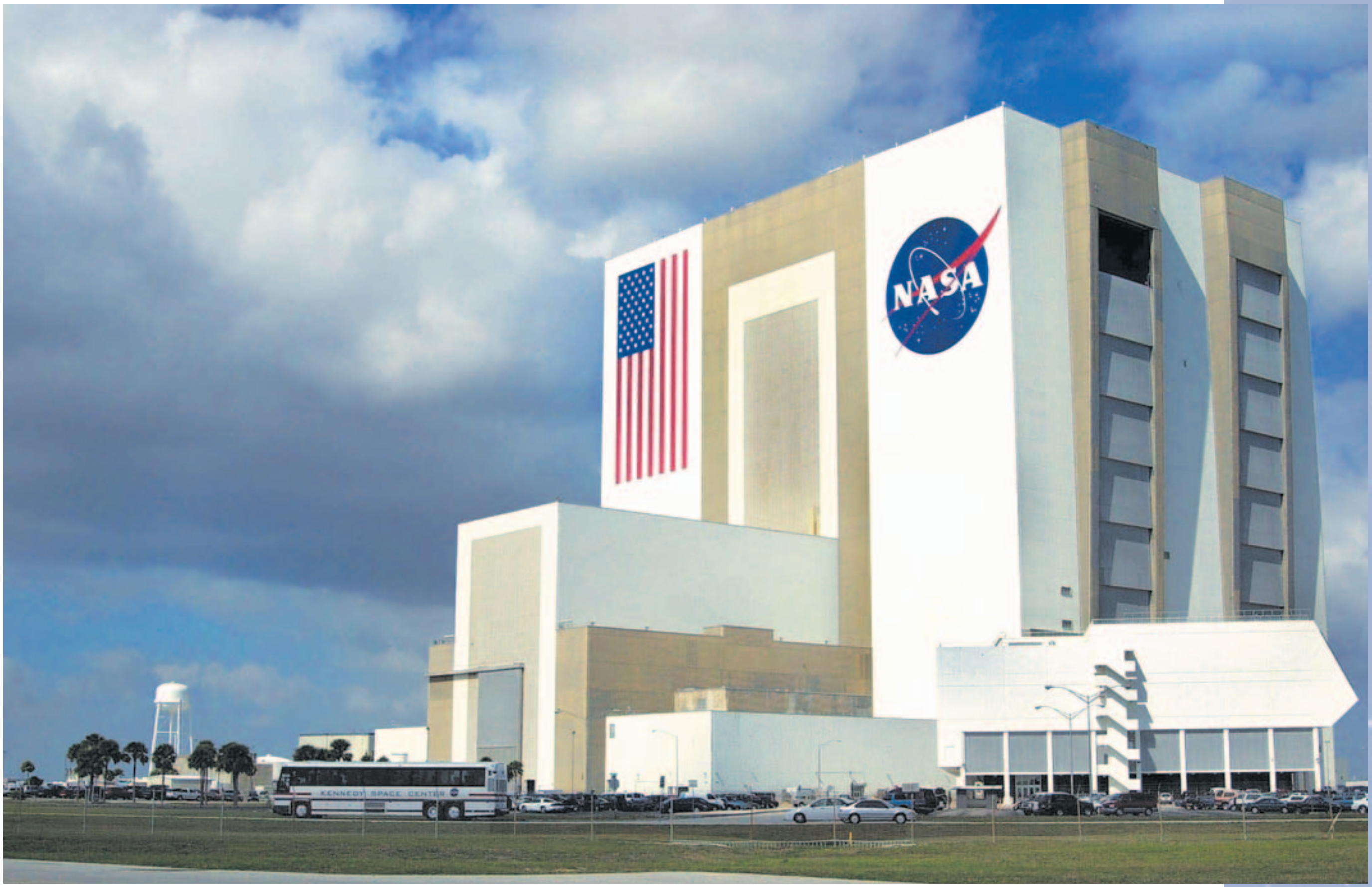
V

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).

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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).

Meridel Ellis

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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).

David S. F. Portree

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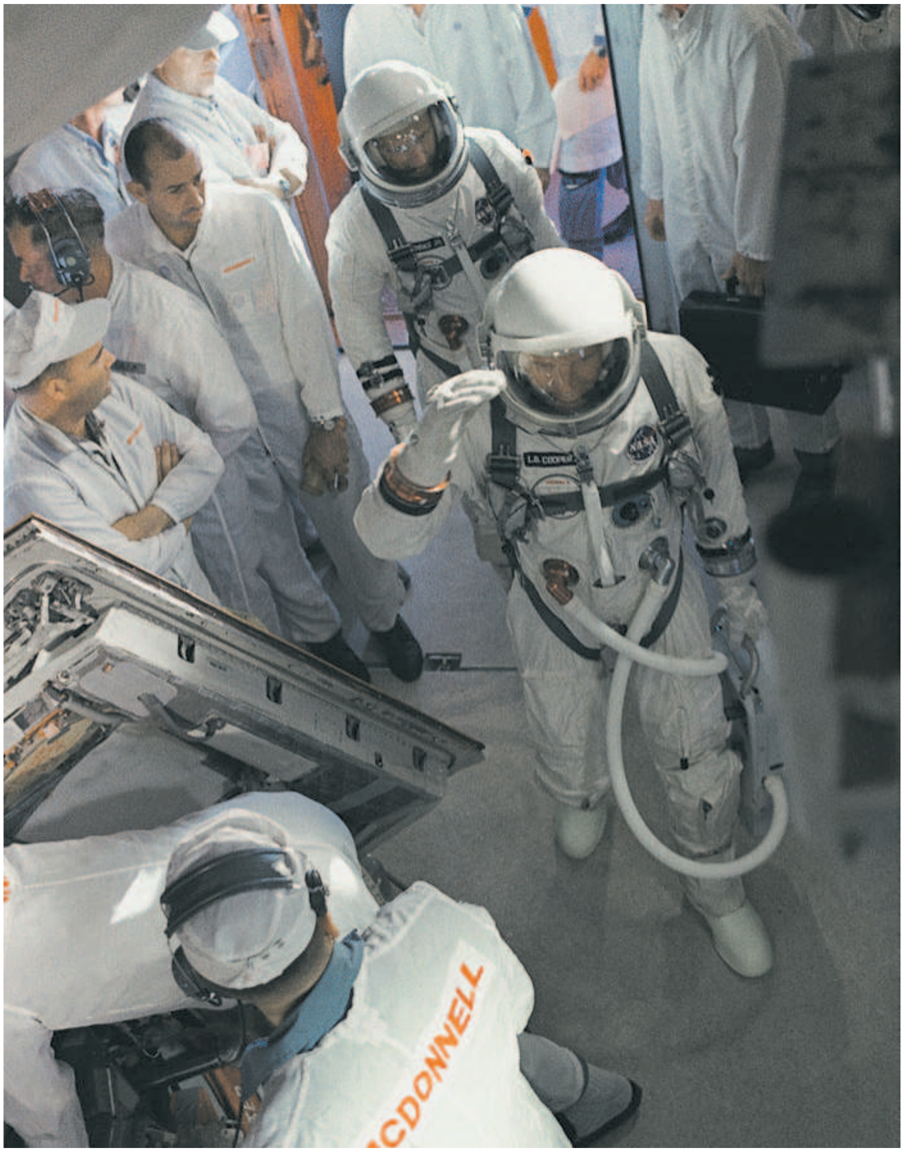
W

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).

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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.

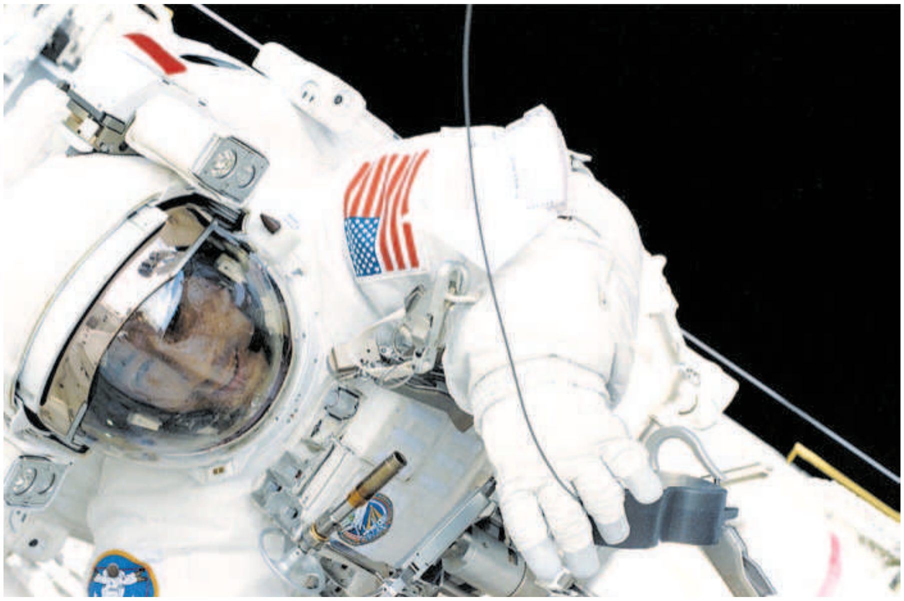
Spaceflight as a Psychological Boost

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."

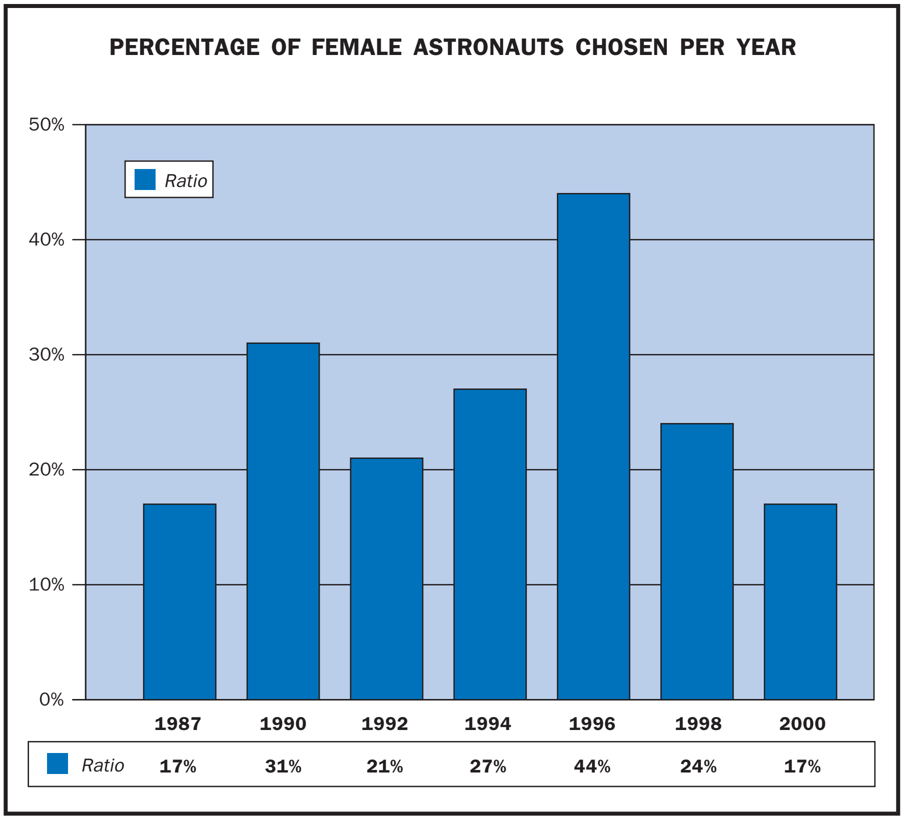
While all the women did well in the testing (and in most cases, better than the men according to one of the doctors in a public statement), NASA dismissed the women before final selections were made. Subsequent hearings in the U.S. Congress on the matter ended in the cancellation of further discussions. 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.

anomalies phenomena that are different from what is expected

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.

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 (VOLume 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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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 × 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

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