Appendix A
Physical Properties of Fluids

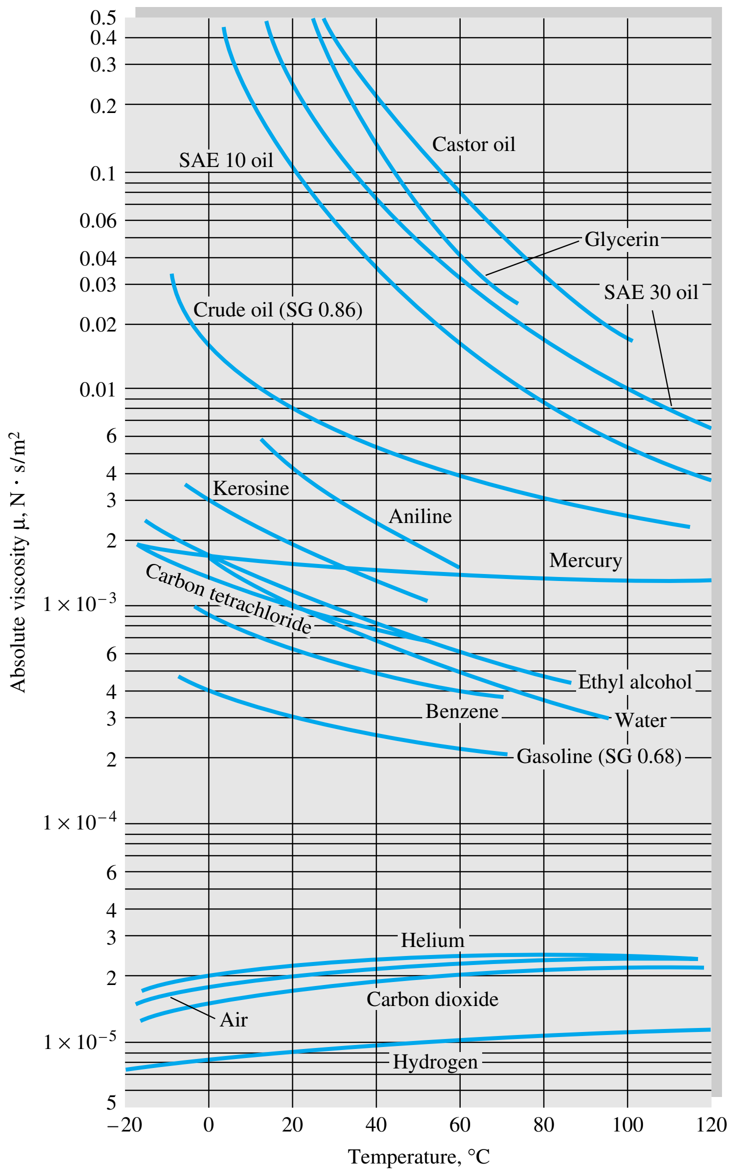


Fig. A.1 Absolute viscosity of common fluids at 1 atm.

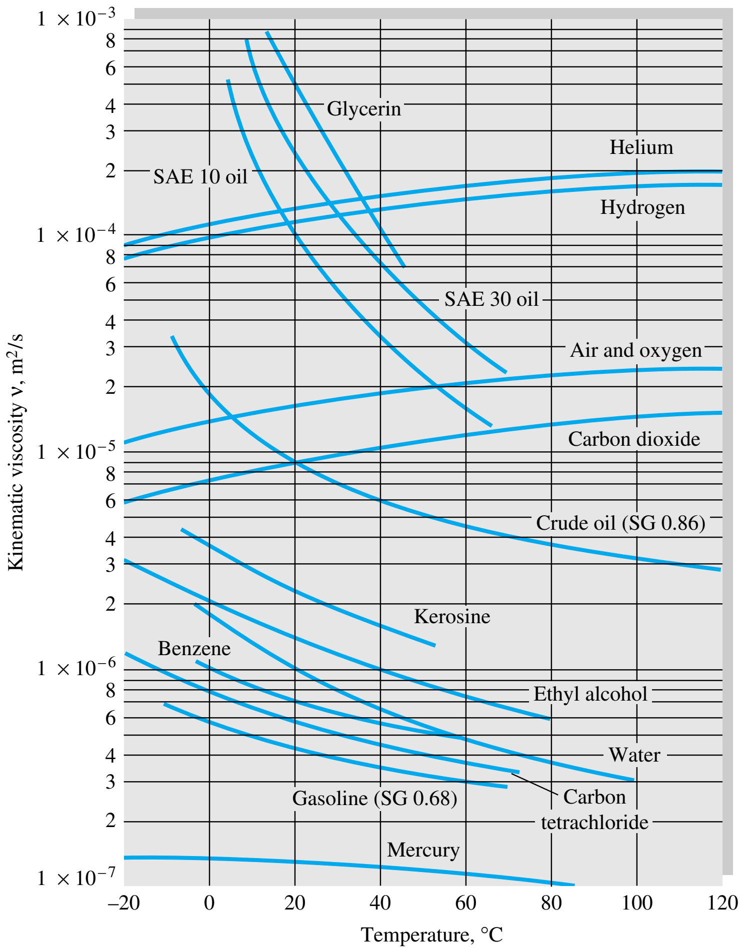


Fig. A.2 Kinematic viscosity of common fluids at 1 atm.

Table A.1 Viscosity and Density of Water at 1 atm

T, °C	ρ, kg/m^3	μ, N · s/m^2	ν, m^2/s	T, °F	ρ, slug/ft^3	μ, lb · s/ft^2	ν, ft^2/s
0	1000	1.788 E-3	1.788 E-6	32	1.940	3.73 E-5	1.925 E-5
10	1000	1.307 E-3	1.307 E-6	50	1.940	2.73 E-5	1.407 E-5
20	998	1.003 E-3	1.005 E-6	68	1.937	2.09 E-5	1.082 E-5
30	996	0.799 E-3	0.802 E-6	86	1.932	1.67 E-5	0.864 E-5
40	992	0.657 E-3	0.662 E-6	104	1.925	1.37 E-5	0.713 E-5
50	988	0.548 E-3	0.555 E-6	122	1.917	1.14 E-5	0.597 E-5
60	983	0.467 E-3	0.475 E-6	140	1.908	0.975 E-5	0.511 E-5
70	978	0.405 E-3	0.414 E-6	158	1.897	0.846 E-5	0.446 E-5
80	972	0.355 E-3	0.365 E-6	176	1.886	0.741 E-5	0.393 E-5
90	965	0.316 E-3	0.327 E-6	194	1.873	0.660 E-5	0.352 E-5
100	958	0.283 E-3	0.295 E-6	212	1.859	0.591 E-5	0.318 E-5

Suggested curve fits for water in the range $0 \le T \le 100$°C:

$$\rho(\text{kg/m}^3) \approx 1000 - 0.0178\,|T°\text{C} - 4°\text{C}|^{1.7} \pm 0.2\%$$

$$\ln \frac{\mu}{\mu_0} \approx -1.704 - 5.306z + 7.003z^2$$

$$z = \frac{273\text{ K}}{T\text{ K}} \qquad \mu_0 = 1.788\text{ E-3 kg/(m} \cdot \text{s)}$$

Table A.2 Viscosity and Density of Air at 1 atm

T, °C	ρ, kg/m^3	μ, N · s/m^2	ν, m^2/s	T, °F	ρ, slug/ft^3	μ, lb · s/ft^2	ν, ft^2/s
−40	1.52	1.51 E-5	0.99 E-5	−40	2.94 E-3	3.16 E-7	1.07 E-4
0	1.29	1.71 E-5	1.33 E-5	32	2.51 E-3	3.58 E-7	1.43 E-4
20	1.20	1.80 E-5	1.50 E-5	68	2.34 E-3	3.76 E-7	1.61 E-4
50	1.09	1.95 E-5	1.79 E-5	122	2.12 E-3	4.08 E-7	1.93 E-4
100	0.946	2.17 E-5	2.30 E-5	212	1.84 E-3	4.54 E-7	2.47 E-4
150	0.835	2.38 E-5	2.85 E-5	302	1.62 E-3	4.97 E-7	3.07 E-4
200	0.746	2.57 E-5	3.45 E-5	392	1.45 E-3	5.37 E-7	3.71 E-4
250	0.675	2.75 E-5	4.08 E-5	482	1.31 E-3	5.75 E-7	4.39 E-4
300	0.616	2.93 E-5	4.75 E-5	572	1.20 E-3	6.11 E-7	5.12 E-4
400	0.525	3.25 E-5	6.20 E-5	752	1.02 E-3	6.79 E-7	6.67 E-4
500	0.457	3.55 E-5	7.77 E-5	932	0.89 E-3	7.41 E-7	8.37 E-4

Suggested curve fits for air:

$$\rho = \frac{p}{RT} \qquad R_{\text{air}} \approx 287\text{ J/(kg} \cdot \text{K)}$$

Power law: $$\frac{\mu}{\mu_0} \approx \left(\frac{T}{T_0}\right)^{0.7}$$

Sutherland law: $$\frac{\mu}{\mu_0} \approx \left(\frac{T}{T_0}\right)^{3/2}\left(\frac{T_0 + S}{T + S}\right) \qquad S_{\text{air}} \approx 110.4\text{ K}$$

with $T_0 = 273$ K, $\mu_0 = 1.71$ E-5 kg/(m · s), and T in kelvins.

Table A.3 Properties of Common Liquids at 1 atm and 20°C (68°F)

Liquid	ρ, kg/m^3	μ, kg/(m · s)	Y, N/m*	p_v, N/m^2	Bulk modulus, N/m^2	Viscosity parameter $C^\dagger$
Ammonia	608	2.20 E-4	2.13 E-2	9.10 E+5	—	1.05
Benzene	881	6.51 E-4	2.88 E-2	1.01 E+4	1.4 E+9	4.34
Carbon tetrachloride	1,590	9.67 E-4	2.70 E-2	1.20 E+4	9.65 E+8	4.45
Ethanol	789	1.20 E-3	2.28 E-2	5.7 E+3	9.0 E+8	5.72
Ethylene glycol	1,117	2.14 E-2	4.84 E-2	1.2 E+1	—	11.7
Freon 12	1,327	2.62 E-4	—	—	—	1.76
Gasoline	680	2.92 E-4	2.16 E-2	5.51 E+4	9.58 E+8	3.68
Glycerin	1,260	1.49	6.33 E-2	1.4 E-2	4.34 E+9	28.0
Kerosine	804	1.92 E-3	2.8 E-2	3.11 E+3	1.6 E+9	5.56
Mercury	13,550	1.56 E-3	4.84 E-1	1.1 E-3	2.55 E+10	1.07
Methanol	791	5.98 E-4	2.25 E-2	1.34 E+4	8.3 E+8	4.63
SAE 10W oil	870	1.04 E-1‡	3.6 E-2	—	1.31 E+9	15.7
SAE 10W30 oil	876	1.7 E-1‡	—	—	—	14.0
SAE 30W oil	891	2.9 E-1‡	3.5 E-2	—	1.38 E+9	18.3
SAE 50W oil	902	8.6 E-1‡	—	—	—	20.2
Water	998	1.00 E-3	7.28 E-2	2.34 E+3	2.19 E+9	Table A.1
Seawater (30%)	1,025	1.07 E-3	7.28 E-2	2.34 E+3	2.33 E+9	7.28

*In contact with air.
†The viscosity-temperature variation of these liquids may be fitted to the empirical expression

$$\frac{\mu}{\mu_{20^\circ\mathrm{C}}} \approx \exp\left[C\left(\frac{293\ \mathrm{K}}{T\ \mathrm{K}} - 1\right)\right]$$

with accuracy of ±6 percent in the range $0 \le T \le 100°\mathrm{C}$.
‡Representative values. The SAE oil classifications allow a viscosity variation of up to ±50 percent, especially at lower temperatures.

Table A.4 Properties of Common Gases at 1 atm and 20°C (68°F)

Gas	Molecular weight	R, m^2/(s^2 · K)	ρg, N/m^3	μ, N · s/m^2	Specific-heat ratio	Power-law exponent $n^\dagger$
H_2	2.016	4124	0.822	9.05 E-6	1.41	0.68
He	4.003	2077	1.63	1.97 E-5	1.66	0.67
H_2O	18.02	461	7.35	1.02 E-5	1.33	1.15
Ar	39.944	208	16.3	2.24 E-5	1.67	0.72
Dry air	28.96	287	11.8	1.80 E-5	1.40	0.67
CO_2	44.01	189	17.9	1.48 E-5	1.30	0.79
CO	28.01	297	11.4	1.82 E-5	1.40	0.71
N_2	28.02	297	11.4	1.76 E-5	1.40	0.67
O_2	32.00	260	13.1	2.00 E-5	1.40	0.69
NO	30.01	277	12.1	1.90 E-5	1.40	0.78
N_2O	44.02	189	17.9	1.45 E-5	1.31	0.89
Cl_2	70.91	117	28.9	1.03 E-5	1.34	1.00
CH_4	16.04	518	6.54	1.34 E-5	1.32	0.87

†The power-law curve fit, Eq. (1.27), $\mu/\mu_{293\mathrm{K}} \approx (T/293)^n$, fits these gases to within ±4 percent in the range $250 \le T \le 1000$ K. The temperature must be in kelvins.

Table A.5 Surface Tension, Vapor Pressure, and Sound Speed of Water

T, °C	Y, N/m	p_v, kPa	*a*, m/s
0	0.0756	0.611	1402
10	0.0742	1.227	1447
20	0.0728	2.337	1482
30	0.0712	4.242	1509
40	0.0696	7.375	1529
50	0.0679	12.34	1542
60	0.0662	19.92	1551
70	0.0644	31.16	1553
80	0.0626	47.35	1554
90	0.0608	70.11	1550
100	0.0589	101.3	1543
120	0.0550	198.5	1518
140	0.0509	361.3	1483
160	0.0466	617.8	1440
180	0.0422	1,002	1389
200	0.0377	1,554	1334
220	0.0331	2,318	1268
240	0.0284	3,344	1192
260	0.0237	4,688	1110
280	0.0190	6,412	1022
300	0.0144	8,581	920
320	0.0099	11,274	800
340	0.0056	14,586	630
360	0.0019	18,651	370
374*	0.0*	22,090*	0*

*Critical point.

Table A.6 Properties of the Standard Atmosphere

z, m	*T*, K	*p*, Pa	ρ, kg/m^3	*a*, m/s
−500	291.41	107,508	1.2854	342.2
0	288.16	101,350	1.2255	340.3
500	284.91	95,480	1.1677	338.4
1,000	281.66	89,889	1.1120	336.5
1,500	278.41	84,565	1.0583	334.5
2,000	275.16	79,500	1.0067	332.6
2,500	271.91	74,684	0.9570	330.6
3,000	268.66	70,107	0.9092	328.6
3,500	265.41	65,759	0.8633	326.6
4,000	262.16	61,633	0.8191	324.6
4,500	258.91	57,718	0.7768	322.6
5,000	255.66	54,008	0.7361	320.6
5,500	252.41	50,493	0.6970	318.5
6,000	249.16	47,166	0.6596	316.5
6,500	245.91	44,018	0.6237	314.4
7,000	242.66	41,043	0.5893	312.3
7,500	239.41	38,233	0.5564	310.2
8,000	236.16	35,581	0.5250	308.1
8,500	232.91	33,080	0.4949	306.0
9,000	229.66	30,723	0.4661	303.8
9,500	226.41	28,504	0.4387	301.7
10,000	223.16	26,416	0.4125	299.5
10,500	219.91	24,455	0.3875	297.3
11,000	216.66	22,612	0.3637	295.1
11,500	216.66	20,897	0.3361	295.1
12,000	216.66	19,312	0.3106	295.1
12,500	216.66	17,847	0.2870	295.1
13,000	216.66	16,494	0.2652	295.1
13,500	216.66	15,243	0.2451	295.1
14,000	216.66	14,087	0.2265	295.1
14,500	216.66	13,018	0.2094	295.1
15,000	216.66	12,031	0.1935	295.1
15,500	216.66	11,118	0.1788	295.1
16,000	216.66	10,275	0.1652	295.1
16,500	216.66	9,496	0.1527	295.1
17,000	216.66	8,775	0.1411	295.1
17,500	216.66	8,110	0.1304	295.1
18,000	216.66	7,495	0.1205	295.1
18,500	216.66	6,926	0.1114	295.1
19,000	216.66	6,401	0.1029	295.1
19,500	216.66	5,915	0.0951	295.1
20,000	216.66	5,467	0.0879	295.1
22,000	218.6	4,048	0.0645	296.4
24,000	220.6	2,972	0.0469	297.8
26,000	222.5	2,189	0.0343	299.1
28,000	224.5	1,616	0.0251	300.4
30,000	226.5	1,197	0.0184	301.7
40,000	250.4	287	0.0040	317.2
50,000	270.7	80	0.0010	329.9
60,000	255.7	22	0.0003	320.6
70,000	219.7	6	0.0001	297.2

Appendix B
Compressible-Flow Tables

Table B.1
Isentropic Flow of a Perfect Gas, $k = 1.4$

Ma	p/p_0	ρ/ρ_0	T/T_0	A/A^*
0.0	1.0	1.0	1.0	∞
0.02	0.9997	0.9998	0.9999	28.9421
0.04	0.9989	0.9992	0.9997	14.4815
0.06	0.9975	0.9982	0.9993	9.6659
0.08	0.9955	0.9968	0.9987	7.2616
0.1	0.9930	0.9950	0.9980	5.8218
0.12	0.9900	0.9928	0.9971	4.8643
0.14	0.9864	0.9903	0.9961	4.1824
0.16	0.9823	0.9873	0.9949	3.6727
0.18	0.9776	0.9840	0.9936	3.2779
0.2	0.9725	0.9803	0.9921	2.9635
0.22	0.9668	0.9762	0.9904	2.7076
0.24	0.9607	0.9718	0.9886	2.4956
0.26	0.9541	0.9670	0.9867	2.3173
0.28	0.9470	0.9619	0.9846	2.1656
0.3	0.9395	0.9564	0.9823	2.0351
0.32	0.9315	0.9506	0.9799	1.9219
0.34	0.9231	0.9445	0.9774	1.8229
0.36	0.9143	0.9380	0.9747	1.7358
0.38	0.9052	0.9313	0.9719	1.6587
0.4	0.8956	0.9243	0.9690	1.5901
0.42	0.8857	0.9170	0.9659	1.5289
0.44	0.8755	0.9094	0.9627	1.4740
0.46	0.8650	0.9016	0.9594	1.4246
0.48	0.8541	0.8935	0.9559	1.3801
0.5	0.8430	0.8852	0.9524	1.3398
0.52	0.8317	0.8766	0.9487	1.3034
0.54	0.8201	0.8679	0.9449	1.2703
0.56	0.8082	0.8589	0.9410	1.2403
0.58	0.7962	0.8498	0.9370	1.2130
0.6	0.7840	0.8405	0.9328	1.1882
0.62	0.7716	0.8310	0.9286	1.1656
0.64	0.7591	0.8213	0.9243	1.1451
0.66	0.7465	0.8115	0.9199	1.1265
0.68	0.7338	0.8016	0.9153	1.1097
0.7	0.7209	0.7916	0.9107	1.0944
0.72	0.7080	0.7814	0.9061	1.0806
0.74	0.6951	0.7712	0.9013	1.0681
0.76	0.6821	0.7609	0.8964	1.0570
0.78	0.6690	0.7505	0.8915	1.0471
0.8	0.6560	0.7400	0.8865	1.0382
0.82	0.6430	0.7295	0.8815	1.0305
0.84	0.6300	0.7189	0.8763	1.0237
0.86	0.6170	0.7083	0.8711	1.0179
0.88	0.6041	0.6977	0.8659	1.0129
0.9	0.5913	0.6870	0.8606	1.0089
0.92	0.5785	0.6764	0.8552	1.0056
0.94	0.5658	0.6658	0.8498	1.0031
0.96	0.5532	0.6551	0.8444	1.0014
0.98	0.5407	0.6445	0.8389	1.0003
1.0	0.5283	0.6339	0.8333	1.0000
1.02	0.5160	0.6234	0.8278	1.0003
1.04	0.5039	0.6129	0.8222	1.0013
1.06	0.4919	0.6024	0.8165	1.0029
1.08	0.4800	0.5920	0.8108	1.0051
1.1	0.4684	0.5817	0.8052	1.0079
1.12	0.4568	0.5714	0.7994	1.0113
1.14	0.4455	0.5612	0.7937	1.0153
1.16	0.4343	0.5511	0.7879	1.0198
1.18	0.4232	0.5411	0.7822	1.0248
1.2	0.4124	0.5311	0.7764	1.0304
1.22	0.4017	0.5213	0.7706	1.0366
1.24	0.3912	0.5115	0.7648	1.0432
1.26	0.3809	0.5019	0.7590	1.0504
1.28	0.3708	0.4923	0.7532	1.0581
1.3	0.3609	0.4829	0.7474	1.0663
1.32	0.3512	0.4736	0.7416	1.0750
1.34	0.3417	0.4644	0.7358	1.0842
1.36	0.3323	0.4553	0.7300	1.0940
1.38	0.3232	0.4463	0.7242	1.1042
1.4	0.3142	0.4374	0.7184	1.1149
1.42	0.3055	0.4287	0.7126	1.1262
1.44	0.2969	0.4201	0.7069	1.1379
1.46	0.2886	0.4116	0.7011	1.1501

Table B.1 (*Cont.*) Isentropic Flow of a Perfect Gas, $k = 1.4$

Ma	p/p_0	ρ/ρ_0	T/T_0	A/A^*	Ma	p/p_0	ρ/ρ_0	T/T_0	A/A^*
1.48	0.2804	0.4032	0.6954	1.1629	2.56	0.0533	0.1232	0.4328	2.7891
1.5	0.2724	0.3950	0.6897	1.1762	2.58	0.0517	0.1205	0.4289	2.8420
1.52	0.2646	0.3869	0.6840	1.1899	2.6	0.0501	0.1179	0.4252	2.8960
1.54	0.2570	0.3789	0.6783	1.2042	2.62	0.0486	0.1153	0.4214	2.9511
1.56	0.2496	0.3710	0.6726	1.2190	2.64	0.0471	0.1128	0.4177	3.0073
1.58	0.2423	0.3633	0.6670	1.2344	2.66	0.0457	0.1103	0.4141	3.0647
1.6	0.2353	0.3557	0.6614	1.2502	2.68	0.0443	0.1079	0.4104	3.1233
1.62	0.2284	0.3483	0.6558	1.2666	2.7	0.0430	0.1056	0.4068	3.1830
1.64	0.2217	0.3409	0.6502	1.2836	2.72	0.0417	0.1033	0.4033	3.2440
1.66	0.2151	0.3337	0.6447	1.3010	2.74	0.0404	0.1010	0.3998	3.3061
1.68	0.2088	0.3266	0.6392	1.3190	2.76	0.0392	0.0989	0.3963	3.3695
1.7	0.2026	0.3197	0.6337	1.3376	2.78	0.0380	0.0967	0.3928	3.4342
1.72	0.1966	0.3129	0.6283	1.3567	2.8	0.0368	0.0946	0.3894	3.5001
1.74	0.1907	0.3062	0.6229	1.3764	2.82	0.0357	0.0926	0.3860	3.5674
1.76	0.1850	0.2996	0.6175	1.3967	2.84	0.0347	0.0906	0.3827	3.6359
1.78	0.1794	0.2931	0.6121	1.4175	2.86	0.0336	0.0886	0.3794	3.7058
1.8	0.1740	0.2868	0.6068	1.4390	2.88	0.0326	0.0867	0.3761	3.7771
1.82	0.1688	0.2806	0.6015	1.4610	2.9	0.0317	0.0849	0.3729	3.8498
1.84	0.1637	0.2745	0.5963	1.4836	2.92	0.0307	0.0831	0.3696	3.9238
1.86	0.1587	0.2686	0.5910	1.5069	2.94	0.0298	0.0813	0.3665	3.9993
1.88	0.1539	0.2627	0.5859	1.5308	2.96	0.0289	0.0796	0.3633	4.0763
1.9	0.1492	0.2570	0.5807	1.5553	2.98	0.0281	0.0779	0.3602	4.1547
1.92	0.1447	0.2514	0.5756	1.5804	3.0	0.0272	0.0762	0.3571	4.2346
1.94	0.1403	0.2459	0.5705	1.6062	3.02	0.0264	0.0746	0.3541	4.3160
1.96	0.1360	0.2405	0.5655	1.6326	3.04	0.0256	0.0730	0.3511	4.3990
1.98	0.1318	0.2352	0.5605	1.6597	3.06	0.0249	0.0715	0.3481	4.4835
2.0	0.1278	0.2300	0.5556	1.6875	3.08	0.0242	0.0700	0.3452	4.5696
2.02	0.1239	0.2250	0.5506	1.7160	3.1	0.0234	0.0685	0.3422	4.6573
2.04	0.1201	0.2200	0.5458	1.7451	3.12	0.0228	0.0671	0.3393	4.7467
2.06	0.1164	0.2152	0.5409	1.7750	3.14	0.0221	0.0657	0.3365	4.8377
2.08	0.1128	0.2104	0.5361	1.8056	3.16	0.0215	0.0643	0.3337	4.9304
2.1	0.1094	0.2058	0.5313	1.8369	3.18	0.0208	0.0630	0.3309	5.0248
2.12	0.1060	0.2013	0.5266	1.8690	3.2	0.0202	0.0617	0.3281	5.1210
2.14	0.1027	0.1968	0.5219	1.9018	3.22	0.0196	0.0604	0.3253	5.2189
2.16	0.0996	0.1925	0.5173	1.9354	3.24	0.0191	0.0591	0.3226	5.3186
2.18	0.0965	0.1882	0.5127	1.9698	3.26	0.0185	0.0579	0.3199	5.4201
2.2	0.0935	0.1841	0.5081	2.0050	3.28	0.0180	0.0567	0.3173	5.5234
2.22	0.0906	0.1800	0.5036	2.0409	3.3	0.0175	0.0555	0.3147	5.6286
2.24	0.0878	0.1760	0.4991	2.0777	3.32	0.0170	0.0544	0.3121	5.7358
2.26	0.0851	0.1721	0.4947	2.1153	3.34	0.0165	0.0533	0.3095	5.8448
2.28	0.0825	0.1683	0.4903	2.1538	3.36	0.0160	0.0522	0.3069	5.9558
2.3	0.0800	0.1646	0.4859	2.1931	3.38	0.0156	0.0511	0.3044	6.0687
2.32	0.0775	0.1609	0.4816	2.2333	3.4	0.0151	0.0501	0.3019	6.1837
2.34	0.0751	0.1574	0.4773	2.2744	3.42	0.0147	0.0491	0.2995	6.3007
2.36	0.0728	0.1539	0.4731	2.3164	3.44	0.0143	0.0481	0.2970	6.4198
2.38	0.0706	0.1505	0.4688	2.3593	3.46	0.0139	0.0471	0.2946	6.5409
2.4	0.0684	0.1472	0.4647	2.4031	3.48	0.0135	0.0462	0.2922	6.6642
2.42	0.0663	0.1439	0.4606	2.4479	3.5	0.0131	0.0452	0.2899	6.7896
2.44	0.0643	0.1408	0.4565	2.4936	3.52	0.0127	0.0443	0.2875	6.9172
2.46	0.0623	0.1377	0.4524	2.5403	3.54	0.0124	0.0434	0.2852	7.0471
2.48	0.0604	0.1346	0.4484	2.5880	3.56	0.0120	0.0426	0.2829	7.1791
2.5	0.0585	0.1317	0.4444	2.6367	3.58	0.0117	0.0417	0.2806	7.3135
2.52	0.0567	0.1288	0.4405	2.6865	3.6	0.0114	0.0409	0.2784	7.4501
2.54	0.0550	0.1260	0.4366	2.7372	3.62	0.0111	0.0401	0.2762	7.5891

Table B.1 (*Cont.*) Isentropic Flow of a Perfect Gas, $k = 1.4$

Ma	p/p_0	ρ/ρ_0	T/T_0	A/A^*	Ma	p/p_0	ρ/ρ_0	T/T_0	A/A^*
3.64	0.0108	0.0393	0.2740	7.7305	4.34	0.0042	0.0202	0.2098	14.4456
3.66	0.0105	0.0385	0.2718	7.8742	4.36	0.0041	0.0198	0.2083	14.6965
3.68	0.0102	0.0378	0.2697	8.0204	4.38	0.0040	0.0194	0.2067	14.9513
3.7	0.0099	0.0370	0.2675	8.1691	4.4	0.0039	0.0191	0.2053	15.2099
3.72	0.0096	0.0363	0.2654	8.3202	4.42	0.0038	0.0187	0.2038	15.4724
3.74	0.0094	0.0356	0.2633	8.4739	4.44	0.0037	0.0184	0.2023	15.7388
3.76	0.0091	0.0349	0.2613	8.6302	4.46	0.0036	0.0181	0.2009	16.0092
3.78	0.0089	0.0342	0.2592	8.7891	4.48	0.0035	0.0178	0.1994	16.2837
3.8	0.0086	0.0335	0.2572	8.9506	4.5	0.0035	0.0174	0.1980	16.5622
3.82	0.0084	0.0329	0.2552	9.1148	4.52	0.0034	0.0171	0.1966	16.8449
3.84	0.0082	0.0323	0.2532	9.2817	4.54	0.0033	0.0168	0.1952	17.1317
3.86	0.0080	0.0316	0.2513	9.4513	4.56	0.0032	0.0165	0.1938	17.4228
3.88	0.0077	0.0310	0.2493	9.6237	4.58	0.0031	0.0163	0.1925	17.7181
3.9	0.0075	0.0304	0.2474	9.7990	4.6	0.0031	0.0160	0.1911	18.0178
3.92	0.0073	0.0299	0.2455	9.9771	4.62	0.0030	0.0157	0.1898	18.3218
3.94	0.0071	0.0293	0.2436	10.1581	4.64	0.0029	0.0154	0.1885	18.6303
3.96	0.0069	0.0287	0.2418	10.3420	4.66	0.0028	0.0152	0.1872	18.9433
3.98	0.0068	0.0282	0.2399	10.5289	4.68	0.0028	0.0149	0.1859	19.2608
4.0	0.0066	0.0277	0.2381	10.7188	4.7	0.0027	0.0146	0.1846	19.5828
4.02	0.0064	0.0271	0.2363	10.9117	4.72	0.0026	0.0144	0.1833	19.9095
4.04	0.0062	0.0266	0.2345	11.1077	4.74	0.0026	0.0141	0.1820	20.2409
4.06	0.0061	0.0261	0.2327	11.3068	4.76	0.0025	0.0139	0.1808	20.5770
4.08	0.0059	0.0256	0.2310	11.5091	4.78	0.0025	0.0137	0.1795	20.9179
4.1	0.0058	0.0252	0.2293	11.7147	4.8	0.0024	0.0134	0.1783	21.2637
4.12	0.0056	0.0247	0.2275	11.9234	4.82	0.0023	0.0132	0.1771	21.6144
4.14	0.0055	0.0242	0.2258	12.1354	4.84	0.0023	0.0130	0.1759	21.9700
4.16	0.0053	0.0238	0.2242	12.3508	4.86	0.0022	0.0128	0.1747	22.3306
4.18	0.0052	0.0234	0.2225	12.5695	4.88	0.0022	0.0125	0.1735	22.6963
4.2	0.0051	0.0229	0.2208	12.7916	4.9	0.0021	0.0123	0.1724	23.0671
4.22	0.0049	0.0225	0.2192	13.0172	4.92	0.0021	0.0121	0.1712	23.4431
4.24	0.0048	0.0221	0.2176	13.2463	4.94	0.0020	0.0119	0.1700	23.8243
4.26	0.0047	0.0217	0.2160	13.4789	4.96	0.0020	0.0117	0.1689	24.2109
4.28	0.0046	0.0213	0.2144	13.7151	4.98	0.0019	0.0115	0.1678	24.6027
4.3	0.0044	0.0209	0.2129	13.9549	5.0	0.0019	0.0113	0.1667	25.0000
4.32	0.0043	0.0205	0.2113	14.1984					

Table B.2 Normal-Shock Relations for a Perfect Gas, $k = 1.4$

Ma_{n1}	Ma_{n2}	p_2/p_1	$V_1/V_2 = \rho_2/\rho_1$	T_2/T_1	p_{02}/p_{01}	A_2^*/A_1^*
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.02	0.9805	1.0471	1.0334	1.0132	1.0000	1.0000
1.04	0.9620	1.0952	1.0671	1.0263	0.9999	1.0001
1.06	0.9444	1.1442	1.1009	1.0393	0.9998	1.0002
1.08	0.9277	1.1941	1.1349	1.0522	0.9994	1.0006
1.1	0.9118	1.2450	1.1691	1.0649	0.9989	1.0011
1.12	0.8966	1.2968	1.2034	1.0776	0.9982	1.0018
1.14	0.8820	1.3495	1.2378	1.0903	0.9973	1.0027
1.16	0.8682	1.4032	1.2723	1.1029	0.9961	1.0040
1.18	0.8549	1.4578	1.3069	1.1154	0.9946	1.0055
1.2	0.8422	1.5133	1.3416	1.1280	0.9928	1.0073
1.22	0.8300	1.5698	1.3764	1.1405	0.9907	1.0094
1.24	0.8183	1.6272	1.4112	1.1531	0.9884	1.0118

Table B.2 (*Cont.*) Normal-Shock Relations for a Perfect Gas, $k = 1.4$

Ma_{n1}	Ma_{n2}	p_2/p_1	$V_1/V_2 = \rho_2/\rho_1$	T_2/T_1	p_{02}/p_{01}	A_2^*/A_1^*
1.26	0.8071	1.6855	1.4460	1.1657	0.9857	1.0145
1.28	0.7963	1.7448	1.4808	1.1783	0.9827	1.0176
1.3	0.7860	1.8050	1.5157	1.1909	0.9794	1.0211
1.32	0.7760	1.8661	1.5505	1.2035	0.9758	1.0249
1.34	0.7664	1.9282	1.5854	1.2162	0.9718	1.0290
1.36	0.7572	1.9912	1.6202	1.2290	0.9676	1.0335
1.38	0.7483	2.0551	1.6549	1.2418	0.9630	1.0384
1.4	0.7397	2.1200	1.6897	1.2547	0.9582	1.0436
1.42	0.7314	2.1858	1.7243	1.2676	0.9531	1.0492
1.44	0.7235	2.2525	1.7589	1.2807	0.9476	1.0552
1.46	0.7157	2.3202	1.7934	1.2938	0.9420	1.0616
1.48	0.7083	2.3888	1.8278	1.3069	0.9360	1.0684
1.5	0.7011	2.4583	1.8621	1.3202	0.9298	1.0755
1.52	0.6941	2.5288	1.8963	1.3336	0.9233	1.0830
1.54	0.6874	2.6002	1.9303	1.3470	0.9166	1.0910
1.56	0.6809	2.6725	1.9643	1.3606	0.9097	1.0993
1.58	0.6746	2.7458	1.9981	1.3742	0.9026	1.1080
1.6	0.6684	2.8200	2.0317	1.3880	0.8952	1.1171
1.62	0.6625	2.8951	2.0653	1.4018	0.8877	1.1266
1.64	0.6568	2.9712	2.0986	1.4158	0.8799	1.1365
1.66	0.6512	3.0482	2.1318	1.4299	0.8720	1.1468
1.68	0.6458	3.1261	2.1649	1.4440	0.8639	1.1575
1.7	0.6405	3.2050	2.1977	1.4583	0.8557	1.1686
1.72	0.6355	3.2848	2.2304	1.4727	0.8474	1.1801
1.74	0.6305	3.3655	2.2629	1.4873	0.8389	1.1921
1.76	0.6257	3.4472	2.2952	1.5019	0.8302	1.2045
1.78	0.6210	3.5298	2.3273	1.5167	0.8215	1.2173
1.8	0.6165	3.6133	2.3592	1.5316	0.8127	1.2305
1.82	0.6121	3.6978	2.3909	1.5466	0.8038	1.2441
1.84	0.6078	3.7832	2.4224	1.5617	0.7948	1.2582
1.86	0.6036	3.8695	2.4537	1.5770	0.7857	1.2728
1.88	0.5996	3.9568	2.4848	1.5924	0.7765	1.2877
1.9	0.5956	4.0450	2.5157	1.6079	0.7674	1.3032
1.92	0.5918	4.1341	2.5463	1.6236	0.7581	1.3191
1.94	0.5880	4.2242	2.5767	1.6394	0.7488	1.3354
1.96	0.5844	4.3152	2.6069	1.6553	0.7395	1.3522
1.98	0.5808	4.4071	2.6369	1.6713	0.7302	1.3695
2.0	0.5774	4.5000	2.6667	1.6875	0.7209	1.3872
2.02	0.5740	4.5938	2.6962	1.7038	0.7115	1.4054
2.04	0.5707	4.6885	2.7255	1.7203	0.7022	1.4241
2.06	0.5675	4.7842	2.7545	1.7369	0.6928	1.4433
2.08	0.5643	4.8808	2.7833	1.7536	0.6835	1.4630
2.1	0.5613	4.9783	2.8119	1.7705	0.6742	1.4832
2.12	0.5583	5.0768	2.8402	1.7875	0.6649	1.5039
2.14	0.5554	5.1762	2.8683	1.8046	0.6557	1.5252
2.16	0.5525	5.2765	2.8962	1.8219	0.6464	1.5469
2.18	0.5498	5.3778	2.9238	1.8393	0.6373	1.5692
2.2	0.5471	5.4800	2.9512	1.8569	0.6281	1.5920
2.22	0.5444	5.5831	2.9784	1.8746	0.6191	1.6154
2.24	0.5418	5.6872	3.0053	1.8924	0.6100	1.6393
2.26	0.5393	5.7922	3.0319	1.9104	0.6011	1.6638
2.28	0.5368	5.8981	3.0584	1.9285	0.5921	1.6888
2.3	0.5344	6.0050	3.0845	1.9468	0.5833	1.7144
2.32	0.5321	6.1128	3.1105	1.9652	0.5745	1.7406

Table B.2 (*Cont.*) Normal-Shock Relations for a Perfect Gas, $k = 1.4$

Ma_{n1}	Ma_{n2}	p_2/p_1	$V_1/V_2 = \rho_2/\rho_1$	T_2/T_1	p_{02}/p_{01}	A_2^*/A_1^*
2.34	0.5297	6.2215	3.1362	1.9838	0.5658	1.7674
2.36	0.5275	6.3312	3.1617	2.0025	0.5572	1.7948
2.38	0.5253	6.4418	3.1869	2.0213	0.5486	1.8228
2.4	0.5231	6.5533	3.2119	2.0403	0.5401	1.8514
2.42	0.5210	6.6658	3.2367	2.0595	0.5317	1.8806
2.44	0.5189	6.7792	3.2612	2.0788	0.5234	1.9105
2.46	0.5169	6.8935	3.2855	2.0982	0.5152	1.9410
2.48	0.5149	7.0088	3.3095	2.1178	0.5071	1.9721
2.5	0.5130	7.1250	3.3333	2.1375	0.4990	2.0039
2.52	0.5111	7.2421	3.3569	2.1574	0.4911	2.0364
2.54	0.5092	7.3602	3.3803	2.1774	0.4832	2.0696
2.56	0.5074	7.4792	3.4034	2.1976	0.4754	2.1035
2.58	0.5056	7.5991	3.4263	2.2179	0.4677	2.1381
2.6	0.5039	7.7200	3.4490	2.2383	0.4601	2.1733
2.62	0.5022	7.8418	3.4714	2.2590	0.4526	2.2093
2.64	0.5005	7.9645	3.4937	2.2797	0.4452	2.2461
2.66	0.4988	8.0882	3.5157	2.3006	0.4379	2.2835
2.68	0.4972	8.2128	3.5374	2.3217	0.4307	2.3218
2.7	0.4956	8.3383	3.5590	2.3429	0.4236	2.3608
2.72	0.4941	8.4648	3.5803	2.3642	0.4166	2.4005
2.74	0.4926	8.5922	3.6015	2.3858	0.4097	2.4411
2.76	0.4911	8.7205	3.6224	2.4074	0.4028	2.4825
2.78	0.4896	8.8498	3.6431	2.4292	0.3961	2.5246
2.8	0.4882	8.9800	2.6636	2.4512	0.3895	2.5676
2.82	0.4868	9.1111	3.6838	2.4733	0.3829	2.6115
2.84	0.4854	9.2432	3.7039	2.4955	0.3765	2.6561
2.86	0.4840	9.3762	3.7238	2.5179	0.3701	2.7017
2.88	0.4827	9.5101	3.7434	2.5405	0.3639	2.7481
2.9	0.4814	9.6450	3.7629	2.5632	0.3577	2.7954
2.92	0.4801	9.7808	3.7821	2.5861	0.3517	2.8436
2.94	0.4788	9.9175	3.8012	2.6091	0.3457	2.8927
2.96	0.4776	10.0552	3.8200	2.6322	0.3398	2.9427
2.98	0.4764	10.1938	3.8387	2.6555	0.3340	2.9937
3.0	0.4752	10.3333	3.8571	2.6790	0.3283	3.0456
3.02	0.4740	10.4738	3.8754	2.7026	0.3227	3.0985
3.04	0.4729	10.6152	3.8935	2.7264	0.3172	3.1523
3.06	0.4717	10.7575	3.9114	2.7503	0.3118	3.2072
3.08	0.4706	10.9008	3.9291	2.7744	0.3065	3.2630
3.1	0.4695	11.0450	3.9466	2.7986	0.3012	3.3199
3.12	0.4685	11.1901	3.9639	2.8230	0.2960	3.3778
3.14	0.4674	11.3362	3.9811	2.8475	0.2910	3.4368
3.16	0.4664	11.4832	3.9981	2.8722	0.2860	3.4969
3.18	0.4654	11.6311	4.0149	2.8970	0.2811	3.5580
3.2	0.4643	11.7800	4.0315	2.9220	0.2762	3.6202
3.22	0.4634	11.9298	4.0479	2.9471	0.2715	3.6835
3.24	0.4624	12.0805	4.0642	2.9724	0.2668	3.7480
3.26	0.4614	12.2322	4.0803	2.9979	0.2622	3.8136
3.28	0.4605	12.3848	4.0963	3.0234	0.2577	3.8803
3.3	0.4596	12.5383	4.1120	3.0492	0.2533	3.9483
3.32	0.4587	12.6928	4.1276	3.0751	0.2489	4.0174
3.34	0.4578	12.8482	4.1431	3.1011	0.2446	4.0877
3.36	0.4569	13.0045	4.1583	3.1273	0.2404	4.1593
3.38	0.4560	13.1618	4.1734	3.1537	0.2363	4.2321
3.4	0.4552	13.3200	4.1884	3.1802	0.2322	4.3062

Table B.2 (*Cont.*) Normal-Shock Relations for a Perfect Gas, $k = 1.4$

Ma_{n1}	Ma_{n2}	p_2/p_1	$V_1/V_2 = \rho_2/\rho_1$	T_2/T_1	p_{02}/p_{01}	A_2^*/A_1^*
3.42	0.4544	13.4791	4.2032	3.2069	0.2282	4.3815
3.44	0.4535	13.6392	4.2178	3.2337	0.2243	4.4581
3.46	0.4527	13.8002	4.2323	3.2607	0.2205	4.5361
3.48	0.4519	13.9621	4.2467	3.2878	0.2167	4.6154
3.5	0.4512	14.1250	4.2609	3.3151	0.2129	4.6960
3.52	0.4504	14.2888	4.2749	3.3425	0.2093	4.7780
3.54	0.4496	14.4535	4.2888	3.3701	0.2057	4.8614
3.56	0.4489	14.6192	4.3026	3.3978	0.2022	4.9461
3.58	0.4481	14.7858	4.3162	3.4257	0.1987	5.0324
3.6	0.4474	14.9533	4.3296	3.4537	0.1953	5.1200
3.62	0.4467	15.1218	4.3429	3.4819	0.1920	5.2091
3.64	0.4460	15.2912	4.3561	3.5103	0.1887	5.2997
3.66	0.4453	15.4615	4.3692	3.5388	0.1855	5.3918
3.68	0.4446	15.6328	4.3821	3.5674	0.1823	5.4854
3.7	0.4439	15.8050	4.3949	3.5962	0.1792	5.5806
3.72	0.4433	15.9781	4.4075	3.6252	0.1761	5.6773
3.74	0.4426	16.1522	4.4200	3.6543	0.1731	5.7756
3.76	0.4420	16.3272	4.4324	3.6836	0.1702	5.8755
3.78	0.4414	16.5031	4.4447	3.7130	0.1673	5.9770
3.8	0.4407	16.6800	4.4568	3.7426	0.1645	6.0801
3.82	0.4401	16.8578	4.4688	3.7723	0.1617	6.1849
3.84	0.4395	17.0365	4.4807	3.8022	0.1589	6.2915
3.86	0.4389	17.2162	4.4924	3.8323	0.1563	6.3997
3.88	0.4383	17.3968	4.5041	3.8625	0.1536	6.5096
3.9	0.4377	17.5783	4.4156	3.8928	0.1510	6.6213
3.92	0.4372	17.7608	4.5270	3.9233	0.1485	6.7348
3.94	0.4366	17.9442	4.5383	3.9540	0.1460	6.8501
3.96	0.4360	18.1285	4.5494	3.9848	0.1435	6.9672
3.98	0.4355	18.3138	4.5605	4.0158	0.1411	7.0861
4.0	0.4350	18.5000	4.5714	4.0469	0.1388	7.2069
4.02	0.4344	18.6871	4.5823	4.0781	0.1364	7.3296
4.04	0.4339	18.8752	4.5930	4.1096	0.1342	7.4542
4.06	0.4334	19.0642	4.6036	4.1412	0.1319	7.5807
4.08	0.4329	19.2541	4.6141	4.1729	0.1297	7.7092
4.1	0.4324	19.4450	4.6245	4.2048	0.1276	7.8397
4.12	0.4319	19.6368	4.6348	4.2368	0.1254	7.9722
4.14	0.4314	19.8295	4.6450	4.2690	0.1234	8.1067
4.16	0.4309	20.0232	4.6550	4.3014	0.1213	8.2433
4.18	0.4304	20.2178	4.6650	4.3339	0.1193	8.3819
4.2	0.4299	20.4133	4.6749	4.3666	0.1173	8.5227
4.22	0.4295	20.6098	4.6847	4.3994	0.1154	8.6656
4.24	0.4290	20.8072	4.6944	4.4324	0.1135	8.8107
4.26	0.4286	21.0055	4.7040	4.4655	0.1116	8.9579
4.28	0.4281	21.2048	4.7135	4.4988	0.1098	9.1074
4.3	0.4277	21.4050	4.7229	4.5322	0.1080	9.2591
4.32	0.4272	21.6061	4.7322	4.5658	0.1062	9.4131
4.34	0.4268	21.8082	4.7414	4.5995	0.1045	9.5694
4.36	0.4264	22.0112	4.7505	4.6334	0.1028	9.7280
4.38	0.4260	22.2151	4.7595	4.6675	0.1011	9.8889
4.4	0.4255	22.4200	4.7685	4.7017	0.0995	10.0522
4.42	0.4251	22.6258	4.7773	4.7361	0.0979	10.2179
4.44	0.4247	22.8325	4.7861	4.7706	0.0963	10.3861
4.46	0.4243	23.0402	4.7948	4.8053	0.0947	10.5567
4.48	0.4239	23.2488	4.8034	4.8401	0.0932	10.7298

Table B.2 (*Cont.*) Normal-Shock Relations for a Perfect Gas, $k = 1.4$

Ma_{n1}	Ma_{n2}	p_2/p_1	$V_1/V_2 = \rho_2/\rho_1$	T_2/T_1	p_{02}/p_{01}	A_2^*/A_1^*
4.5	0.4236	23.4583	4.8119	4.8751	0.0917	10.9054
4.52	0.4232	23.6688	4.8203	4.9102	0.0902	11.0835
4.54	0.4228	23.8802	4.8287	4.9455	0.0888	11.2643
4.56	0.4224	24.0925	4.8369	4.9810	0.0874	11.4476
4.58	0.4220	24.3058	4.8451	5.0166	0.0860	11.6336
4.6	0.4217	24.5200	4.8532	5.0523	0.0846	11.8222
4.62	0.4213	24.7351	4.8612	5.0882	0.0832	12.0136
4.64	0.4210	24.9512	4.8692	5.1243	0.0819	12.2076
4.66	0.4206	25.1682	4.8771	5.1605	0.0806	12.4044
4.68	0.4203	25.3861	4.8849	5.1969	0.0793	12.6040
4.7	0.4199	25.6050	4.8926	5.2334	0.0781	12.8065
4.72	0.4196	25.8248	4.9002	5.2701	0.0769	13.0117
4.74	0.4192	26.0455	4.9078	5.3070	0.0756	13.2199
4.76	0.4189	26.2672	4.9153	5.3440	0.0745	13.4310
4.78	0.4186	26.4898	4.9227	5.3811	0.0733	13.6450
4.8	0.4183	26.7133	4.9301	5.4184	0.0721	13.8620
4.82	0.4179	26.9378	4.9374	5.4559	0.0710	14.0820
4.84	0.4176	27.1632	4.9446	5.4935	0.0699	14.3050
4.86	0.4173	27.3895	4.9518	5.5313	0.0688	14.5312
4.88	0.4170	27.6168	4.9589	5.5692	0.0677	14.7604
4.9	0.4167	27.8450	4.9659	5.6073	0.0667	14.9928
4.92	0.4164	28.0741	4.9728	5.6455	0.0657	15.2284
4.94	0.4161	28.3042	4.9797	5.6839	0.0647	15.4672
4.96	0.4158	28.5352	4.9865	5.7224	0.0637	15.7902
4.98	0.4155	28.7671	4.9933	5.7611	0.0627	15.9545
5.0	0.4152	29.0000	5.0000	5.8000	0.0617	16.2032

Table B.3 Adiabatic Frictional Flow in a Constant-Area Duct for $k = 1.4$

Ma	$\bar{f}L^*/D$	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
0.0	∞	∞	1.2000	0.0	∞
0.02	1778.4500	54.7701	1.1999	0.0219	28.9421
0.04	440.3520	27.3817	1.1996	0.0438	14.4815
0.06	193.0310	18.2508	1.1991	0.0657	9.6659
0.08	106.7180	13.6843	1.1985	0.0876	7.2616
0.1	66.9216	10.9435	1.1976	0.1094	5.8218
0.12	45.4080	9.1156	1.1966	0.1313	4.8643
0.14	32.5113	7.8093	1.1953	0.1531	4.1824
0.16	24.1978	6.8291	1.1939	0.1748	3.6727
0.18	18.5427	6.0662	1.1923	0.1965	3.2779
0.2	14.5333	5.4554	1.1905	0.2182	2.9635
0.22	11.5961	4.9554	1.1885	0.2398	2.7076
0.24	9.3865	4.5383	1.1863	0.2614	2.4956
0.26	7.6876	4.1851	1.1840	0.2829	2.3173
0.28	6.3572	3.8820	1.1815	0.3043	2.1656
0.3	5.2993	3.6191	1.1788	0.3257	2.0351
0.32	4.4467	3.3887	1.1759	0.3470	1.9219
0.34	3.7520	3.1853	1.1729	0.3682	1.8229
0.36	3.1801	3.0042	1.1697	0.3893	1.7358
0.38	2.7054	2.8420	1.1663	0.4104	1.6587
0.4	2.3085	2.6958	1.1628	0.4313	1.5901
0.42	1.9744	2.5634	1.1591	0.4522	1.5289

Table B.3 (*Cont.*) Adiabatic Frictional Flow in a Constant-Area Duct for $k = 1.4$

Ma	$\bar{f} L^*/D$	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
0.44	1.6915	2.4428	1.1553	0.4729	1.4740
0.46	1.4509	2.3326	1.1513	0.4936	1.4246
0.48	1.2453	2.2313	1.1471	0.5141	1.3801
0.5	1.0691	2.1381	1.1429	0.5345	1.3398
0.52	0.9174	2.0519	1.1384	0.5548	1.3034
0.54	0.7866	1.9719	1.1339	0.5750	1.2703
0.56	0.6736	1.8975	1.1292	0.5951	1.2403
0.58	0.5757	1.8282	1.1244	0.6150	1.2130
0.6	0.4908	1.7634	1.1194	0.6348	1.1882
0.62	0.4172	1.7026	1.1143	0.6545	1.1656
0.64	0.3533	1.6456	1.1091	0.6740	1.1451
0.66	0.2979	1.5919	1.1038	0.6934	1.1265
0.68	0.2498	1.5413	1.0984	0.7127	1.1097
0.7	0.2081	1.4935	1.0929	0.7318	1.0944
0.72	0.1721	1.4482	1.0873	0.7508	1.0806
0.74	0.1411	1.4054	1.0815	0.7696	1.0681
0.76	0.1145	1.3647	1.0757	0.7883	1.0570
0.78	0.0917	1.3261	1.0698	0.8068	1.0471
0.8	0.0723	1.2893	1.0638	0.8251	1.0382
0.82	0.0559	1.2542	1.0578	0.8433	1.0305
0.84	0.0423	1.2208	1.0516	0.8614	1.0237
0.86	0.0310	1.1889	1.0454	0.8793	1.0179
0.88	0.0218	1.1583	1.0391	0.8970	1.0129
0.9	0.0145	1.1291	1.0327	0.9146	1.0089
0.92	0.0089	1.1011	1.0263	0.9320	1.0056
0.94	0.0048	1.0743	1.0198	0.9493	1.0031
0.96	0.0021	1.0485	1.0132	0.9663	1.0014
0.98	0.0005	1.0238	1.0066	0.9833	1.0003
1.0	0.0000	1.0000	1.0000	1.0000	1.0000
1.02	0.0005	0.9771	0.9933	1.0166	1.0003
1.04	0.0018	0.9551	0.9866	1.0330	1.0013
1.06	0.0038	0.9338	0.9798	1.0492	1.0029
1.08	0.0066	0.9133	0.9730	1.0653	1.0051
1.1	0.0099	0.8936	0.9662	1.0812	1.0079
1.12	0.0138	0.8745	0.9593	1.0970	1.0113
1.14	0.0182	0.8561	0.9524	1.1126	1.0153
1.16	0.0230	0.8383	0.9455	1.1280	1.0198
1.18	0.0281	0.8210	0.9386	1.1432	1.0248
1.2	0.0336	0.8044	0.9317	1.1583	1.0304
1.22	0.0394	0.7882	0.9247	1.1732	1.0366
1.24	0.0455	0.7726	0.9178	1.1879	1.0432
1.26	0.0517	0.7574	0.9108	1.2025	1.0504
1.28	0.0582	0.7427	0.9038	1.2169	1.0581
1.3	0.0648	0.7285	0.8969	1.2311	1.0663
1.32	0.0716	0.7147	0.8899	1.2452	1.0750
1.34	0.0785	0.7012	0.8829	1.2591	1.0842
1.36	0.0855	0.6882	0.8760	1.2729	1.0940
1.38	0.0926	0.6755	0.8690	1.2864	1.1042
1.4	0.0997	0.6632	0.8621	1.2999	1.1149
1.42	0.1069	0.6512	0.8551	1.3131	1.1262
1.44	0.1142	0.6396	0.8482	1.3262	1.1379
1.46	0.1215	0.6282	0.8413	1.3392	1.1501
1.48	0.1288	0.6172	0.8344	1.3520	1.1629
1.5	0.1361	0.6065	0.8276	1.3646	1.1762

Table B.3 (*Cont.*) Adiabatic Frictional Flow in a Constant-Area Duct for $k = 1.4$

Ma	$\bar{f} L^*/D$	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
1.52	0.1433	0.5960	0.8207	1.3770	1.1899
1.54	0.1506	0.5858	0.8139	1.3894	1.2042
1.56	0.1579	0.5759	0.8071	1.4015	1.2190
1.58	0.1651	0.5662	0.8004	1.4135	1.2344
1.6	0.1724	0.5568	0.7937	1.4254	1.2502
1.62	0.1795	0.5476	0.7869	1.4371	1.2666
1.64	0.1867	0.5386	0.7803	1.4487	1.2836
1.66	0.1938	0.5299	0.7736	1.4601	1.3010
1.68	0.2008	0.5213	0.7670	1.4713	1.3190
1.7	0.2078	0.5130	0.7605	1.4825	1.3376
1.72	0.2147	0.5048	0.7539	1.4935	1.3567
1.74	0.2216	0.4969	0.7474	1.5043	1.3764
1.76	0.2284	0.4891	0.7410	1.5150	1.3967
1.78	0.2352	0.4815	0.7345	1.5256	1.4175
1.8	0.2419	0.4741	0.7282	1.5360	1.4390
1.82	0.2485	0.4668	0.7218	1.5463	1.4610
1.84	0.2551	0.4597	0.7155	1.5564	1.4836
1.86	0.2616	0.4528	0.7093	1.5664	1.5069
1.88	0.2680	0.4460	0.7030	1.5763	1.5308
1.9	0.2743	0.4394	0.6969	1.5861	1.5553
1.92	0.2806	0.4329	0.6907	1.5957	1.5804
1.94	0.2868	0.4265	0.6847	1.6052	1.6062
1.96	0.2929	0.4203	0.6786	1.6146	1.6326
1.98	0.2990	0.4142	0.6726	1.6239	1.6597
2.0	0.3050	0.4082	0.6667	1.6330	1.6875
2.02	0.3109	0.4024	0.6608	1.6420	1.7160
2.04	0.3168	0.3967	0.6549	1.6509	1.7451
2.06	0.3225	0.3911	0.6491	1.6597	1.7750
2.08	0.3282	0.3856	0.6433	1.6683	1.8056
2.1	0.3339	0.3802	0.6376	1.6769	1.8369
2.12	0.3394	0.3750	0.6320	1.6853	1.8690
2.14	0.3449	0.3698	0.6263	1.6936	1.9018
2.16	0.3503	0.3648	0.6208	1.7018	1.9354
2.18	0.3556	0.3598	0.6152	1.7099	1.9698
2.2	0.3609	0.3549	0.6098	1.7179	2.0050
2.22	0.3661	0.3502	0.6043	1.7258	2.0409
2.24	0.3712	0.3455	0.5989	1.7336	2.0777
2.26	0.3763	0.3409	0.5936	1.7412	2.1153
2.28	0.3813	0.3364	0.5883	1.7488	2.1538
2.3	0.3862	0.3320	0.5831	1.7563	2.1931
2.32	0.3911	0.3277	0.5779	1.7637	2.2333
2.34	0.3959	0.3234	0.5728	1.7709	2.2744
2.36	0.4006	0.3193	0.5677	1.7781	2.3164
2.38	0.4053	0.3152	0.5626	1.7852	2.3593
2.4	0.4099	0.3111	0.5576	1.7922	2.4031
2.42	0.4144	0.3072	0.5527	1.7991	2.4479
2.44	0.4189	0.3033	0.5478	1.8059	2.4936
2.46	0.4233	0.2995	0.5429	1.8126	2.5403
2.48	0.4277	0.2958	0.5381	1.8192	2.5880
2.5	0.4320	0.2921	0.5333	1.8257	2.6367
2.52	0.4362	0.2885	0.5286	1.8322	2.6865
2.54	0.4404	0.2850	0.5239	1.8386	2.7372
2.56	0.4445	0.2815	0.5193	1.8448	2.7891
2.58	0.4486	0.2781	0.5147	1.8510	2.8420

Table B.3 (*Cont.*) Adiabatic Frictional Flow in a Constant-Area Duct for $k = 1.4$

Ma	$\bar{f}L^*/D$	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
2.6	0.4526	0.2747	0.5102	1.8571	2.8960
2.62	0.4565	0.2714	0.5057	1.8632	2.9511
2.64	0.4604	0.2682	0.5013	1.8691	3.0073
2.66	0.4643	0.2650	0.4969	1.8750	3.0647
2.68	0.4681	0.2619	0.4925	1.8808	3.1233
2.7	0.4718	0.2588	0.4882	1.8865	3.1830
2.72	0.4755	0.2558	0.4839	1.8922	3.2440
2.74	0.4791	0.2528	0.4797	1.8978	3.3061
2.76	0.4827	0.2498	0.4755	1.9033	3.3695
2.78	0.4863	0.2470	0.4714	1.9087	3.4342
2.8	0.4898	0.2441	0.4673	1.9140	3.5001
2.82	0.4932	0.2414	0.4632	1.9193	3.5674
2.84	0.4966	0.2386	0.4592	1.9246	3.6359
2.86	0.5000	0.2359	0.4552	1.9297	3.7058
2.88	0.5033	0.2333	0.4513	1.9348	3.7771
2.9	0.5065	0.2307	0.4474	1.9398	3.8498
2.92	0.5097	0.2281	0.4436	1.9448	3.9238
2.94	0.5129	0.2256	0.4398	1.9497	3.9993
2.96	0.5160	0.2231	0.4360	1.9545	4.0763
2.98	0.5191	0.2206	0.4323	1.9593	4.1547
3.0	0.5222	0.2182	0.4286	1.9640	4.2346
3.02	0.5252	0.2158	0.4249	1.9686	4.3160
3.04	0.5281	0.2135	0.4213	1.9732	4.3989
3.06	0.5310	0.2112	0.4177	1.9777	4.4835
3.08	0.5339	0.2090	0.4142	1.9822	4.5696
3.1	0.5368	0.2067	0.4107	1.9866	4.6573
3.12	0.5396	0.2045	0.4072	1.9910	4.7467
3.14	0.5424	0.2024	0.4038	1.9953	4.8377
3.16	0.5451	0.2002	0.4004	1.9995	4.9304
3.18	0.5478	0.1981	0.3970	2.0037	5.0248
3.2	0.5504	0.1961	0.3937	2.0079	5.1210
3.22	0.5531	0.1940	0.3904	2.0120	5.2189
3.24	0.5557	0.1920	0.3872	2.0160	5.3186
3.26	0.5582	0.1901	0.3839	2.0200	5.4201
3.28	0.5607	0.1881	0.3807	2.0239	5.5234
3.3	0.5632	0.1862	0.3776	2.0278	5.6286
3.32	0.5657	0.1843	0.3745	2.0317	5.7358
3.34	0.5681	0.1825	0.3714	2.0355	5.8448
3.36	0.5705	0.1806	0.3683	2.0392	5.9558
3.38	0.5729	0.1788	0.3653	2.0429	6.0687
3.4	0.5752	0.1770	0.3623	2.0466	6.1837
3.42	0.5775	0.1753	0.3594	2.0502	6.3007
3.44	0.5798	0.1736	0.3564	2.0537	6.4198
3.46	0.5820	0.1718	0.3535	2.0573	6.5409
3.48	0.5842	0.1702	0.3507	2.0607	6.6642
3.5	0.5864	0.1685	0.3478	2.0642	6.7896
3.52	0.5886	0.1669	0.3450	2.0676	6.9172
3.54	0.5907	0.1653	0.3422	2.0709	7.0471
3.56	0.5928	0.1637	0.3395	2.0743	7.1791
3.58	0.5949	0.1621	0.3368	2.0775	7.3135
3.6	0.5970	0.1616	0.3341	2.0808	7.4501
3.62	0.5990	0.1590	0.3314	2.0840	7.5891
3.64	0.6010	0.1575	0.3288	2.0871	7.7305
3.66	0.6030	0.1560	0.3262	2.0903	7.8742

Table B.3 (*Cont.*) Adiabatic Frictional Flow in a Constant-Area Duct for $k = 1.4$

Ma	$\bar{f} L^*/D$	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
3.68	0.6049	0.1546	0.3236	2.0933	8.0204
3.7	0.6068	0.1531	0.3210	2.0964	8.1691
3.72	0.6087	0.1517	0.3185	2.0994	8.3202
3.74	0.6106	0.1503	0.3160	2.1024	8.4739
3.76	0.6125	0.1489	0.3135	2.1053	8.6302
3.78	0.6143	0.1475	0.3111	2.1082	8.7891
3.8	0.6161	0.1462	0.3086	2.1111	8.9506
3.82	0.6179	0.1449	0.3062	2.1140	9.1148
3.84	0.6197	0.1436	0.3039	2.1168	9.2817
3.86	0.6214	0.1423	0.3015	2.1195	9.4513
3.88	0.6231	0.1410	0.2992	2.1223	9.6237
3.9	0.6248	0.1397	0.2969	2.1250	9.7990
3.92	0.6265	0.1385	0.2946	2.1277	9.9771
3.94	0.6282	0.1372	0.2923	2.1303	10.1581
3.96	0.6298	0.1360	0.2901	2.1329	10.3420
3.98	0.6315	0.1348	0.2879	2.1355	10.5289
4.0	0.6331	0.1336	0.2857	2.1381	10.7188

Table B.4 Frictionless Duct Flow with Heat Transfer for $k = 1.4$

Ma	T_0/T_0^*	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
0.0	0.0	2.4000	0.0	0.0	1.2679
0.02	0.0019	2.3987	0.0023	0.0010	1.2675
0.04	0.0076	2.3946	0.0092	0.0038	1.2665
0.06	0.0171	2.3800	0.0205	0.0086	1.2647
0.08	0.0302	2.3787	0.0362	0.0152	1.2623
0.1	0.0468	2.3669	0.0560	0.0237	1.2591
0.12	0.0666	2.3526	0.0797	0.0339	1.2554
0.14	0.0895	2.3359	0.1069	0.0458	1.2510
0.16	0.1151	2.3170	0.1374	0.0593	1.2461
0.18	0.1432	2.2959	0.1708	0.0744	1.2406
0.2	0.1736	2.2727	0.2066	0.0909	1.2346
0.22	0.2057	2.2477	0.2445	0.1088	1.2281
0.24	0.2395	2.2209	0.2841	0.1279	1.2213
0.26	0.2745	2.1925	0.3250	0.1482	1.2140
0.28	0.3104	2.1626	0.3667	0.1696	1.2064
0.3	0.3469	2.1314	0.4089	0.1918	1.1985
0.32	0.3837	2.0991	0.4512	0.2149	1.1904
0.34	0.4206	2.0657	0.4933	0.2388	1.1822
0.36	0.4572	2.0314	0.5348	0.2633	1.1737
0.38	0.4935	1.9964	0.5755	0.2883	1.1652
0.4	0.5290	1.9608	0.6151	0.3137	1.1566
0.42	0.5638	1.9247	0.6535	0.3395	1.1480
0.44	0.5975	1.8882	0.6903	0.3656	1.1394
0.46	0.6301	1.8515	0.7254	0.3918	1.1308
0.48	0.6614	1.8147	0.7587	0.4181	1.1224
0.5	0.6914	1.7778	0.7901	0.4444	1.1141
0.52	0.7199	1.7409	0.8196	0.4708	1.1059
0.54	0.7470	1.7043	0.8469	0.4970	1.0979
0.56	0.7725	1.6678	0.8723	0.5230	1.0901
0.58	0.7965	1.6316	0.8955	0.5489	1.0826
0.6	0.8189	1.5957	0.9167	0.5745	1.0753

Table B.4 (*Cont.*) Frictionless Duct Flow with Heat Transfer for $k = 1.4$

Ma	T_0/T_0^*	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
0.62	0.8398	1.5603	0.9358	0.5998	1.0682
0.64	0.8592	1.5253	0.9530	0.6248	1.0615
0.66	0.8771	1.4908	0.9682	0.6494	1.0550
0.68	0.8935	1.4569	0.9814	0.6737	1.0489
0.7	0.9085	1.4235	0.9929	0.6975	1.0431
0.72	0.9221	1.3907	1.0026	0.7209	1.0376
0.74	0.9344	1.3585	1.0106	0.7439	1.0325
0.76	0.9455	1.3270	1.0171	0.7665	1.0278
0.78	0.9553	1.2961	1.0220	0.7885	1.0234
0.8	0.9639	1.2658	1.0255	0.8101	1.0193
0.82	0.9715	1.2362	1.0276	0.8313	1.0157
0.84	0.9781	1.2073	1.0285	0.8519	1.0124
0.86	0.9836	1.1791	1.0283	0.8721	1.0095
0.88	0.9883	1.1515	1.0269	0.8918	1.0070
0.9	0.9921	1.1246	1.0245	0.9110	1.0049
0.92	0.9951	1.0984	1.0212	0.9297	1.0031
0.94	0.9973	1.0728	1.0170	0.9480	1.0017
0.96	0.9988	1.0479	1.0121	0.9658	1.0008
0.98	0.9997	1.0236	1.0064	0.9831	1.0002
1.0	1.0000	1.0000	1.0000	1.0000	1.0000
1.02	0.9997	0.9770	0.9930	1.0164	1.0002
1.04	0.9989	0.9546	0.9855	1.0325	1.0008
1.06	0.9977	0.9327	0.9776	1.0480	1.0017
1.08	0.9960	0.9115	0.9691	1.0632	1.0031
1.1	0.9939	0.8909	0.9603	1.0780	1.0049
1.12	0.9915	0.8708	0.9512	1.0923	1.0070
1.14	0.9887	0.8512	0.9417	1.1063	1.0095
1.16	0.9856	0.8322	0.9320	1.1198	1.0124
1.18	0.9823	0.8137	0.9220	1.1330	1.0157
1.2	0.9787	0.7958	0.9118	1.1459	1.0194
1.22	0.9749	0.7783	0.9015	1.1584	1.0235
1.24	0.9709	0.7613	0.8911	1.1705	1.0279
1.26	0.9668	0.7447	0.8805	1.1823	1.0328
1.28	0.9624	0.7287	0.8699	1.1938	1.0380
1.3	0.9580	0.7130	0.8592	1.2050	1.0437
1.32	0.9534	0.6978	0.8484	1.2159	1.0497
1.34	0.9487	0.6830	0.8377	1.2264	1.0561
1.36	0.9440	0.6686	0.8269	1.2367	1.0629
1.38	0.9391	0.6546	0.8161	1.2467	1.0701
1.4	0.9343	0.6410	0.8054	1.2564	1.0777
1.42	0.9293	0.6278	0.7947	1.2659	1.0856
1.44	0.9243	0.6149	0.7840	1.2751	1.0940
1.46	0.9193	0.6024	0.7735	1.2840	1.1028
1.48	0.9143	0.5902	0.7629	1.2927	1.1120
1.5	0.9093	0.5783	0.7525	1.3012	1.1215
1.52	0.9042	0.5668	0.7422	1.3095	1.1315
1.54	0.8992	0.5555	0.7319	1.3175	1.1419
1.56	0.8942	0.5446	0.7217	1.3253	1.1527
1.58	0.8892	0.5339	0.7117	1.3329	1.1640
1.6	0.8842	0.5236	0.7017	1.3403	1.1756
1.62	0.8792	0.5135	0.6919	1.3475	1.1877
1.64	0.8743	0.5036	0.6822	1.3546	1.2002
1.66	0.8694	0.4940	0.6726	1.3614	1.2131
1.68	0.8645	0.4847	0.6631	1.3681	1.2264

Table B.4 (*Cont.*) Frictionless Duct Flow with Heat Transfer for $k = 1.4$

Ma	T_0/T_0^*	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
1.7	0.8597	0.4756	0.6538	1.3746	1.2402
1.72	0.8549	0.4668	0.6445	1.3809	1.2545
1.74	0.8502	0.4581	0.6355	1.3870	1.2692
1.76	0.8455	0.4497	0.6265	1.3931	1.2843
1.78	0.8409	0.4415	0.6176	1.3989	1.2999
1.8	0.8363	0.4335	0.6089	1.4046	1.3159
1.82	0.8317	0.4257	0.6004	1.4102	1.3324
1.84	0.8273	0.4181	0.5919	1.4156	1.3494
1.86	0.8228	0.4107	0.5836	1.4209	1.3669
1.88	0.8185	0.4035	0.5754	1.4261	1.3849
1.9	0.8141	0.3964	0.5673	1.4311	1.4033
1.92	0.8099	0.3895	0.5594	1.4360	1.4222
1.94	0.8057	0.3828	0.5516	1.4408	1.4417
1.96	0.8015	0.3763	0.5439	1.4455	1.4616
1.98	0.7974	0.3699	0.5364	1.4501	1.4821
2.0	0.7934	0.3636	0.5289	1.4545	1.5031
2.02	0.7894	0.3575	0.5216	1.4589	1.5246
2.04	0.7855	0.3516	0.5144	1.4632	1.5467
2.06	0.7816	0.3458	0.5074	1.4673	1.5693
2.08	0.7778	0.3401	0.5004	1.4714	1.5924
2.1	0.7741	0.3345	0.4936	1.4753	1.6162
2.12	0.7704	0.3291	0.4868	1.4792	1.6404
2.14	0.7667	0.3238	0.4802	1.4830	1.6653
2.16	0.7631	0.3186	0.4737	1.4867	1.6908
2.18	0.7596	0.3136	0.4673	1.4903	1.7168
2.2	0.7561	0.3086	0.4611	1.4938	1.7434
2.22	0.7527	0.3038	0.4549	1.4973	1.7707
2.24	0.7493	0.2991	0.4488	1.5007	1.7986
2.26	0.7460	0.2945	0.4428	1.5040	1.8271
2.28	0.7428	0.2899	0.4370	1.5072	1.8562
2.3	0.7395	0.2855	0.4312	1.5104	1.8860
2.32	0.7364	0.2812	0.4256	1.5134	1.9165
2.34	0.7333	0.2769	0.4200	1.5165	1.9476
2.36	0.7302	0.2728	0.4145	1.5194	1.9794
2.38	0.7272	0.2688	0.4091	1.5223	2.0119
2.4	0.7242	0.2648	0.4038	1.5252	2.0451
2.42	0.7213	0.2609	0.3986	1.5279	2.0789
2.44	0.7184	0.2571	0.3935	1.5306	2.1136
2.46	0.7156	0.2534	0.3885	1.5333	2.1489
2.48	0.7128	0.2497	0.3836	1.5359	2.1850
2.5	0.7101	0.2462	0.3787	1.5385	2.2218
2.52	0.7074	0.2427	0.3739	1.5410	2.2594
2.54	0.7047	0.2392	0.3692	1.5434	2.2978
2.56	0.7021	0.2359	0.3646	1.5458	2.3370
2.58	0.6995	0.2326	0.3601	1.5482	2.3770
2.6	0.6970	0.2294	0.3556	1.5505	2.4177
2.62	0.6945	0.2262	0.3512	1.5527	2.4593
2.64	0.6921	0.2231	0.3469	1.5549	2.5018
2.66	0.6896	0.2201	0.3427	1.5571	2.5451
2.68	0.6873	0.2171	0.3385	1.5592	2.5892
2.7	0.6849	0.2142	0.3344	1.5613	2.6343
2.72	0.6826	0.2113	0.3304	1.5634	2.6802
2.74	0.6804	0.2085	0.3264	1.5654	2.7270
2.76	0.6781	0.2058	0.3225	1.5673	2.7748

Table B.4 (*Cont.*) Frictionless Duct Flow with Heat Transfer for $k = 1.4$

Ma	T_0/T_0^*	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
2.78	0.6761	0.2030	0.3186	1.5693	2.8235
2.8	0.6738	0.2004	0.3149	1.5711	2.8731
2.82	0.6717	0.1978	0.3111	1.5730	2.9237
2.84	0.6696	0.1953	0.3075	1.5748	2.9752
2.86	0.6675	0.1927	0.3039	1.5766	3.0278
2.88	0.6655	0.1903	0.3004	1.5784	3.0813
2.9	0.6635	0.1879	0.2969	1.5801	3.1359
2.92	0.6615	0.1855	0.2934	1.5818	3.1914
2.94	0.6596	0.1832	0.2901	1.5834	3.2481
2.96	0.6577	0.1809	0.2868	1.5851	3.3058
2.98	0.6558	0.1787	0.2835	1.5867	3.3646
3.0	0.6540	0.1765	0.2803	1.5882	3.4245
3.02	0.6522	0.1743	0.2771	1.5898	3.4854
3.04	0.6504	0.1722	0.2740	1.5913	3.5476
3.06	0.6486	0.1701	0.2709	1.5928	3.6108
3.08	0.6469	0.1681	0.2679	1.5942	3.6752
3.1	0.6452	0.1660	0.2650	1.5957	3.7408
3.12	0.6435	0.1641	0.2620	1.5971	3.8076
3.14	0.6418	0.1621	0.2592	1.5985	3.8756
3.16	0.6402	0.1602	0.2563	1.5998	3.9449
3.18	0.6386	0.1583	0.2535	1.6012	4.0154
3.2	0.6370	0.1565	0.2508	1.6025	4.0871
3.22	0.6354	0.1547	0.2481	1.6038	4.1602
3.24	0.6339	0.1529	0.2454	1.6051	4.2345
3.26	0.6324	0.1511	0.2428	1.6063	4.3101
3.28	0.6309	0.1494	0.2402	1.6076	4.3871
3.3	0.6294	0.1477	0.2377	1.6088	4.4655
3.32	0.6280	0.1461	0.2352	1.6100	4.5452
3.34	0.6265	0.1444	0.2327	1.6111	4.6263
3.36	0.6251	0.1428	0.2303	1.6123	4.7089
3.38	0.6237	0.1412	0.2279	1.6134	4.7929
3.4	0.6224	0.1397	0.2255	1.6145	4.8783
3.42	0.6210	0.1381	0.2232	1.6156	4.9652
3.44	0.6197	0.1366	0.2209	1.6167	5.0536
3.46	0.6184	0.1351	0.2186	1.6178	5.1435
3.48	0.6171	0.1337	0.2164	1.6188	5.2350
3.5	0.6158	0.1322	0.2142	1.6198	5.3280
3.52	0.6145	0.1308	0.2120	1.6208	5.4226
3.54	0.6133	0.1294	0.2099	1.6218	5.5188
3.56	0.6121	0.1280	0.2078	1.6228	5.6167
3.58	0.6109	0.1267	0.2057	1.6238	5.7162
3.6	0.6097	0.1254	0.2037	1.6247	5.8173
3.62	0.6085	0.1241	0.2017	1.6257	5.9201
3.64	0.6074	0.1228	0.1997	1.6266	6.0247
3.66	0.6062	0.1215	0.1977	1.6275	6.1310
3.68	0.6051	0.1202	0.1958	1.6284	6.2390
3.7	0.6040	0.1190	0.1939	1.6293	6.3488
3.72	0.6029	0.1178	0.1920	1.6301	6.4605
3.74	0.6018	0.1166	0.1902	1.6310	6.5739
3.76	0.6008	0.1154	0.1884	1.6318	6.6893
3.78	0.5997	0.1143	0.1866	1.6327	6.8065
3.8	0.5987	0.1131	0.1848	1.6335	6.9256
3.82	0.5977	0.1120	0.1830	1.6343	7.0466
3.84	0.5967	0.1109	0.1813	1.6351	7.1696

Table B.4 (*Cont.*) Frictionless Duct Flow with Heat Transfer for $k = 1.4$

Ma	T_0/T_0^*	p/p^*	T/T^*	$\rho^*/\rho = V/V^*$	p_0/p_0^*
3.86	0.5957	0.1098	0.1796	1.6359	7.2945
3.88	0.5947	0.1087	0.1779	1.6366	7.4215
3.9	0.5937	0.1077	0.1763	1.6374	7.5505
3.92	0.5928	0.1066	0.1746	1.6381	7.6816
3.94	0.5918	0.1056	0.1730	1.6389	7.8147
3.96	0.5909	0.1046	0.1714	1.6396	7.9499
3.98	0.5900	0.1036	0.1699	1.6403	8.0873
4.0	0.5891	0.1026	0.1683	1.6410	8.2269

Table B.5 Prandtl-Meyer Supersonic Expansion Function for $k = 1.4$

Ma	ω, deg	Ma	ω, deg	Ma	ω, deg	Ma	ω, deg
1.00	0.0						
1.05	0.49	3.05	50.71	5.05	77.38	7.05	91.23
1.10	1.34	3.10	51.65	5.10	77.84	7.10	91.49
1.15	2.38	3.15	52.57	5.15	78.29	7.15	91.75
1.20	3.56	3.20	53.47	5.20	78.73	7.20	92.00
1.25	4.83	3.25	54.35	5.25	79.17	7.25	92.24
1.30	6.17	3.30	55.22	5.30	79.60	7.30	92.49
1.35	7.56	3.35	56.07	5.35	80.02	7.35	92.73
1.40	8.99	3.40	56.91	5.40	80.43	7.40	92.97
1.45	10.44	3.45	57.73	5.45	80.84	7.45	93.21
1.50	11.91	3.50	58.53	5.50	81.24	7.50	93.44
1.55	13.38	3.55	59.32	5.55	81.64	7.55	93.67
1.60	14.86	3.60	60.09	5.60	82.03	7.60	93.90
1.65	16.34	3.65	60.85	5.65	82.42	7.65	94.12
1.70	17.81	3.70	61.60	5.70	82.80	7.70	94.34
1.75	19.27	3.75	62.33	5.75	83.17	7.75	94.56
1.80	20.73	3.80	63.04	5.80	83.54	7.80	94.78
1.85	22.16	3.85	63.75	5.85	83.90	7.85	95.00
1.90	23.59	3.90	64.44	5.90	84.26	7.90	95.21
1.95	24.99	3.95	65.12	5.95	84.61	7.95	95.42
2.00	26.38	4.00	65.78	6.00	84.96	8.00	95.62
2.05	27.75	4.05	66.44	6.05	85.30	8.05	95.83
2.10	29.10	4.10	67.08	6.10	85.63	8.10	96.03
2.15	30.43	4.15	67.71	6.15	85.97	8.15	96.23
2.20	31.73	4.20	68.33	6.20	86.29	8.20	96.43
2.25	33.02	4.25	68.94	6.25	86.62	8.25	96.63
2.30	34.28	4.30	69.54	6.30	86.94	8.30	96.82
2.35	35.53	4.35	70.13	6.35	87.25	8.35	97.01
2.40	36.75	4.40	70.71	6.40	87.56	8.40	97.20
2.45	37.95	4.45	71.27	6.45	87.87	8.45	97.39
2.50	39.12	4.50	71.83	6.50	88.17	8.50	97.57
2.55	40.28	4.55	72.38	6.55	88.47	8.55	97.76
2.60	41.41	4.60	72.92	6.60	88.76	8.60	97.94
2.65	42.53	4.65	73.45	6.65	89.05	8.65	98.12
2.70	43.62	4.70	73.97	6.70	89.33	8.70	98.29
2.75	44.69	4.75	74.48	6.75	89.62	8.75	98.47
2.80	45.75	4.80	74.99	6.80	89.90	8.80	98.64
2.85	46.78	4.85	75.48	6.85	90.17	8.85	98.81
2.90	47.79	4.90	75.97	6.90	90.44	8.90	98.98
2.95	48.78	4.95	76.45	6.95	90.71	8.95	99.15
3.00	49.76	5.00	76.92	7.00	90.97	9.00	99.32

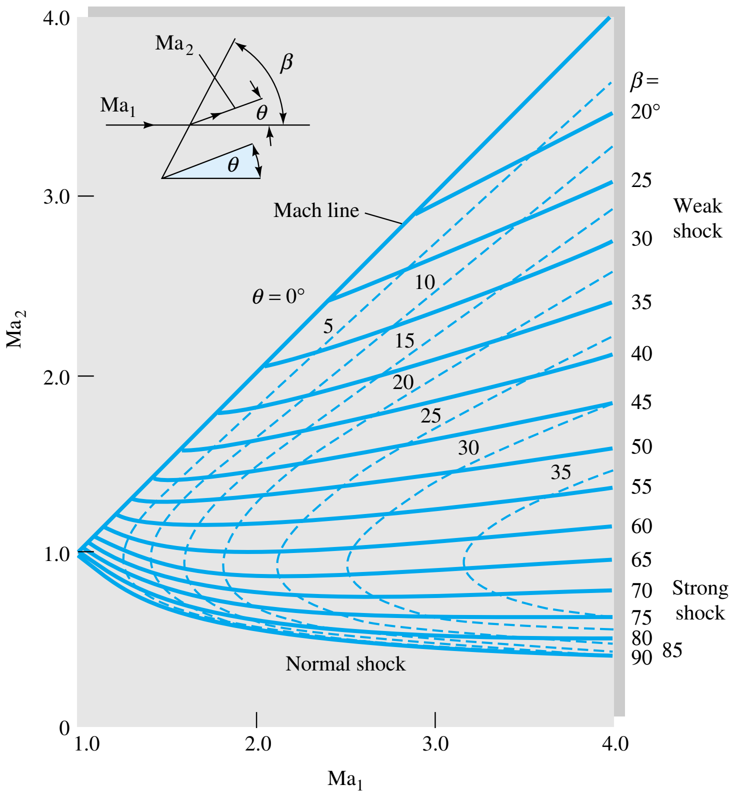


Fig. B.1 Mach number downstream of an oblique shock for $k = 1.4$.

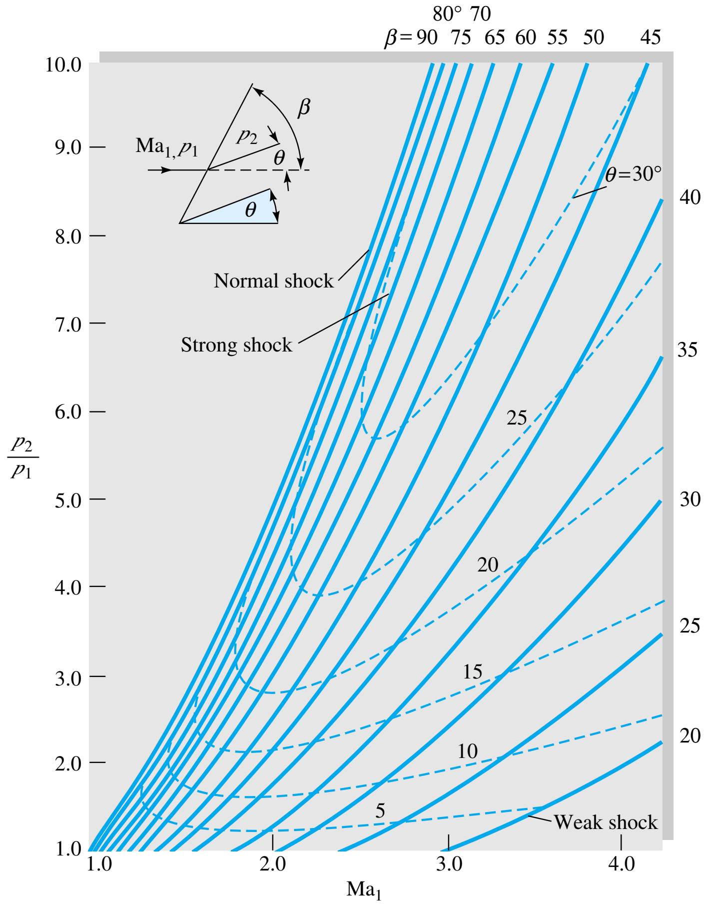


Fig. B.2 Pressure ratio downstream of an oblique shock for k = 1.4.

Appendix C
Conversion Factors

During this period of transition there is a constant need for conversions between BG and SI units (see Table 1.2). Some additional conversions are given here. Conversion factors are given inside the front cover.

Length	Volume
1 ft = 12 in = 0.3048 m 1 mi = 5280 ft = 1609.344 m 1 nautical mile (nmi) = 6076 ft = 1852 m 1 yd = 3 ft = 0.9144 m 1 angstrom (Å) = 1.0 E-10 m	1 ft^3 = 0.028317 m^3 1 U.S. gal = 231 in^3 = 0.0037854 m^3 1 L = 0.001 m^3 = 0.035315 ft^3 1 U.S. fluid ounce = 2.9574 E-5 m^3 1 U.S. quart (qt) = 9.4635 E-4 m^3
Mass	**Area**
1 slug = 32.174 lbm = 14.594 kg 1 lbm = 0.4536 kg 1 short ton = 2000 lbm = 907.185 kg 1 tonne = 1000 kg	1 ft^2 = 0.092903 m^2 1 mi^2 = 2.78784 E7 ft^2 = 2.59 E6 m^2 1 acre = 43,560 ft^2 = 4046.9 m^2 1 hectare (ha) = 10,000 m^2
Velocity	**Acceleration**
1 ft/s = 0.3048 m/s 1 mi/h = 1.466666 ft/s = 0.44704 m/s 1 kn = 1 nmi/h = 1.6878 ft/s = 0.5144 m/s	1 ft/s^2 = 0.3048 m/s^2
Mass flow	**Volume flow**
1 slug/s = 14.594 kg/s 1 lbm/s = 0.4536 kg/s	1 gal/min = 0.002228 ft^3/s = 0.06309 L/s 1×10^6 gal/day = 1.5472 ft^3/s = 0.04381 m^3/s
Pressure	**Force**
1 lbf/ft^2 = 47.88 Pa 1 lbf/in^2 = 144 lbf/ft^2 = 6895 Pa 1 atm = 2116.2 lbf/ft^2 = 14.696 lbf/in^2 = 101,325 Pa 1 inHg (at 20°C) = 3375 Pa 1 bar = 1.0 E5 Pa	1 lbf = 4.448222 N = 16 oz 1 kgf = 2.2046 lbf = 9.80665 N 1 U.S. (short) ton = 2000 lbf 1 dyne = 1.0 E-5 N 1 ounce (avoirdupois) (oz) = 0.27801 N

Energy	Power
1 ft · lbf = 1.35582 J 1 Btu = 252 cal = 1055.056 J = 778.17 ft · lbf 1 kilowatt hour (kWh) = 3.6 E6 J	1 hp = 550 ft · lbf/s = 745.7 W 1 ft · lbf/s = 1.3558 W
Specific weight	**Density**
1 lbf/ft^3 = 157.09 N/m^3	1 slug/ft^3 = 515.38 kg/m^3 1 lbm/ft^3 = 16.0185 kg/m^3 1 g/cm^3 = 1000 kg/m^3
Viscosity	**Kinematic viscosity**
1 slug/(ft · s) = 47.88 kg/(m · s) 1 poise (P) = 1 g/(cm · s) = 0.1 kg/(m · s)	1 ft^2/h = 0.000025806 m^2/s 1 stokes (St) = 1 cm^2/s = 0.0001 m^2/s

Temperature scale readings

$T_F = \frac{9}{5}T_C + 32$ $\quad$ $T_C = \frac{5}{9}(T_F - 32)$ $\quad$ $T_R = T_F + 459.69$ $\quad$ $T_K = T_C + 273.16$

where subscripts F, C, R, and K refer to readings on the Fahrenheit, Celsius, Kelvin, and Rankine scales, respectively

Specific heat or gas constant*	Thermal conductivity*
1 ft · lbf/(slug · °R) = 0.16723 N · m/(kg · K) 1 Btu/(lb · °R) = 4186.8 J/(kg · K)	1 Btu/(h · ft · °R) = 1.7307 W/(m · K)

*Although the absolute (Kelvin) and Celsius temperature scales have different starting points, the intervals are the same size: 1 kelvin = 1 Celsius degree. The same holds true for the nonmetric absolute (Rankine) and Fahrenheit scales: 1 Rankine degree = 1 Fahrenheit degree. It is customary to express temperature differences in absolute-temperature units.

Appendix D
Equations of Motion in Cylindrical Coordinates

The equations of motion of an incompressible newtonian fluid with constant μ, k, and c_p are given here in cylindrical coordinates (r, θ, z), which are related to cartesian coordinates (x, y, z) as in Fig. 4.2:

$$x = r \cos \theta \qquad y = r \sin \theta \qquad z = z \tag{D.1}$$

The velocity components are υ_r, υ_θ, and υ_z. The equations are:

Continuity:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\upsilon_r) + \frac{1}{r}\frac{\partial}{\partial \theta}(\upsilon_\theta) + \frac{\partial}{\partial z}(\upsilon_z) = 0 \tag{D.2}$$

Convective time derivative:

$$\mathbf{V} \cdot \nabla = \upsilon_r \frac{\partial}{\partial r} + \frac{1}{r}\upsilon_\theta \frac{\partial}{\partial \theta} + \upsilon_z \frac{\partial}{\partial z} \tag{D.3}$$

Laplacian operator:

$$\nabla^2 = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2}{\partial \theta^2} + \frac{\partial^2}{\partial z^2} \tag{D.4}$$

The r-momentum equation:

$$\frac{\partial \upsilon_r}{\partial t} + (\mathbf{V} \cdot \nabla)\upsilon_r - \frac{1}{r}\upsilon_\theta^2 = -\frac{1}{\rho}\frac{\partial p}{\partial r} + g_r + \nu\left(\nabla^2 \upsilon_r - \frac{\upsilon_r}{r^2} - \frac{2}{r^2}\frac{\partial \upsilon_\theta}{\partial \theta}\right) \tag{D.5}$$

The θ-momentum equation:

$$\frac{\partial \upsilon_\theta}{\partial t} + (\mathbf{V} \cdot \nabla)\upsilon_\theta + \frac{1}{r}\upsilon_r\upsilon_\theta = -\frac{1}{\rho r}\frac{\partial p}{\partial \theta} + g_\theta + \nu\left(\nabla^2 \upsilon_\theta - \frac{\upsilon_\theta}{r^2} + \frac{2}{r^2}\frac{\partial \upsilon_r}{\partial \theta}\right) \tag{D.6}$$

The z-momentum equation:

$$\frac{\partial \upsilon_z}{\partial t} + (\mathbf{V} \cdot \nabla)\upsilon_z = -\frac{1}{\rho}\frac{\partial p}{\partial z} + g_z + \nu\nabla^2 \upsilon_z \tag{D.7}$$

The energy equation:

$$\rho c_p\left[\frac{\partial T}{\partial t} + (\mathbf{V}\cdot\nabla)T\right] = k\nabla^2 T + \mu[2(\epsilon_{rr}^2 + \epsilon_{\theta\theta}^2 + \epsilon_{zz}^2) + \epsilon_{\theta z}^2 + \epsilon_{rz}^2 + \epsilon_{r\theta}^2] \qquad \text{(D.8)}$$

where

$$\epsilon_{rr} = \frac{\partial \upsilon_r}{\partial r} \qquad \epsilon_{\theta\theta} = \frac{1}{r}\left(\frac{\partial \upsilon_\theta}{\partial \theta} + \upsilon_r\right)$$

$$\epsilon_{zz} = \frac{\partial \upsilon_z}{\partial z} \qquad \epsilon_{\theta z} = \frac{1}{r}\frac{\partial \upsilon_z}{\partial \theta} + \frac{\partial \upsilon_\theta}{\partial z} \qquad \text{(D.9)}$$

$$\epsilon_{rz} = \frac{\partial \upsilon_r}{\partial z} + \frac{\partial \upsilon_z}{\partial r} \qquad \epsilon_{r\theta} = \frac{1}{r}\left(\frac{\partial \upsilon_r}{\partial \theta} - \upsilon_\theta\right) + \frac{\partial \upsilon_\theta}{\partial r}$$

Viscous stress components:

$$\tau_{rr} = 2\mu\epsilon_{rr} \qquad \tau_{\theta\theta} = 2\mu\epsilon_{\theta\theta} \qquad \tau_{zz} = 2\mu\epsilon_{zz}$$

$$\tau_{r\theta} = \mu\epsilon_{r\theta} \qquad \tau_{\theta z} = \mu\epsilon_{\theta z} \qquad \tau_{rz} = \mu\epsilon_{rz} \qquad \text{(D.10)}$$

Angular-velocity components:

$$\omega_r = \frac{1}{r}\frac{\partial \upsilon_z}{\partial \theta} - \frac{\partial \upsilon_\theta}{\partial z}$$

$$\omega_\theta = \frac{\partial \upsilon_r}{\partial z} - \frac{\partial \upsilon_z}{\partial r} \qquad \text{(D.11)}$$

$$\omega_z = \frac{1}{r}\frac{\partial}{\partial r}(r\upsilon_\theta) - \frac{1}{r}\frac{\partial \upsilon_r}{\partial \theta}$$

Appendix E
Introduction to EES

Overview

EES (pronounced "ease") is an acronym for Engineering Equation Solver. The basic function provided by EES is the numerical solution of nonlinear algebraic and differential equations. In addition, EES provides built-in thermodynamic and transport property functions for many fluids, including water, dry and moist air, refrigerants, and combustion gases. Additional property data can be added by the user. The combination of equation solving capability and engineering property data makes EES a very powerful tool.

A license for EES is provided to departments of educational institutions which adopt this text by WCB/McGraw-Hill. If you need more information, contact your local WCB/McGraw-Hill representative, call 1-800-338-3987, or visit our website at www.mhhe.com. A commercial version of EES can be obtained from:

F-Chart Software
4406 Fox Bluff Rd
Middleton, WI 53562
Phone: (608)836-8531
Fax: (608)836-8536

Background Information

The EES program is probably installed on your departmental computer. In addition, the license agreement for EES allows students and faculty in a participating educational department to copy the program for educational use on their personal computer systems. Ask your instructor for details.

To start EES from the Windows File Manager or Explorer, double-click on the EES program icon or on any file created by EES. You can also start EES from the **`Windows Run`** command in the **`Start`** menu. EES begins by displaying a dialog window which shows registration information, the version number, and other information. Click the OK button to dismiss the dialog window.

Detailed help is available at any point in EES. Pressing the F1 key will bring up a Help window relating to the foremost window. (See Fig. E.1.) Clicking the Contents

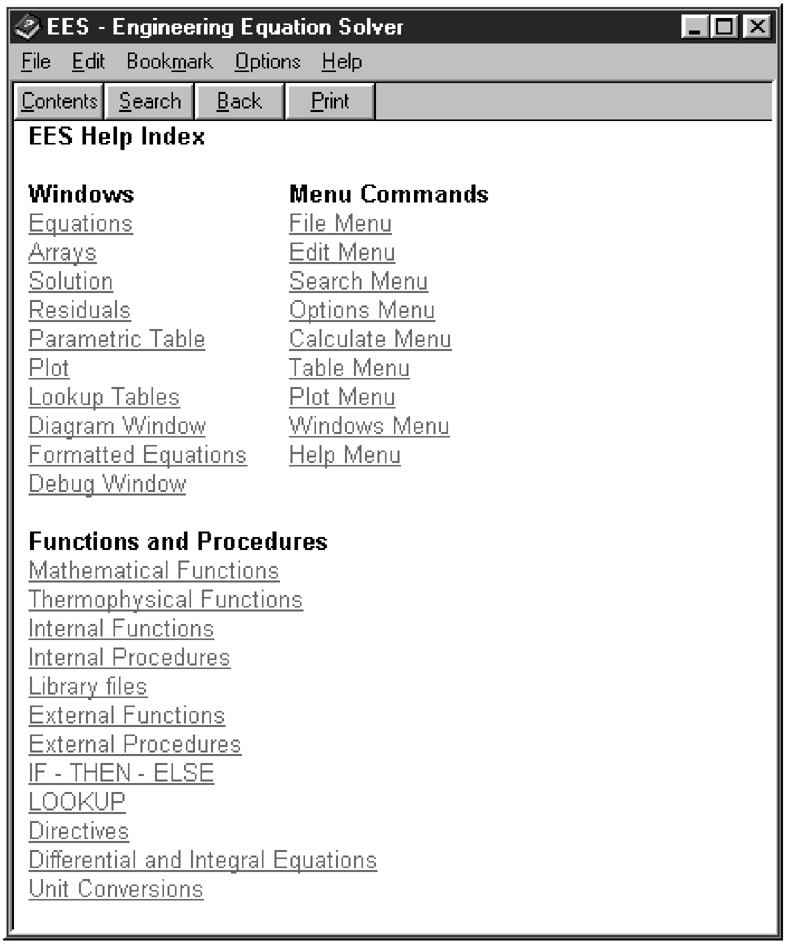


Fig. E.1 EES Help index.

button will present the Help index shown below. Clicking on an underlined word (shown in green on color monitors) will provide help relating to that subject.

EES commands are distributed among nine pull-down menus as shown below. Many of the commands are accessible with the speed button palette that appears below the menu bar. A brief summary of their functions follows. (A tenth pull-down menu, which is made visible with the **Load Textbook** command described below, provides access to problems from this text.)

The **System** menu appears above the **File** menu. The **System** menu is not part of EES but rather is a feature of the Windows operating system. It holds commands which allow window moving, resizing, and switching to other applications.

The **File** menu provides commands for loading, merging, and saving work files; libraries; and printing. The **Load Textbook** command in this menu reads the problem disk developed for this text and creates a new menu to the right of the **Help** menu for easy access to EES problems accompanying this text.

The **Edit** menu provides the editing commands to cut, copy, and paste information.

The **Search** menu provides **Find** and **Replace** commands for use in the Equations window.

The **Options** menu provides commands for setting the guess values and bounds of variables, the unit system, default information, and program preferences. A command is also provided for displaying information on built-in and user-supplied functions.

The **Calculate** menu contains the commands to check, format, and solve the equation set.

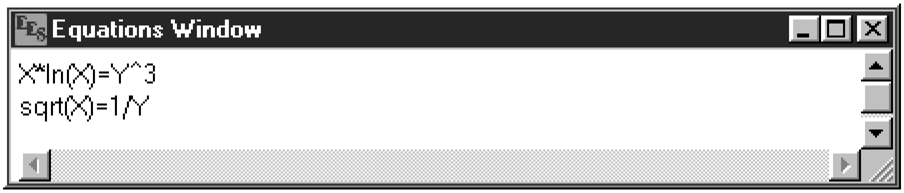
The **Tables** menu contains commands to set up and alter the contents of the parametric and lookup tables and to do linear regression on the data in these tables. The parametric table, which is similar to a spreadsheet, allows the equation set to be solved repeatedly while varying the values of one or more variables. The lookup table holds user-supplied data which can be interpolated and used in the solution of the equation set.

The **Plot** menu provides commands to modify an existing plot or prepare a new plot of data in the parametric, lookup, or array tables. Curve-fitting capability is also provided.

The **Windows** menu provides a convenient method of bringing any of the EES windows to the front or to organize the windows.

The **Help** menu provides commands for accessing the on-line help documentation.

A basic capability provided by EES is the solution of a set of nonlinear algebraic equations. To demonstrate this capability, start EES and enter this simple example problem in the Equations window.



Text is entered in the same manner as for any word processor. Formatting rules are as follows:

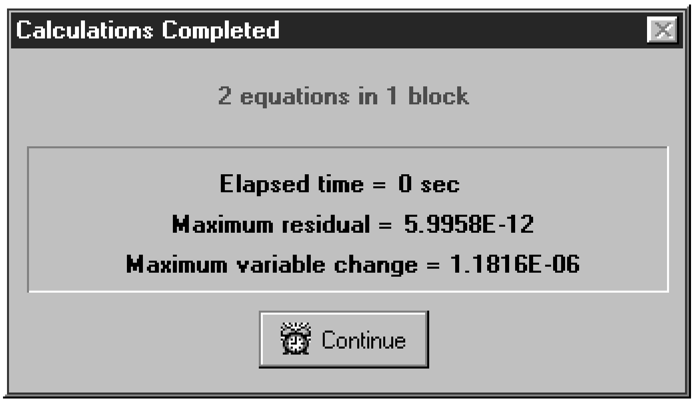
1. Uppercase and lowercase letters are not distinguished. EES will (optionally) change the case of all variables to match the manner in which they first appear.

2. Blank lines and spaces may be entered as desired since they are ignored.

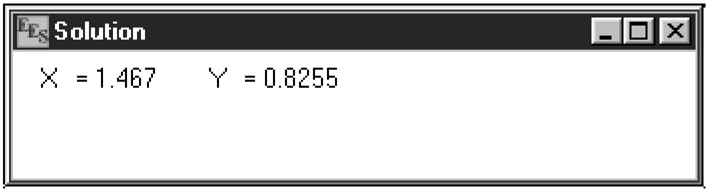
3. Comments must be enclosed within braces { } or within quotation marks " ". Comments may span as many lines as needed. Comments within braces may be nested, in which case only the outermost set of braces is recognized. Comments within quotes will also be displayed in the Formatted Equations window.
4. Variable names must start with a letter and consist of any keyboard characters except ( ) ‘ | */ + − ^ { } : " or ;. Array variables are identified with square braces around the array index or indices, e.g., X[5,3]. The maximum variable length is 30 characters.
5. Multiple equations may be entered on one line if they are separated by a semi-colon (;). The maximum line length is 255 characters.
6. The caret symbol (^) or ** is used to indicate raising to a power.
7. The order in which the equations are entered does not matter.
8. The position of knowns and unknowns in the equation does not matter.

If you wish, you may view the equations in mathematical notation by selecting the **`Formatted Equations`** command from the **`Windows`** menu.

Select the **`Solve`** command from the **`Calculate`** menu. A Dialog window will appear indicating the progress of the solution. When the calculations are completed, the button will change from Abort to Continue.



Click the Continue button. The solution to this equation set will then be displayed.



A Pipe Friction Example Problem

Let us now solve Prob. 6.55 from the text, for a cast-iron pipe, to illustrate the capabilities of the EES program. This problem, without EES, would require iteration for Reynolds number, velocity, and friction factor, a daunting task. State the problem:

6.55 Reservoirs 1 and 2 contain water at 20°C. The pipe is cast iron, with $L =$ 4500 m and $D = 4$ cm. What will be the flow rate in m^3/h if $\Delta z = 100$ m?

This is a representative problem in pipe flow (see Fig. E.2), and, being water in a reasonably large (noncapillary) pipe, it will probably be turbulent (Re > 4000). The steady-flow energy equation (3.71) may be written between the surfaces of reservoirs 1 and 2:

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + h_f \qquad \text{where} \qquad h_f = f\frac{L}{D}\frac{V_{\text{pipe}}^2}{2g}$$

Since $p_1 = p_2 = p_{\text{atm}}$ and $V_1 \approx V_2 \approx 0$, this relation simplifies to

$$\Delta z = f\frac{L}{D}\frac{V^2}{2g} \tag{1}$$

where $V = Q/A$ is the velocity in the pipe. The friction factor f is a function of Reynolds number and pipe roughness ratio, if the flow is turbulent, from Eq. (6.64):

$$\frac{1}{f^{1/2}} = -2.0 \log_{10}\left(\frac{\epsilon/D}{3.7} + \frac{2.51}{\text{Re}\, f^{1/2}}\right) \qquad \text{if Re} > 4000 \tag{2}$$

Finally, we need the definitions of Reynolds number and volume flow rate:

$$\text{Re} = \frac{\rho V D}{\mu} \tag{3}$$

and

$$Q = V\frac{\pi}{4}D^2 \tag{4}$$

where ρ and μ are the fluid density and viscosity, respectively.

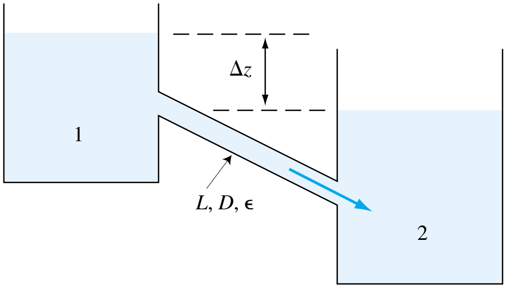


Fig. E.2 Sketch of the flow system.

There are a total of 11 variables involved in this problem: (L, D, Δz, ϵ, g, μ, ρ, V, Re, f, Q). Of these, seven can be specified at the start (L, D, Δz, ϵ, g, μ, ρ), while four (V, Re, f, Q) must be calculated from relations (1) to (4) above. These four equations in four unknowns are well posed and solvable but only by laborious iteration, exactly what EES is designed to do.

Start EES or select the **New** command from the **File** menu if you have already been using the program. A blank Equations window will appear. Our recommendation is to always set the unit system immediately: Select **Unit System** from the **Options** menu (Fig. E.3). We select *SI* and *Mass* units and trig *Degrees,* although we do not actually have trigonometric functions this time. We select *kPa* for pressure and *Celsius* for temperature, which will be handy for using the EES built-in physical properties of water.

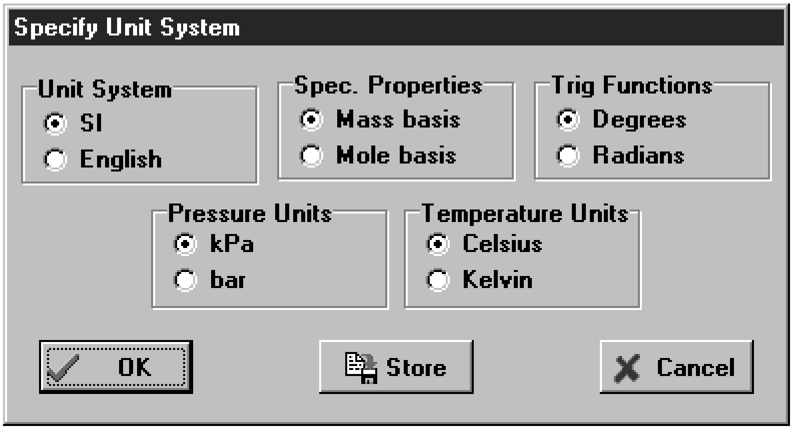


Fig. E.3 Unit Selection dialog window.

Now, onto the blank screen, enter the equations for this problem (Fig. E.4), of which five are known input values, two are property evaluations, and four are the relations (1) to (4) from above.

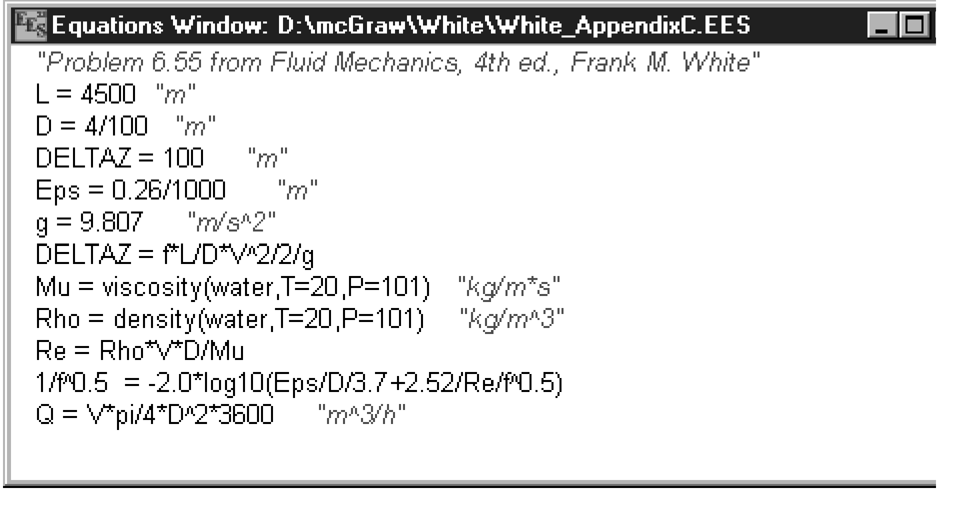


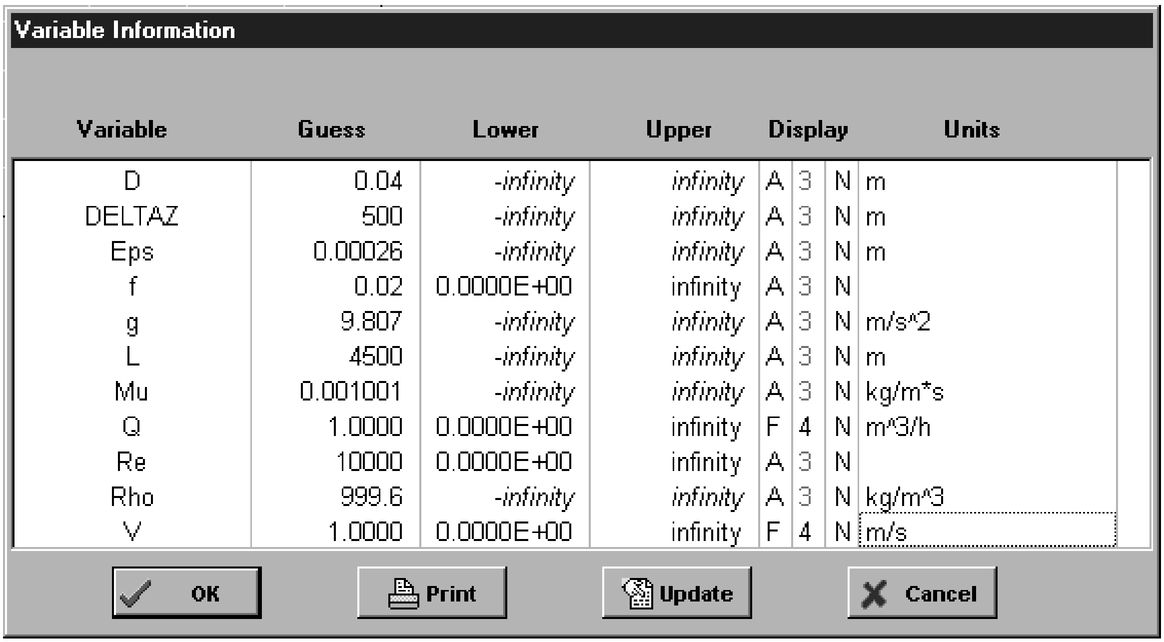
Fig. E.4 Equations window.

There are several things to notice in Fig. E.4. First, quantities in quotes, such as “m,” are for the user’s benefit and ignored by EES. Second, we changed *Eps* and *D* to meters right away, to keep the SI units consistent. Third, we called on EES to input the viscosity and density of water at 20°C and 1 atm, a procedure well explained in the **`Help`** menu. For example, **`viscosity(water,T=20,P=101)`** meets the EES requirement that temperature (T) and pressure (P) should be input in °C and kPa—EES will then evaluate μ in kg/(m · s). Finally, note that EES recognizes **`pi`** to be 3.141593.

In Fig. E.4 we used only one built-in function, **`log10.`** There are many such functions, found by scrolling down the **`Function Information`** command in the **`Options`** menu.

Having entered the equations, check the syntax by using the **`Check/Format`** command in the **`Calculate`** menu. If you did well, EES will report that the 11 equations in 11 unknowns look OK. If not, EES will guess at what might be wrong. If OK, why not go for it? Hit the **`Solve`** command in the **`Options`** menu. EES reports “logarithm of a negative number—try setting limits on the variables”. We might have known. Go to the **`Variable Information`** command in the **`Options`** menu. A box, listing the 11 variables, will appear (Fig. E.5). All default EES “guesses” are unity; all default limits are $-\infty$ to $+\infty$, which is too broad a range. Enter (as already shown in Fig. E.5) guesses for $f = 0.02$ and Re = 10,000, while $V = 1$ and $Q = 1$ seem adequate, and other variables are fixed. Make sure that *f*, Re, *V*, and *Q* cannot be negative. The “display” columns normally say “A”, automatic, satisfactory for most variables. We have changed “A” to “F” (fixed decimal) for *Q* and *V* to make sure they are displayed to four decimal places. The “units” column is normally blank—type in the correct units and they will be displayed in the solution.

Our guesses and limits are excellent, and the **`Solve`** command now iterates and reports success: “max residual = 2E-10”, a negligible error. (The default runs for 100


Variable Information

Variable	Guess	Lower	Upper	Display			Units
D	0.04	-infinity	infinity	A	3	N	m
DELTAZ	500	-infinity	infinity	A	3	N	m
Eps	0.00026	-infinity	infinity	A	3	N	m
f	0.02	0.0000E+00	infinity	A	3	N	
g	9.807	-infinity	infinity	A	3	N	m/s^2
L	4500	-infinity	infinity	A	3	N	m
Mu	0.001001	-infinity	infinity	A	3	N	kg/m*s
Q	1.0000	0.0000E+00	infinity	F	4	N	m^3/h
Re	10000	0.0000E+00	infinity	A	3	N	
Rho	999.6	-infinity	infinity	A	3	N	kg/m^3
V	1.0000	0.0000E+00	infinity	F	4	N	m/s

Fig. E.5 Variable Information window with units and guess values entered.

iterations, which can be modified by the **Stop Criteria** command in the **Options** menu.) Hit **Continue,** and the complete solution is displayed for all variables (Fig. E.6).

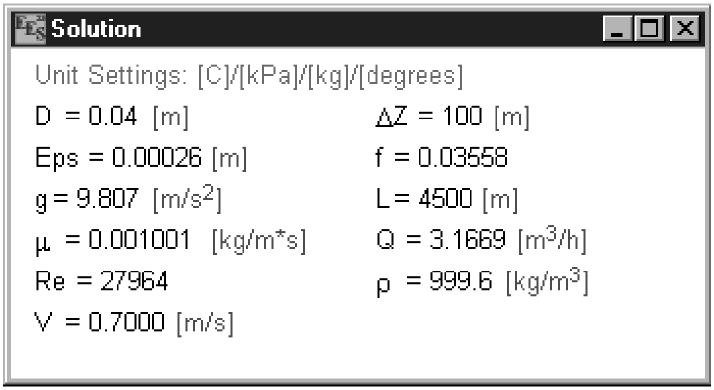


Fig. E.6 The Solutions window for Prob. 6.55.

This is the correct solution to Prob. 6.55: this cast-iron pipe, when subjected to a 100-m elevation difference, will deliver $Q = 3.17\ \text{m}^3/\text{h}$ of water. EES did all the iteration.

Parametric Studies with Tabular Input

One of the most useful features of EES is its ability to provide parametric studies. For example, suppose we wished to know how varying Δz changed the flow rate Q. First comment out the equation that reads DELTAZ = 100 by enclosing it within braces. (If you select the equation and press the right mouse button, EES will automatically enter the braces.) Select the **New Parametric Table** command in the **Options** menu. A dialog will be displayed (Fig. E.7) listing all the variables in the problem. Highlight what you wish to vary: Δz. Also highlight variables to be calculated and tabulated: V, Q, Re, and f.

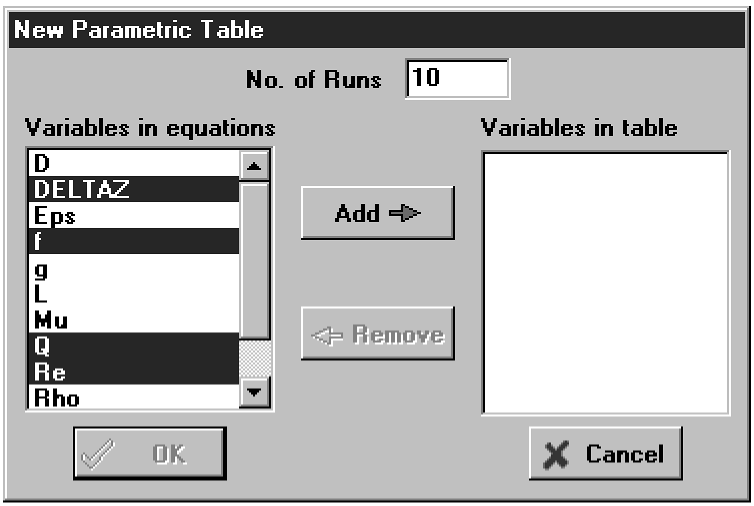


Fig. E.7 New Parametric Table window showing selected variables (V is not shown).

Click the **OK** button and the new table will be displays (Fig. E.8). Enter 10 values of Δz that cover the range of interest—we have selected the linear range $10 < \Delta z < 500$ m.

Parametric Table

	1 V [m/s]	2 Re	3 Q [m3/h]	4 f	5 ΔZ [m]
Run 1					10
Run 2					64.44
Run 3					118.9
Run 4					173.3
Run 5					227.8
Run 6					282.2
Run 7					336.7
Run 8					391.1
Run 9					445.6
Run 10					500

Fig. E.8 Parametric Table window.

Clearly the parametric table operates much like a spreadsheet. Select **Solve Table** from the **Calculate** menu, and the Solve Table dialog window will appear (Fig. E.9). These are satisfactory default values; the author has changed nothing. Hit the **OK** button and the calculations will be made and the entire parametric table filled out, as in Fig. E.10.

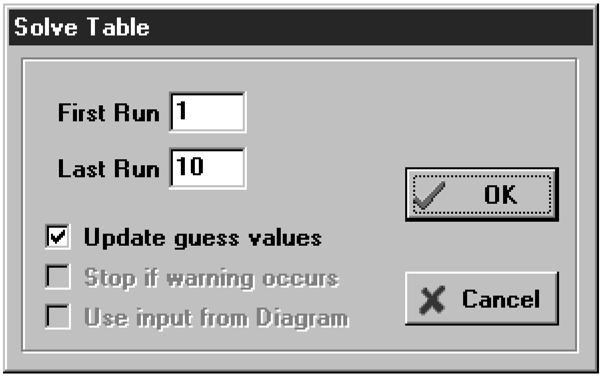


Fig. E.9 Solve Table Dialog.

The flow rates can be seen in Fig. E.10, but as always, in the author's experience, a plot is more illuminating. Select **New Plot window** from the **Plot** menu. The New Plot window dialog (Fig. E.11) will appear. Choose Δz as the x-axis and Q as the y-axis. We added grid lines. Click the OK button, and the desired plot will appear in the Plot window (Fig. E.12). We see a nonlinear relationship, roughly a square-root type, and learn that flow rate Q is not linearly proportional to head difference Δz.

The plot appearance in Fig. E.12 can be modified in several ways. Double-click the mouse in the plot rectangle to see some of these options.

Parametric Table

	1 V [m/s]	2 Re	3 Q [m3/h]	4 f	5 ΔZ [m]
Run 1	0.2076	8292	0.9391	0.04046	10
Run 2	0.5573	22261	2.5209	0.03618	64.44
Run 3	0.7655	30580	3.4631	0.03537	118.9
Run 4	0.9296	37135	4.2054	0.03497	173.3
Run 5	1.0695	42722	4.8382	0.03472	227.8
Run 6	1.1935	47675	5.3991	0.03455	282.2
Run 7	1.3060	52170	5.9081	0.03441	336.7
Run 8	1.4098	56316	6.3776	0.03431	391.1
Run 9	1.5065	60182	6.8154	0.03423	445.6
Run 10	1.5976	63818	7.2272	0.03416	500

Fig. E.10 Parametric Table window after calculations are completed.

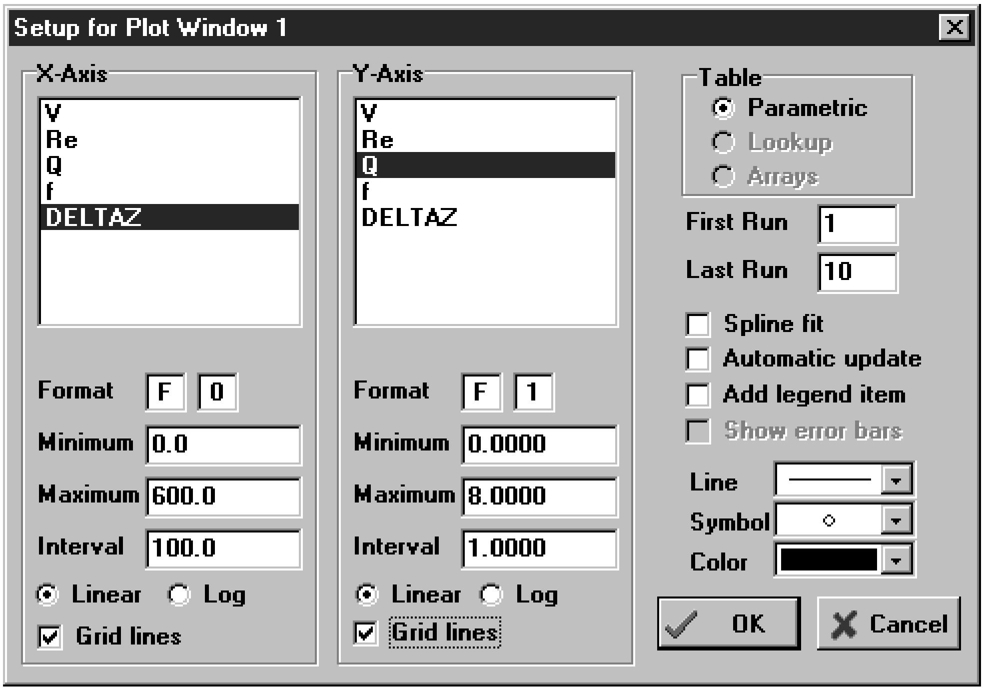


Fig. E.11 New Plot Setup dialog window.

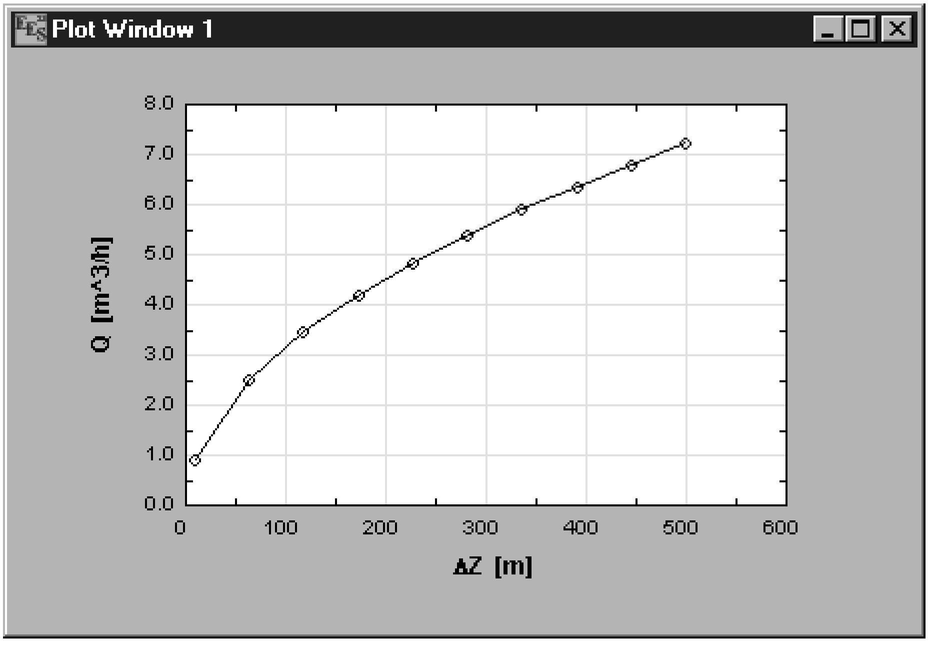


Fig. E.12 Plot window for flow rate versus elevation difference.

Loading a Textbook File

A problems disk developed for EES has been included with this textbook. Place the disk in the disk drive, and then select the **Load Textbook** command in the **File** menu. Use the **Windows Open File** command to open the textbook problem index file which, for this book, is named WHITE.TXB. A new menu called **Fluid Mechanics** will appear to the right of the **Help** menu. This menu will provide access to all the EES problem solutions developed for this book organized by chapter. As an example, select Chap. 6 from the **Fluid Mechanics** menu. A dialog window will appear listing the problems in Chap. 6. Select Problem 6.55—Flow Between Reservoirs. This problem is a modification (smooth instead of cast-iron pipe) of the problem you just entered. It provides a diagram window in which you can enter Δz. Enter other values, and then select the **Solve** command in the **Calculate** menu to see their effect on the flow rate.

At this point, you should explore. Try whatever you wish. You can't hurt anything. The on-line help (invoked by pressing F1) will provide details for the **EES** commands. EES is a powerful tool that you will find very useful in your studies.

Answers to Selected Problems

Chapter 1

1.2 1.3 E44 molecules
1.4 1.63 slug/ft^3, 839 kg/m^3
1.6 (*a*) $\{L^2/T^2\}$; (*b*) $\{M/T\}$
1.8 $\sigma \approx 1.00\ My/I$
1.10 Yes, all terms are $\{ML/T^2\}$
1.12 $\{B\} = \{L^{-1}\}$
1.14 $Q = \text{Const}\ B\ g^{1/2}H^{3/2}$
1.16 All terms are $\{ML^{-2}T^{-2}\}$
1.18 $V = V_0 e^{-mt/K}$
1.20 $z_{max} = 64.2$ m at $t = 3.36$ s
1.22 (*a*) $-0.372U_\infty^2/R$; (*b*) $x = -1.291\ R$
1.24 $e = 221{,}000$ J/kg
1.26 $W_{air} = 0.71$ lbf
1.28 $\rho_{wet} = 1.10$ kg/m^3, $\rho_{dry} = 1.13$ kg/m^3
1.30 $W_{1\text{-}2} = 21$ ft · lbf
1.32 (*a*) 76 kN; (*b*) 501 kN
1.34 1300 atm
1.36 (*a*) $B_{N_2O} = 1.33$ E5 Pa; (*b*) $B_{water} = 2.13$ E9 Pa
1.38 $\tau = 1380$ Pa, $Re_L = 28$
1.40 $A = 0.0016$ kg/(m · s), $B = 1903$ K
1.42 $\mu/\mu_{200K} \approx (T\ \text{K}/200\ \text{K})^{0.68}$
1.44 Data 50 percent higher; Andrade fit varies ±50 percent
1.46 $V \approx 15$ m/s
1.48 $F \approx (\mu_1/h_1 + \mu_2/h_2)AV$
1.50 $\mu \approx M(r_o - r_i)/(2\pi\Omega r_i^3 L)$
1.52 $P \approx 73$ W
1.54 $M \approx \pi\mu\Omega R^4/h$
1.56 $\mu = 3M \sin\theta/(2\pi\Omega R^3)$
1.58 $\mu = 0.040$ kg/(m · s), last 2 points are *turbulent* flow
1.60 $\mu = 0.88 \pm 0.023$ kg/(m · s)
1.62 28,500 Pa
1.64 (*a*) -0.023 m; (*b*) $+0.069$ m
1.66 $F = 0.014$ N
1.68 $h = (\Upsilon/\rho g)^{1/2} \cot\theta$
1.70 $h = 2\Upsilon \cos\theta/(\rho g W)$
1.72 $z \approx 4800$ m
1.74 Cavitation occurs for both (*a*) and (*b*)
1.76 $z \approx 7500$ m
1.78 (*a*) 25°C; (*b*) 4°C
1.80 $x^2y - y^3/3 = \text{constant}$
1.82 $y = x \tan\theta + \text{constant}$
1.84 $x = x_0\{\ln(y/y_0) + \ln^2(y/y_0)\}$

Chapter 2

2.2 $\sigma_{xy} = -289$ lb/ft^2, $\tau_{AA} = -577$ lb/ft^2
2.4 $x = \text{Const}\ e^{-2Cz/B}$
2.6 (*a*) 30.3 ft; (*b*) 30.0 in; (*c*) 10.35 m; (*d*) 13,100 mm
2.8 DALR = 9.77°C/km
2.10 10,500 Pa
2.12 8.0 cm
2.14 74,450 Pa with air; 75,420 Pa without air
2.16 (*a*) 21,526 cm^3; (*b*) 137 kPa
2.18 1.56
2.20 14 lbf
2.22 0.94 cm
2.24 $p_{sealevel} \approx 117$ kPa, $m_{exact} = 5.3$ E18 kg
2.26 (*a*) 2580 m; (*b*) 5410 m
2.28 4400 ± 400 ft
2.30 101,100 Pa
2.32 22.6 cm
2.34 $\Delta p = \Delta h[\gamma_{water}(1 + d^2/D^2) - \gamma_{oil}(1 - d^2/D^2)]$
2.36 25°
2.38 (*a*) $p_{1,gage} = (\rho_m - \rho_a)gh - (\rho_t - \rho_a)gH$
2.40 21.3 cm
2.42 $p_A - p_B = (\rho_2 - \rho_1)gh$
2.44 (*a*) 171 lb/ft^2; (*b*) 392 lb/ft^2; manometer reads friction loss

2.46	1.45
2.48	$F = 39700$ N
2.50	(*a*) 524 kN; (*b*) 350 kN; (*c*) 100 kN
2.52	0.96
2.54	879 kg/m^3
2.56	16.08 ft
2.58	0.40 m
2.60	$F_{net} = 23{,}940$ N at 1.07 m above B
2.62	10.6 ft
2.64	1.35 m
2.66	$F = 1.18$ E9 N, $M_C = 3.13$ E9 N $\cdot$ m counterclockwise, no tipping
2.68	18,040 N
2.70	4490 lbf at 1.44 ft to right and 1.67 ft up from point B
2.72	33,500 N
2.74	$F = ba^2\rho_0\{(a^2/g)[\exp(gh/a^2) - 1] - h\}$
2.76	$P = (\gamma/24)h^2 b(3 + \csc^2\theta)$
2.78	$P = \pi\gamma R^3/4$
2.80	(*a*) 58,800 Pa; (*b*) 0.44 m
2.82	$F_H = 97.9$ MN, $F_V = 153.8$ MN
2.84	$F_H = 4895$ N, $F_V = 7343$ N
2.86	$F_H = 0$, $F_V = 6800$ lbf
2.88	$F_H = 176$ kN, $F_V = 31.9$ kN, yes
2.90	467 lbf
2.92	$F_{one\ bolt} \approx 11{,}300$ N
2.94	$C_x = 2996$ lb, $C_z = 313$ lbf
2.96	(*a*) 940 kN; (*b*) 1074 kN; (*c*) 1427 kN
2.98	$F_H = 7987$ lbf, $F_V = 2280$ lbf
2.100	$F_H = 0$, $F_V = 297$ kN
2.102	124 kN
2.104	5.0 N
2.106	4310 N/m^3
2.108	12.6 N
2.110	$h \approx$ (*a*) 7.05 mm; (*b*) 7.00 mm
2.112	(*a*) 39 N; (*b*) 0.64
2.114	0.636
2.116	19100 N/m^3
2.118	(*a*) draft = 7.24 in; (*b*) 25 lbf
2.120	34.3°
2.122	$a/b \approx 0.834$
2.124	6850 m
2.126	$h/H = Z - (Z^2 - 1 + \beta)^{1/2}$, $\beta = d/H$, $Z = (2 + \lambda - \beta)/2$, $\lambda = p_a/(\rho g H)$
2.128	Yes, stable if $S > 0.789$
2.130	Slightly unstable, MG = -0.007 m
2.132	Stable if $R/h > 3.31$
2.134	(*a*) unstable; (*b*) stable
2.136	$MG = L^2/(3\pi R) - 4R/(3\pi) > 0$ if $L > 2R$
2.138	2.77 in deep; volume = 10.8 fluid ounces
2.140	$a_x =$ (*a*) -1.96 m/s^2 (deceleration); (*b*) -5.69 m/s^2 (deceleration)
2.142	(*a*) 16.3 cm; (*b*) 15.7 N
2.144	(*a*) $a_x \approx 319$ m/s^2; (*b*) no effect, $p_A = p_B$
2.146	Leans to the right at $\theta = 27°$
2.148	Leans to the left at $\theta = 27°$
2.150	5.5 cm; linear scale OK
2.152	(*a*) 224 r/min; (*b*) 275 r/min
2.154	(*a*) both are paraboloids; (*b*) $p_B = 2550$ Pa (gage)
2.157	77 r/min, minimum pressure halfway between B and C
2.158	10.57 r/min

Chapter 3

3.2	$\mathbf{r}$ = position vector from point O
3.6	$Q = (2b/3)(2g)^{1/2}[(h + L)^{3/2} - (h - L)^{3/2}]$
3.8	$Q = K$ per unit depth
3.10	$(\pi/3)R^2\rho U_0 c_p T_w$
3.12	(*a*) 44 m^3/h; (*b*) 9.6 m/s
3.14	$dh/dt = (Q_1 + Q_2 - Q_3)/(\pi d^2/4)$
3.16	$Q_{top} = 3U_0 b\delta/8$
3.18	(*b*) $Q = 16bhu_{max}/9$
3.20	(*a*) 7.97 mL/s; (*b*) 1.27 cm/s
3.22	(*a*) 0.06 kg/s; (*b*) 1060 m/s; (*c*) 3.4
3.24	$h = [3Kt^2d^2/(8\tan^2\theta)]^{1/3}$
3.26	$Q = 2U_0 bh/3$
3.28	$t = \pi(1 - 1/\sqrt{3})h_0^{1/2}/(2CA\sqrt{2g})$
3.30	(*a*) $dh/dt = Q/(2hb\cot 20°)$
3.32	$V_{hole} = 6.1$ m/s
3.34	$V_2 = 4660$ ft/s
3.36	$U_3 = 6.33$ m/s
3.38	$V = V_0 r/(2h)$
3.40	500 N to the left
3.42	$F = (p_1 - p_a)A_1 - \rho_1 A_1 V_1^2[(D_1/D_2)^2 - 1]$
3.44	$F = \rho U^2 Lb/3$
3.46	$\alpha = (1 + \cos\theta)/2$
3.48	$V_0 \approx 2.27$ m/s
3.50	102 kN
3.52	$F = \rho WhV_1^2[1/(1 - \sin\theta) - 1]$ to the left
3.54	163 N
3.56	2.45 N/m
3.58	40 N
3.60	2100 N
3.62	3100 N
3.64	980 N
3.66	8800 N
3.70	91 lbf
3.72	Drag $\approx$ 4260 N
3.74	$F_x = 0$, $F_y = -17$ N, $F_z = 126$ N
3.76	77 m/s
3.80	$F = (\rho/2)gb(h_1^2 - h_2^2) - \rho h_1 b V_1^2(h_1/h_2 - 1)$
3.82	25 m/s
3.84	23 N
3.86	274 kPa

3.88 $V = \zeta + [\zeta^2 + 2V_j]^{1/2}$, $\zeta = \rho Q/2k$
3.90 $dV/dt = g$
3.92 $dV/dt = gh/(L + h)$
3.94 $h = 0$ at $t \approx 70$ s
3.96 $d^2Z/dt^2 + 2gZ/L = 0$
3.100 (*a*) 507 m/s and 1393 m; (*b*) 14.5 km
3.102 $h_2/h_1 = -\frac{1}{2} + \frac{1}{2}[1 + 8V_1^2/(gh_1)]^{1/2}$
3.104 $\Omega = (-V_e/R) \ln (1 - \dot{m}t/M_0)$
3.106 $\Omega_{final} = 75$ rad/s
3.108 (*a*) $V = V_0/(1 + CV_0t/M)$, $C = \rho bh(1 - \cos \theta)$
3.110 (*a*) 0.113 ft · lbf; (*b*) 250 r/min
3.112 $T = \dot{m}R_0^2\Omega$
3.114 (*a*) 414 r/min; (*b*) 317 r/min
3.116 $P = \rho Q r_2 \omega[r_2\omega - Q \cot \theta_2/(2\pi r_2 b_2)]$
3.118 $P = \rho Q u V_n(\cot \alpha_1 + \cot \alpha_2)$
3.120 (*a*) 22 ft/s; (*b*) 110 ft/s; (*c*) 710 hp
3.122 $L = -h_1 (\cot \theta)/2$
3.124 41 r/min
3.126 −15.5 kW (work done *on* the fluid)
3.128 1.07 m^3/s
3.130 34 kW
3.134 4500 hp
3.136 5.6 m^3/h
3.138 $\mu = \pi\rho g d^4(H + \bar{L})/(128\bar{L}Q) - \alpha_2\rho Q/(16\pi\bar{L})$
3.140 1640 hp
3.142 (*a*) 1150 gal/min; (*b*) 67 hp
3.144 26 kW
3.146 $h = 3.6$ ft
3.148 $h_f = 0.21$ m
3.152 (*a*) 85.9°; (*b*) 55.4°
3.154 $h = 0.133$ m
3.156 (*a*) 102 kPa; (*b*) 88 mi/h
3.158 (*a*) 169.4 kPa; (*b*) 209 m^3/h
3.160 (*a*) 31 m^3/s; (*b*) 54 kW
3.162 $Q = 166\ ft^3/min$, $\Delta p = 0.0204\ lbf/in^2$
3.164 (*a*) 5.25 kg/s; (*b*) 2.9 cm
3.166 (*a*) 60 mi/h; (*b*) 1 atm
3.168 $h = 1.08$ ft
3.170 $h = 1.76$ m
3.172 $D = 0.132$ ft
3.174 (*a*) 5.61 ft/s; (*b*) further constriction *reduces* V_2
3.176 (*a*) 9.3 m/s; (*b*) 68 kN/m
3.178 $h_2 = 2.03$ ft (subcritical) or 0.74 ft (supercritical)
3.180 $V = V_f \tanh (V_f t/2L)$, $V_f = (2gh)^{1/2}$
3.182 $kp/[(k - 1)\rho] + V^2/2 + gz = \text{constant}$

Chapter 4

4.2 (*a*) $du/dt = (2V_0^2/L)(1 + 2x/L)$
4.4 At (2, 1), $dT/dt = 125$ units
4.6 (*a*) $6V_0^2/L$; (*b*) $L \ln 3/(2V_0)$
4.8 (*a*) $0.0196\ V^2/L$; (*b*) at $t = 1.05\ L/U$
4.12 If $\upsilon_\theta = \upsilon_\phi = 0$, $\upsilon_r = r^{-2}$ fcn (θ, ϕ)
4.14 $\upsilon_\theta = \text{fcn}(r)$ only
4.16 $\upsilon = y^2 - 3x^2y + \text{fcn}(x, z)$
4.18 $\rho = \rho_0 L_0/(L_0 - Vt)$
4.20 $\upsilon = \upsilon_0 = \text{const}$, $\{K\} = \{L/T\}$, $\{a\} = \{L^{-1}\}$
4.22 $\rho_{x=L} = 1.82\ kg/m^3$
4.28 Exact solution for any *a* or *b*
4.30 $p = \text{const} - (\rho K^2/2)(x^2 + y^2)$
4.32 $f_1 = C_1 r$; $f_2 = C_2/r$
4.34 $p = p(0) - 4\mu u_{max} z/R^2$
4.36 $C = \rho g \sin \theta/(2\mu)$
4.38 $C_z = \tau_{yx} - \tau_{xy}$
4.42 $T_{mean} \approx (\int uT\, dy)/(\int u\, dy)$
4.48 $\psi = Kxy + \text{const}$
4.50 Inviscid flow around a 180° turn
4.52 $\psi = -4Q\theta/(\pi b)$
4.54 $Q = ULb$
4.60 Irrotational, $z_0 = H - \omega^2R^2/(2g)$
4.62 $\psi = Vy^2/(2h) + \text{const}$
4.66 $\psi = -K \sin \theta/r$
4.68 $\psi = m \tan^{-1}[2xy/(x^2 - y^2 + a^2)]$
4.70 $\phi = \lambda \cos \theta/r^2$, $\lambda = 2am$
4.72 (*a*) 8.8m; (*b*) 55 m
4.74 $\psi = Uy + K \ln r$
4.76 (*a*) 0.106 m from A; (*b*) 0.333 m above the wall
4.78 (*a*) $V_{wall,max} = m/\bar{L}$; (*b*) p_{min} at $x = \bar{L}$
4.80 (*a*) $w = (\rho g/2\mu)(2\delta x - x^2)$
4.82 Obsessive result: $\upsilon_\theta = \Omega R^2/r$
4.84 $\upsilon_z = (\rho g b^2/2\mu) \ln (r/a) - (\rho g/4\mu)(r^2 - a^2)$
4.86 $Q = 0.0031\ m^3/(s \cdot m)$
4.88 $\upsilon_z = U \ln (r/b)/[\ln (a/b)]$
4.90 $F \approx 3.34$ N

Chapter 5

5.2 1.21 m
5.4 $V = 1.55$ m/s, $F = 1.3$ N
5.6 $F \approx 450$ N
5.10 (*a*) $\{ML^{-2}T^{-2}\}$; (*b*) $\{MLT^{-2}\}$
5.14 $\delta/x = fcn\ (\rho Ux/\mu)$
5.16 Stanton number $= h/(\rho V c_p)$
5.18 $Q\mu/[(\Delta p/L)b^4] = \text{const}$
5.20 $P/(\rho\Omega^3D^5) = \text{fcn}[Q/(\Omega D^3), \rho\Omega D^2/\mu]$
5.22 $\Omega D/V = \text{fcn}(N, H/L)$
5.24 $F/(\rho V^2L^2) = \text{fcn}(\alpha, \rho VL/\mu, L/D, V/a)$
5.26 (*a*) indeterminate; (*b*) $T = 2.75$ s
5.28 $\delta/L = \text{fcn}[L/D, \rho VD/\mu, E/(\rho V^2)]$
5.30 $hL/k = \text{fcn}(\rho UL/\mu, \mu c_p/k)$
5.32 $Q/(bg^{1/2}H^{3/2}) = \text{const}$
5.34 $k_{hydrogen} \approx 0.182\ W/(m \cdot K)$

5.36 (*a*) $Q_{\text{loss}}R/(A\Delta T)$ = constant
5.38 $d/D = \text{fcn}(\rho UD/\mu, \rho U^2D/Y)$
5.40 $h/L = \text{fcn}(\rho gL^2/Y, \alpha, \theta)$
5.44 (*a*) $\{\sigma\} = \{L^2\}$
5.48 $F \approx 0.17$ N; (doubling U quadruples F)
5.50 (*a*) $F/(\mu UL)$ = constant
5.52 $U \approx 5$ ft/s, $F \approx 0.003$ lbf/ft
5.54 Power ≈ 7 hp
5.56 $V \approx 128$ ft/s = 87 mi/h
5.58 $V \approx 2.8$ m/s
5.60 Prototype power ≈ 157 hp
5.62 $\Omega_{\max} \approx 26.5$ r/s; $\Delta p \approx 22{,}300$ Pa
5.64 $\omega_{\text{aluminum}} = 0.77$ Hz
5.66 (*a*) $V = 27$ m/s; (*b*) $z = 27$ m
5.68 (*a*) $F/(\mu U)$ = constant; (*b*) No, not plausible
5.70 $F = 87$ lbf
5.72 $V = 25$ ft/s
5.74 Prototype moment = 88 kN · m
5.76 Drag = 107,000 lbf
5.78 Weber no. ≈ 100 if $L_m/L_p = 0.0090$
5.80 (*a*) 1.86 m/s; (*b*) 42,900; (*c*) 254,000
5.82 Speeds: 19.6, 30.2, and 40.8 ft/s;
Drags: 14,600; 31,800; and 54,600 lbf
5.84 $V_m = 39$ cm/s; $T_m = 3.1$ s; $H_m = 0.20$ m
5.88 At 340 W, $D = 0.109$ m
5.90 $\Delta pD/(\rho V^2L) = 0.155(\rho VD/\mu)^{-1/4}$

Chapter 6

6.2 (*a*) $x = 2.1$ m; (*b*) $x = 0.14$ m
6.4 (*a*) 39 m^3/h; (*b*) 1.3 m^3/h
6.6 (*a*) laminar; (*b*) laminar
6.8 (*a*) −3600 Pa/m; (*b*) −13,400 Pa/m
6.10 (*a*) from *A* to *B*; (*b*) $h_f = 7.8$ m
6.18 (*a*) 0.054 m^3/s; (*b*) 8.5 m/s; (*c*) 122 Pa; (*d*) 542 kPa
6.20 (*a*) 0.204 m; (*b*) −19,800 Pa/m; (*c*) −9980 Pa/m
6.22 (*a*) 39 kg/s; (*b*) 1430
6.24 Head loss ≈ 25 m
6.26 4 mm
6.28 $Q \approx 0.31$ m^3/h
6.30 $F = 4$ N
6.32 (*a*) 127 MPa; (*b*) 127 kW
6.34 $\mu = 0.000823$ kg/(m · s)
6.36 $\Delta p \approx 65$ Pa
6.38 (*a*) 19.3 m^3/h; (*b*) flow is *up*
6.40 (*a*) flow is up; (*b*) 1.86 m^3/h
6.44 $h_f \approx 10.5$ m, $\Delta p \approx 1.4$ MPa
6.46 Input power ≈ 11.2 MW
6.48 $r/R = 1 - e^{-3/2}$
6.50 (*a*) −4000 Pa/m; (*b*) 50 Pa; (*c*) 46 percent
6.52 $p_1 = 2.38$ MPa
6.54 $D \approx 0.118$ m
6.56 (*a*) 188 km; (*b*) 27 MW
6.58 Power ≈ 870 kW
6.64 $Q = 19.6$ m^3/h (laminar, Re = 1450)
6.66 (*a*) 56 kPa; (*b*) 85 m^3/h; (*c*) $u = 3.3$ m/s at $r = 1$ cm
6.68 Power = 204 hp
6.70 $Q = 2.21$ ft^3/s
6.72 Optimum $\theta = 90°$ (0.7 m rise)
6.74 $D = 0.52$ in
6.76 $Q = 15$ m^3/h
6.78 $Q = 25$ m^3/h (to the left)
6.80 $Q = 0.905$ m^3/s
6.82 $D = 0.394$ m
6.84 $D \approx 0.104$ m
6.86 (*a*) 3.0 m/s; (*b*) 0.325 m/m; (*c*) 2770 Pa/m
6.90 $Q = 19.6$ ft^3/s
6.92 (*a*) 1530 m^3/h; (*b*) 6.5 Pa (vacuum)
6.94 260 Pa/m
6.96 Cross section 0.106 m by 0.531 m
6.98 Approximately 128 squares
6.102 (*a*) 5.55 hp; (*b*) 5.31 hp with 6° cone
6.104 $\Delta p = 0.0305$ lbf/in^2
6.106 $Q = 0.0296$ ft^3/s
6.108 $Q = 0.22$ ft^3/s
6.110 840 W
6.112 $Q = 0.0151$ ft^3/s
6.114 (*a*) $Q_1 = 0.0167$ m^3/s, $Q_2 = 0.0193$ m^3/s, $\Delta p = 774$ kPa
6.116 $Q = 0.027$ m^3/s
6.118 $\Delta p = 131$ lbf/in^2
6.120 $Q_1 = 0.0109$ m^3/s, $Q_2 = 0.0264$ m^3/s, $Q_3 = 0.0183$ m^3/s
6.122 Increased ϵ/d and L/d are the causes
6.124 $Q_1 = -2.09$ ft^3/s, $Q_2 = 1.61$ ft^3/s, $Q_3 = 0.49$ ft^3/s
6.126 $\theta_{\text{opening}} = 35°$
6.128 $Q_{AB} = 3.47$, $Q_{BC} = 2.90$, $Q_{BD} = 0.58$, $Q_{CD} = 5.28$, $Q_{AC} = 2.38$ ft^3/s (all)
6.130 $Q_{AB} = 0.95$, $Q_{BC} = 0.24$, $Q_{BD} = 0.19$, $Q_{CD} = 0.31$, $Q_{AC} = 1.05$ ft^3/s (all)
6.132 $2\theta = 6°$, $D_e = 2.0$ m, $p_e = 224$ kPa
6.134 $2\theta = 10°$, $W_e = 8.4$ ft, $p_e = 2180$ lbf/ft^2
6.136 (*a*) 25.5 m/s, (*b*) 0.109 m^3/s, (*c*) 1.23 Pa
6.138 46.7 m/s
6.140 $\Delta p = 273$ kPa
6.142 $Q = 18.6$ gal/min, $d_{\text{reducer}} = 0.84$ cm
6.144 $Q = 54$ m^3/h
6.146 (*a*) 0.00653 m^3/s; (*b*) 100 kPa
6.148 (*a*) 1.58 m; (*b*) 1.7 m
6.150 $\Delta p = 27$ kPa
6.152 $D = 4.12$ cm
6.154 $h = 59$ cm

6.156 $Q = 0.924\ ft^3/s$
6.158 (*a*) 49 m^3/h; (*b*) 6200 Pa

Chapter 7

7.2 $Re_c = 1.5$ E7
7.4 $d = 8$ mm lies in the transition region
7.6 $H = 2.5$ (versus 2.59 for Blasius)
7.8 Approximately 0.08 N
7.12 Does not satisfy $\partial^2 u/\partial y^2 = 0$ at $y = 0$
7.14 $C = \rho v_0/\mu = \text{const} < 0$ (wall suction)
7.16 (*a*) F = 181 N; (*b*) 256 N
7.18 $\theta \approx 0.16°$; $F_{drag} \approx 0.024$ N
7.20 $x \approx 0.91$ m
7.22 $\psi = (\nu x U)^{1/2} f(\eta)$
7.24 $h_1 = 9.2$ mm; $h_2 = 5.5$ mm
7.26 $F_a = 2.83\ F_1$, $F_b = 2.0\ F_1$
7.28 (*a*) $F_{drag} = 2.66\ N^2(\rho\mu L)^{1/2}U^{3/2}a$
7.30 (*a*) $F = 72$ N; (*b*) 79 N
7.32 $F = 0.0245\ \rho\nu^{1/7}\ L^{6/7}\ U_0^{13/7}\ \delta$
7.34 $F = 725$ N
7.36 7.2 m/s = 14 kn
7.38 (*a*) 7.6 m/s; (*b*) 6.2 m/s
7.40 $L = 3.53$ m, $b = 1.13$ m
7.42 $P_{4\ blades} \approx 0.032\mu^{1/7}(\rho C)^{6/7}\ \Omega^{20/7}\ R^{27/7}$
7.44 Accurate to about ±6 percent
7.46 $\epsilon \approx 9$ mm, $U = 11.2$ m/s = 22 kn
7.48 Separation at $x/L = 0.158$ (1 percent error)
7.50 Separation at $x/R = 1.80$ rad = 103.1°
7.52 $C_D\ (Re_{\bar{L}})^{1/2} \approx 2.67$ (by numerical integration)
7.54 Moment ≈ 200,000 N · m
7.56 (*a*) 10 N; (*b*) 80 N
7.58 (*a*) 3200 N/m; (*b*) 2300 N/m
7.60 Tow power = 140 hp
7.62 Square side length ≈ 0.83 m
7.64 $\Delta t_{1000-2000m} = 202$ s
7.68 (*a*) 34 m/s; (*b*) no, only 67 percent of terminal velocity at impact
7.70 (*a*) 642 ft; (*b*) 425 ft
7.72 (*a*) $L = 6.3$ m; (*b*) 120 m
7.78 $\Delta p = 100$ Pa
7.80 $\theta = 72°$
7.82 $V_{min} = 138$ ft/s; (*b*) $V_{max} = 377$ ft/s
7.84 $V = 9$ m/s
7.86 Approximately 3.05 m by 6.1 m
7.88 (*a*) 62 hp; (*b*) 86 hp
7.90 $V_{overturn} \approx 145$ ft/s = 99 mi/h
7.94 Torque $\approx (C_D/4)\rho\Omega^2 DR^4$, $\Omega_{max} = 85$ r/min
7.96 $\Omega_{avg} \approx 0.21\ U/D$
7.98 (*b*) $h \approx 0.18$ m
7.100 (*b*) $D_{max} = 78\ \mu m$
7.106 (*a*) 300 m; (*b*) 380 m
7.108 $\Delta x_{ball} \approx 13$ m
7.110 $\Delta y \approx 1.9$ ft
7.114 $V_{final} \approx 18.3$ m/s = 66 km/h
7.116 (*a*) 87 mi/h; (*b*) 680 hp
7.118 (*a*) 21 m/s; (*b*) 360 m
7.120 $(L/D)_{max} = 21$; $\alpha = 4.8°$
7.122 (*a*) 6.7 m/s; (*b*) 13.5 m/s = 26 kn
7.124 $\Omega_{crude\ theory} \approx 340$ r/s

Chapter 8

8.2 $\Gamma = \pi\Omega(R_2^2 - R_1^2)$
8.4 No, $1/r$ is not a proper two-dimensional potential
8.6 $\psi = B(y^2 - x^2)$
8.8 $\Gamma = 4B$
8.12 $\Gamma = 0$
8.14 Irrotational outer, rotational inner; minimum $p = p_\infty - \rho\omega^2 R^2$ at $r = 0$
8.18 From afar: a single source $4m$
8.20 Vortex near a wall (see Fig. 8.17*b*)
8.22 Same as Fig. 8.6 except upside down
8.24 $C_p = -\{2(x/a)/[1 + (x/a)^2]\}^2$, $C_{p,min} = -1.0$ at $x = a$
8.26 $V_{resultant} = 9.4$ m/s at $\theta = 47°$
8.28 Creates a source in a square corner
8.34 Two stagnation points, at $x = \pm a/\sqrt{3}$
8.36 $U_\infty = 12.9$ m/s, $2L = 53$ cm, $V_{max} = 22.5$ m/s
8.42 $K/(U_\infty a) = 0.396$, $h/a = 1.124$
8.44 $K = 4.6\ m^2/s$; (*a*) 218 kPa; (*b*) 214 kPa at upper shoulder, −6 kPa at lower shoulder (cavitation)
8.46 $F_{1\text{-}bolt} = 5000$ N
8.50 $h = 3a/2$, $U_{max} = 5U/4$
8.52 $V_{boat} = 10.2$ ft/s with wind at 44°
8.54 $F_{parallel} = 6700$ lbf, $F_{normal} = 2700$ lbf, power ≈ 560 hp (very approximate)
8.56 $C_D \approx 2.67$ (too high, incorrect p_{rear})
8.60 This is Fig. 8.15*a*, flow in a 60° corner
8.62 Stagnation flow near a "bump"
8.64 All favorable gradients: no separation
8.66 $\lambda = 0.45m/(5m + 1)$ if $U = Cx^m$
8.68 Flow past a Rankine oval
8.70 Applied to wind-tunnel "blockage"
8.72 Adverse gradient for $x > a$
8.74 $V_{B,total} = (8K\mathbf{i} + 4K\mathbf{j})/(15a)$
8.78 Need an infinite array of images
8.82 (*a*) 4.5 m/s; (*b*) 1.13; (*c*) 1.26 hp
8.84 (*a*) 0.21; (*b*) 1.9°
8.86 (*a*) 26 m; (*b*) 8.7; (*c*) 1600 N
8.88 $Thrust_{1\text{-}engine} \approx 2900$ lbf
8.90 (*a*) 4.0; (*b*) 4.8°
8.92 (*a*) 0.77 m; (*b*) $V = 4.5$ m/s at $(r, \theta) = (1.81, 51°)$ and $(1.11, 88°)$
8.94 Yes, they are orthogonal

8.98 Yes, a closed teardrop shape appears
8.100 $V = 14.1$ m/s, $p_A = 115$ kPa
8.102 (*a*) 1250 ft; (*b*) 1570 ft (crudely)

Chapter 9

9.2 (*a*) $V_2 = 450$ m/s, $\Delta s = 515$ J/(kg · K); (*b*) $V_2 = 453$ m/s, $\Delta s = 512$ J/(kg · K)
9.4 About 50 m/s
9.6 Exit at about $T_2 \approx 54$°C and $V_2 \approx 1445$ m/s
9.8 410 K
9.10 Ma = 0.78
9.12 (*a*) 2.13 E9 Pa and 1460 m/s; (*b*) 2.91 E9 Pa and 1670 m/s; (*c*) 2645 m/s
9.18 (*a*) 930 ft/s; (*b*) 878 ft/s
9.20 (*a*) air: 144 kPa and 995 m/s; (*b*) helium: 128 kPa and 2230 m/s
9.22 (*a*) 267 m/s; (*b*) 286 m/s
9.24 (*b*) at Ma ≈ 0.576
9.28 (*a*) 0.17 kg/s; (*b*) 0.90
9.30 (*a*) 262 m/s; (*b*) 0.563; (*c*) 0.905 kg/m^3
9.32 (*a*) 141 kPa; (*b*) 101 kPa; (*c*) 0.706
9.34 (*a*) 0.00424 slug/s; (*b*) 0.00427 slug/s
9.40 (*a*) 2.50; (*b*) 7.6 cm^2; (*c*) 1.27 kg/s; (*d*) $\text{Ma}_2 = 1.50$
9.42 (*a*) Ma = 0.90, $T = 260$ K, $V = 291$ m/s
9.44 $V_e = 5680$ ft/s, $p_e = 15.7$ psia, $T_e = 1587$°R, thrust = 4000 lbf
9.46 $R_x = -8$ N (to the left)
9.48 (*a*) 313 m/s; (*b*) 0.124 m/s; (*c*) 0.00331 kg/s
9.50 (*a*) $D_{\text{exit}} = 5.8$ cm
9.52 (*a*) 5.9 cm^2; (*b*) 773 kPa
9.54 $\text{Ma}_2 = 0.648$, $V_2 = 279$ m/s, $T_2 = 461$°K, $p_2 = 458$ kPa, $p_{02} = 607$ kPa
9.56 At about $A_1 \approx 24.7$ cm^2
9.58 (*a*) 306 m/s; (*b*) 599 kPa; (*c*) 498 kPa
9.60 Upstream: Ma = 1.92, $V = 585$ m/s
9.62 $C = 19{,}100$ ft/s, $V_{\text{inside}} = 15{,}900$ ft/s
9.64 (*a*) 0.150 kg/s; (*b*, *c*) 0.157 kg/s
9.66 $h = 1.09$ m
9.68 $p_{\text{atm}} = 92.6$ kPa; max flow = 0.140 kg/s
9.70 (*a*) 388 kPa; (*b*) 19 kPa
9.72 Mass flow = 0.5 kg/s, $p_e = 185$ kPa, $\text{Ma}_e = 0.407$
9.74 (*a*) 1.096 MPa; (*b*) 2.24 kg/s
9.76 $\Delta t_{\text{shocks}} \approx 23$ s; $\Delta t_{\text{choking-stops}} \approx 39$ s
9.78 Case *A*: 0.0071 kg/s; *B*: 0.0068 kg/s
9.80 $A^* = 2.4$ E-6 ft^2 or $D_{\text{hole}} = 0.021$ in
9.82 $V_e = 110$ m/s, $\text{Ma}_e = 0.67$ (yes)
9.84 (*a*) 0.96 kg/s; (*b*) 0.27; (*c*) 435 kPa
9.86 $V_2 = 107$ m/s, $p_2 = 371$ kPa, $T_2 = 330$ K, $p_{02} = 394$ kPa
9.88 $L = 2$ m, yes, a shock at $\text{Ma}_2 = 2.14$
9.90 (*a*) 0.764 kg/s; (*b*) 0.590 kg/s; (*c*) 0.314 kg/s
9.92 (*a*) 0.45; (*b*) 2.04 kg/s
9.98 (*a*) 430; (*b*) 0.12; (*c*) 0.00243 kg/h
9.100 $L_{\text{pipe}} = 69$ m
9.102 Flow is choked at 0.69 kg/s
9.104 $p_{\text{tank}} = 99$ kPa
9.106 (*a*) 0.031 m; (*b*) 0.53 m; (*c*) 26 m
9.108 Mass flow drops by about 32 percent
9.112 (*a*) 105 m/s; (*b*) 215 kPa
9.116 $V_{\text{plane}} \approx 2640$ ft/s
9.118 $V = 204$ m/s, Ma = 0.6
9.120 *P* is 3 m ahead of the small circle, Ma = 2.0, $T_{\text{stag}} =$ 518 K
9.122 $\beta = 23.13°$, $\text{Ma}_2 = 2.75$, $p_2 = 145$ kPa
9.126 (*a*) 25.9°; (*b*) 26.1°
9.128 $\delta_{\text{wedge}} \approx 15.5°$
9.130 (*a*) 57.87°; (*b*) 21.82°
9.132 (*a*) $p_A = 18.0$ psia; (*b*) $p_B = 121$ psia
9.134 $\text{Ma}_3 = 1.02$, $p_3 = 727$ kPa, $\phi = 42.8°$
9.136 (*a*) $h = 0.40$ m; (*b*) $\text{Ma}_3 = 2.43$
9.138 $p_r = 21.7$ kPa
9.140 $\text{Ma}_2 = 2.75$, $p_2 = 145$ kPa
9.142 (*a*) $\text{Ma}_2 = 2.641$, $p_2 = 60.3$ kPa; (*b*) $\text{Ma}_2 = 2.299$, $p_2 =$ 24.1 kPa
9.146 $\Delta\theta = 9.47°$ (helium)
9.148 $C_L = 0.184$ (approximately linear), $C_D = 0.0193$ (approximately parabolic)
9.150 (*a*) $\alpha = 4.10°$; (*b*) drag = 2150 N/m
9.152 Parabolic shape has 33 percent more drag

Chapter 10

10.2 (*a*) $C = 3.31$ m/s; (*b*) $\delta V = 0.030$ m/s
10.4 These are piezometer tubes (no flow)
10.6 (*a*) Fr = 3.8; (*b*) $V_{\text{current}} = 7.7$ m/s
10.8 $\Delta t_{\text{travel}} = 6.3$ h
10.10 $\lambda_{\text{crit}} = 2\pi(\Upsilon/\rho g)^{1/2}$
10.14 Flow must be fully rough turbulent (high Re) for Chézy to be valid
10.16 20 percent less flow, independent of *n*
10.18 $y_n = 0.993$ m
10.20 $Q = 74$ ft^3/s
10.22 $S_0 = 0.00038$ (or 0.38 m/km)
10.24 $y_n = 0.56$ m
10.26 (*a*) 17.8 m^3/s; (*b*) 1.79 m
10.30 $\Delta t \approx 32$ min
10.32 74,000 gal/min
10.34 If $b = 4$ ft, $y = 9.31$ ft, $P = 22.62$ ft; if $b = 8$ ft, $y = 4.07$ ft, $P = 16.14$ ft
10.36 $y_2 = 3.6$ m
10.38 $D_{\text{semicircle}} = 2.67$ m (16 percent less perimeter)
10.42 $P = 41.3$ ft (71 percent more than Prob. 10.39)
10.44 Hexagon side length $b = 2.12$ ft
10.46 Best $h_0/b = 0.53 \pm 0.03$

10.48 (*a*) 0.00634; (*b*) 0.00637
10.50 (*a*) 2.37; (*b*) 0.62 m; (*c*) 0.0026
10.52 $W = 2.06$ m
10.54 (*a*) 1.98 m; (*b*) 3.11 m/s; (*c*) 0.00405
10.56 (*a*) 1.02 m^3/s; (*b*) 0.0205
10.58 $Fr = 0.628R^{1/6}$, R in meters
10.60 (*a*) 0.052 $m^3/(m \cdot s)$; (*b*) 0.0765 m
10.64 $h_{max} \approx 0.35$ m
10.66 (*a*) 1.47; (*b*) $y_2 = 1.19$ m
10.70 (*a*) 0.15 m; (*b*) 3.2; (*c*) 0.59 $m^3/(s \cdot m)$
10.72 (*a*) 0.046 m; (*b*) 4.33 m/s; (*c*) 6.43
10.76 $H \approx 0.011$ m
10.78 $\Delta t \approx 8.6$ s (crude analysis)
10.80 (*a*) 3.83 m; (*b*) 4.83 $m^3/(s \cdot m)$
10.82 (*a*) 0.88 m; (*b*) 17.6 m/s; (*c*) 2.89 m
10.84 $y_2 = 0.82$ ft; $y_3 = 5.11$ ft; 47 percent
10.86 (*a*) 6.07 m/s; (*b*) $\Delta V = 2.03$ m/s
10.88 (*a*) downstream; (*b*) 5.7 percent
10.90 0.0207 (or 1.19°)
10.92 (*a*) 3370 ft^3/s; (*b*) 7000 hp
10.94 (*a*) 0.61 m; (*b*) 3.74 m/s; (*c*) 0.89 m
10.98 (*a*) steep S-3; (*b*) S-2; (*c*) S-1
10.106 No entry depth leads to critical flow
10.108 (*a*, *b*) Both curves reach $y \approx y_n \approx 0.5$ m at $x = 250$ m
10.110 (*a*) $y_{crest} \approx 0.782$ m; (*b*) $y(L) \approx 0.909$ m
10.112 M-1 curve, with $y = 2$ m at $L \approx 214$ m
10.114 Vexing! Flow chokes at $Q \approx 17$ m^3/s
10.116 $Q \approx 9.51$ m^3/s
10.120 $Y = 0.64$ m, $\alpha = 34°$
10.122 5500 gal/min
10.124 M-1 curve, $y = 10$ ft at $x = -3040$ ft
10.126 At $x = -100$ m, $y = 2.81$ m
10.128 At 300 m upstream, $y = 2.37$ m

Chapter 11

11.6 This is a diaphragm pump
11.8 (*a*) $H = 112$ ft and $\Delta p = 49$ lb/in^2; (*b*) $H = 112$ ft (of gasoline); $P = 15$ hp
11.10 (*a*) 1300 r/min; (*b*) 2080 lbf/in^2
11.12 (*a*) 11.3 m; (*b*) 1520 W
11.14 1870 W
11.16 (*a*) 1450 W; (*b*) 1030 r/min
11.18 $V_{vane} = (1/3)V_{jet}$ for max power
11.20 (*a*) 2 roots: $Q = 7.5$ and 38.3 ft^3/s; (*b*) 2 roots; $H =$ 180 ft and 35 ft
11.22 (*a*) BEP ≈ 92 percent at $Q \approx 0.22$ m^3/s
11.26 Correlation is "fair," not geometrically similar
11.28 BEP at about 6 ft^3/s; $N_s \approx 1430$, $Q_{max} \approx 12$ ft^3/s
11.30 (*a*) 1700 r/min; (*b*) 8.9 ft^3/s; (*c*) 330 ft
11.32 Correlation "fair," not geometrically similar
11.34 (*a*) 11.5 in; (*b*) 28 hp; (*c*) 100 ft; (*d*) 78 percent
11.36 $D = 9.8$ in, $n = 2100$ r/min
11.38 (*a*) 18.5 hp; (*b*) 7.64 in; (*c*) 415 gal/min; (*d*) 81 percent
11.40 (*a*) $D_s = D(gH^*)^{1/4}/Q^{*1/2}$
11.42 $NPSH_{proto} \approx 23$ ft
11.44 No cavitation, required depth is only 5 ft
11.46 $D_s \approx C/N_s$, $C = 7800 \pm 7$ percent
11.52 (*a*) 7.97 m^3/s; (*b*) 14.6 kW; (*c*) 28.3°
11.54 Centrifugal pumps, $D \approx 7.2$ ft
11.56 (*a*) $D = 5.67$ ft, $n = 255$ r/min, $P = 700$ hp; (*b*) $D = 1.76$ ft, $n = 1770$ r/min, $P = 740$ hp
11.58 Centrifugal pump, $\eta = 67$ percent, $D = 0.32$ ft
11.60 (*a*) 623; (*b*) 762 gal/min; (*c*) 1.77 ft
11.62 $D = 18.7$ ft, $\Delta p = 1160$ Pa
11.64 *No* speed is able to get to BEP
11.66 $Q \approx 1240$ ft^3/min
11.68 $Q_{new} \approx 15{,}300$ gal/min
11.70 (*a*) 212 ft; (*b*) 5.8 ft^3/s
11.72 (*a*) 10 gal/min; (*b*) 1.3 in
11.74 (*a*) 14.9; (*b*) 15.9; (*c*) 20.7 kgal/min
11.76 $D_{pipe} \approx 1.70$ ft
11.78 $D_{pipe} \approx 1.67$ ft, $P \approx 2000$ hp
11.80 $Q_{32} \approx 22{,}900$ gal/min; $Q_{28} \approx 8400$ gal/min, $H \approx 343$ ft for both
11.84 Two turbines: (*a*) $D \approx 9.6$ ft; (*b*) $D \approx 3.3$ ft
11.86 $N_{sp} \approx 70$, hence Francis turbines
11.88 $Q \approx 52$ ft^3/s, $D \approx 10.5$ ft
11.90 $P \approx 800$ kW
11.92 Pelton and Francis wheels both OK
11.94 (*a*) 71 percent; (*b*) $N_{sp} \approx 19$
11.96 (*a*) 1.68 ft; (*b*) 0.78 ft
11.100 (*a*) 190 kW; (*b*) 24 r/min; (*c*) 9.3 ft/s
11.102 $Q \approx 29$ gal/min

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