

Appendix A

Physical Properties of Fluids

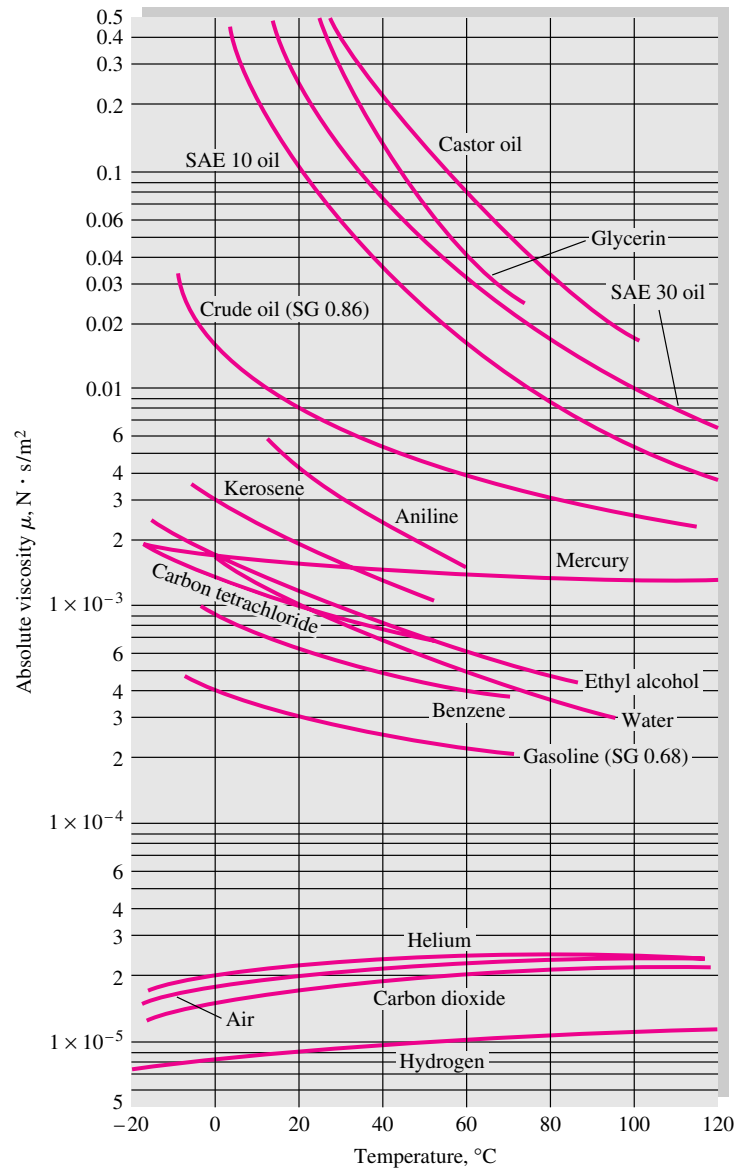


Fig. A.1 Absolute viscosity of common fluids at 1 atm.

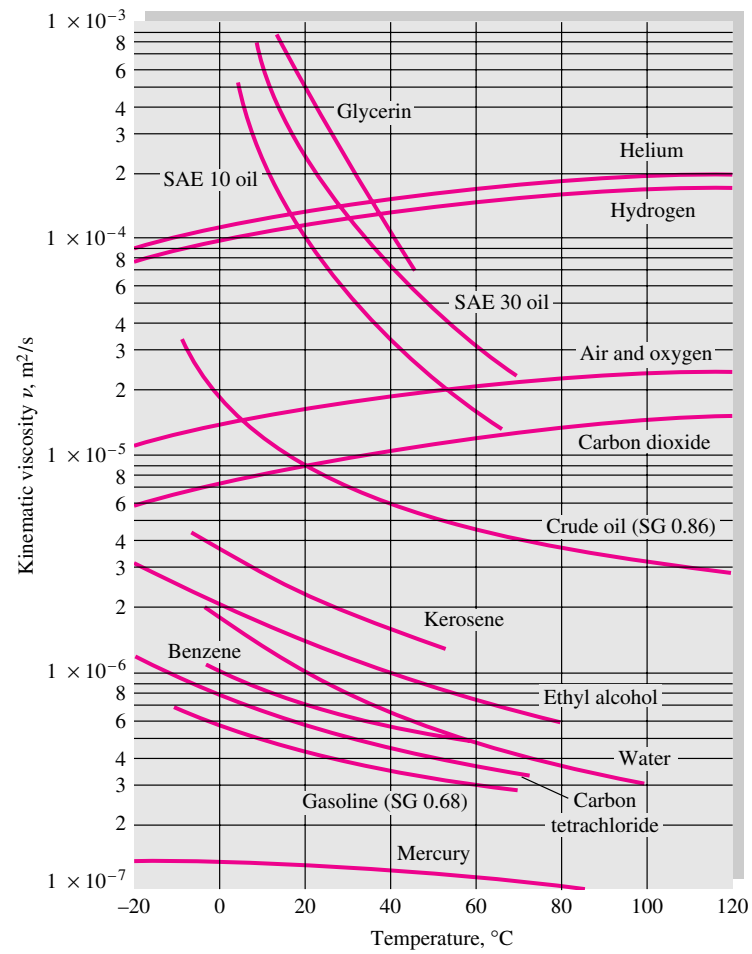


Fig. A.2 Kinematic viscosity of common fluids at 1 atm.

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

$T, ^\circ\text{C}$	$\rho, \text{kg/m}^3$	$\mu, \text{N} \cdot \text{s/m}^2$	$\nu, \text{m}^2/\text{s}$	$T, ^\circ\text{F}$	$\rho, \text{slug/ft}^3$	$\mu, \text{lb} \cdot \text{s/ft}^2$	$\nu, \text{ft}^2/\text{s}$
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 $0 \leq T \leq 100^\circ\text{C}$:

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

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

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

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

$T, ^\circ\text{C}$	$\rho, \text{kg/m}^3$	$\mu, \text{N} \cdot \text{s/m}^2$	$\nu, \text{m}^2/\text{s}$	$T, ^\circ\text{F}$	$\rho, \text{slug/ft}^3$	$\mu, \text{lb} \cdot \text{s/ft}^2$	$\nu, \text{ft}^2/\text{s}$
-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:

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

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

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

with $T_0 = 273 \text{ K}$, $\mu_0 = 1.71 \text{ E-5 kg/(m} \cdot \text{s)}$, 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)	γ , 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	1590	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	1117	2.14 E-2	4.84 E-2	1.2 E+1	—	11.7
Freon 12	1327	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	1260	1.49	6.33 E-2	1.4 E-2	4.34 E+9	28.0
Kerosene	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%)	1025	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

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

with accuracy of ± 6 percent in the range $0 \leq T \leq 100^\circ\text{C}$.

[‡]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)	ρ_g , N/m ³	μ , N · s/m ²	Specific-heat ratio	Power-law exponent n^*
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 ₂ O	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 ₂ O	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), $\mu/\mu_{293\text{K}} \approx (T/293)^n$, fits these gases to within ± 4 percent in the range $250 \leq T \leq 1000$ K. The temperature must be in kelvins.

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

<i>T</i> , °C	<i>Y</i> , N/m	<i>p_v</i> , kPa	<i>a</i> , 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	1002	1389
200	0.0377	1554	1334
220	0.0331	2318	1268
240	0.0284	3344	1192
260	0.0237	4688	1110
280	0.0190	6412	1022
300	0.0144	8581	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

<i>z</i> , m	<i>T</i> , K	<i>p</i> , Pa	<i>ρ</i> , kg/m ³	<i>a</i> , 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
1000	281.66	89,889	1.1120	336.5
1500	278.41	84,565	1.0583	334.5
2000	275.16	79,500	1.0067	332.6
2500	271.91	74,684	0.9570	330.6
3000	268.66	70,107	0.9092	328.6
3500	265.41	65,759	0.8633	326.6
4000	262.16	61,633	0.8191	324.6
4500	258.91	57,718	0.7768	322.6
5000	255.66	54,008	0.7361	320.6
5500	252.41	50,493	0.6970	318.5
6000	249.16	47,166	0.6596	316.5
6500	245.91	44,018	0.6237	314.4
7000	242.66	41,043	0.5893	312.3
7500	239.41	38,233	0.5564	310.2
8000	236.16	35,581	0.5250	308.1
8500	232.91	33,080	0.4949	306.0
9000	229.66	30,723	0.4661	303.8
9500	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	9496	0.1527	295.1
17,000	216.66	8775	0.1411	295.1
17,500	216.66	8110	0.1304	295.1
18,000	216.66	7495	0.1205	295.1
18,500	216.66	6926	0.1114	295.1
19,000	216.66	6401	0.1029	295.1
19,500	216.66	5915	0.0951	295.1
20,000	216.66	5467	0.0879	295.1
22,000	218.6	4048	0.0645	296.4
24,000	220.6	2972	0.0469	297.8
26,000	222.5	2189	0.0343	299.1
28,000	224.5	1616	0.0251	300.4
30,000	226.5	1197	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^*	Ma	p/p_0	ρ/ρ_0	T/T_0	A/A^*
0.0	1.0	1.0	1.0	∞	0.74	0.6951	0.7712	0.9013	1.0681
0.02	0.9997	0.9998	0.9999	28.9421	0.76	0.6821	0.7609	0.8964	1.0570
0.04	0.9989	0.9992	0.9997	14.4815	0.78	0.6690	0.7505	0.8915	1.0471
0.06	0.9975	0.9982	0.9993	9.6659	0.8	0.6560	0.7400	0.8865	1.0382
0.08	0.9955	0.9968	0.9987	7.2616	0.82	0.6430	0.7295	0.8815	1.0305
0.1	0.9930	0.9950	0.9980	5.8218	0.84	0.6300	0.7189	0.8763	1.0237
0.12	0.9900	0.9928	0.9971	4.8643	0.86	0.6170	0.7083	0.8711	1.0179
0.14	0.9864	0.9903	0.9961	4.1824	0.88	0.6041	0.6977	0.8659	1.0129
0.16	0.9823	0.9873	0.9949	3.6727	0.9	0.5913	0.6870	0.8606	1.0089
0.18	0.9776	0.9840	0.9936	3.2779	0.92	0.5785	0.6764	0.8552	1.0056
0.2	0.9725	0.9803	0.9921	2.9635	0.94	0.5658	0.6658	0.8498	1.0031
0.22	0.9668	0.9762	0.9904	2.7076	0.96	0.5532	0.6551	0.8444	1.0014
0.24	0.9607	0.9718	0.9886	2.4956	0.98	0.5407	0.6445	0.8389	1.0003
0.26	0.9541	0.9670	0.9867	2.3173	1.0	0.5283	0.6339	0.8333	1.0000
0.28	0.9470	0.9619	0.9846	2.1656	1.02	0.5160	0.6234	0.8278	1.0003
0.3	0.9395	0.9564	0.9823	2.0351	1.04	0.5039	0.6129	0.8222	1.0013
0.32	0.9315	0.9506	0.9799	1.9219	1.06	0.4919	0.6024	0.8165	1.0029
0.34	0.9231	0.9445	0.9774	1.8229	1.08	0.4800	0.5920	0.8108	1.0051
0.36	0.9143	0.9380	0.9747	1.7358	1.1	0.4684	0.5817	0.8052	1.0079
0.38	0.9052	0.9313	0.9719	1.6587	1.12	0.4568	0.5714	0.7994	1.0113
0.4	0.8956	0.9243	0.9690	1.5901	1.14	0.4455	0.5612	0.7937	1.0153
0.42	0.8857	0.9170	0.9659	1.5289	1.16	0.4343	0.5511	0.7879	1.0198
0.44	0.8755	0.9094	0.9627	1.4740	1.18	0.4232	0.5411	0.7822	1.0248
0.46	0.8650	0.9016	0.9594	1.4246	1.2	0.4124	0.5311	0.7764	1.0304
0.48	0.8541	0.8935	0.9559	1.3801	1.22	0.4017	0.5213	0.7706	1.0366
0.5	0.8430	0.8852	0.9524	1.3398	1.24	0.3912	0.5115	0.7648	1.0432
0.52	0.8317	0.8766	0.9487	1.3034	1.26	0.3809	0.5019	0.7590	1.0504
0.54	0.8201	0.8679	0.9449	1.2703	1.28	0.3708	0.4923	0.7532	1.0581
0.56	0.8082	0.8589	0.9410	1.2403	1.3	0.3609	0.4829	0.7474	1.0663
0.58	0.7962	0.8498	0.9370	1.2130	1.32	0.3512	0.4736	0.7416	1.0750
0.6	0.7840	0.8405	0.9328	1.1882	1.34	0.3417	0.4644	0.7358	1.0842
0.62	0.7716	0.8310	0.9286	1.1656	1.36	0.3323	0.4553	0.7300	1.0940
0.64	0.7591	0.8213	0.9243	1.1451	1.38	0.3232	0.4463	0.7242	1.1042
0.66	0.7465	0.8115	0.9199	1.1265	1.4	0.3142	0.4374	0.7184	1.1149
0.68	0.7338	0.8016	0.9153	1.1097	1.42	0.3055	0.4287	0.7126	1.1262
0.7	0.7209	0.7916	0.9107	1.0944	1.44	0.2969	0.4201	0.7069	1.1379
0.72	0.7080	0.7814	0.9061	1.0806	1.46	0.2886	0.4116	0.7011	1.1501

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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
(Concluded)
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

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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 (Concluded) 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

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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

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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 (Concluded) 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

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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

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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 (Concluded)
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

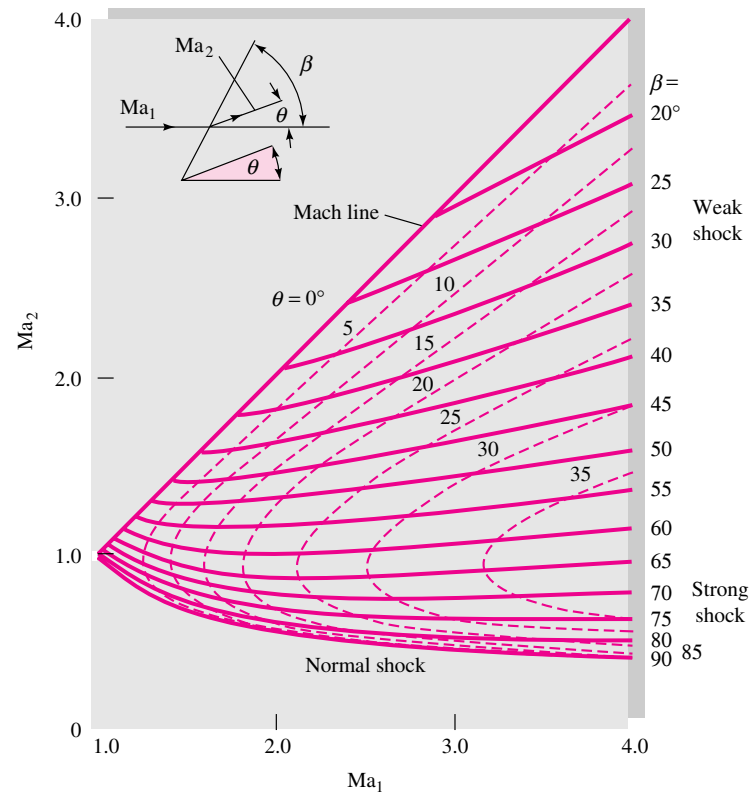


Fig. B.1 Mach number downstream of an oblique shock for $k = 1.4$.

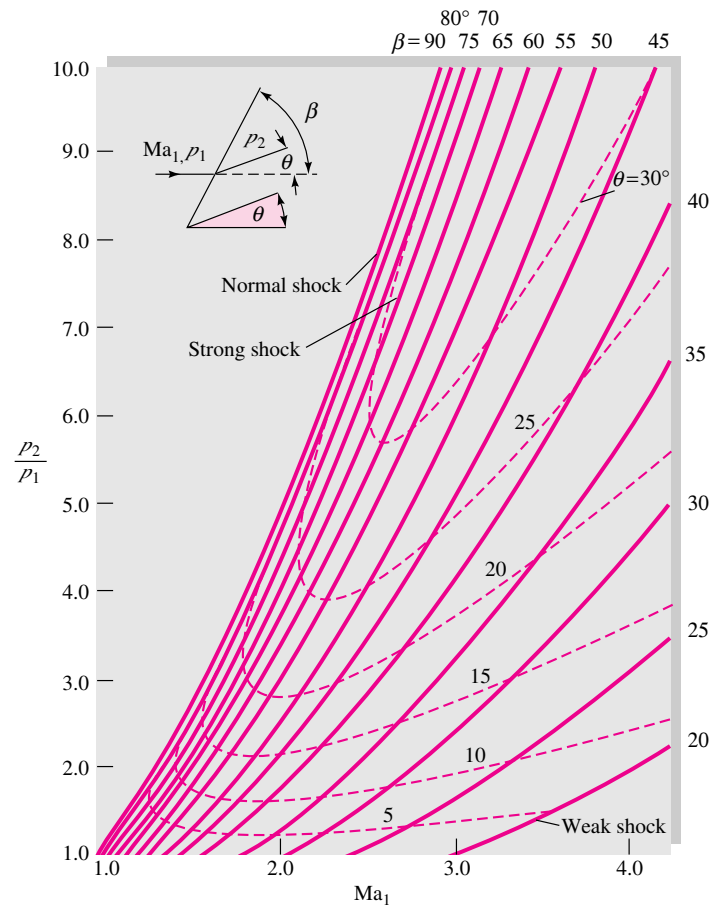


Fig. B.2 Pressure ratio downstream of an oblique shock for $k = 1.4$.

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	
$T_F = \frac{9}{5}T_C + 32$ $T_C = \frac{5}{9}(T_F - 32)$ $T_R = T_F + 459.69$ $T_K = T_C + 273.16$ 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/(lbm · °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:

$$x = r \cos \theta \quad y = r \sin \theta \quad z = z \quad (\text{D.1})$$

The velocity components are v_r , v_θ , and v_z . Here are the equations:

Continuity:

$$\frac{1}{r} \frac{\partial}{\partial r}(r v_r) + \frac{1}{r} \frac{\partial}{\partial \theta}(v_\theta) + \frac{\partial}{\partial z}(v_z) = 0 \quad (\text{D.2})$$

Convective time derivative:

$$\mathbf{V} \cdot \nabla = v_r \frac{\partial}{\partial r} + \frac{1}{r} v_\theta \frac{\partial}{\partial \theta} + v_z \frac{\partial}{\partial z} \quad (\text{D.3})$$

Laplacian operator:

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

The r -momentum equation:

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

The θ -momentum equation:

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

The z -momentum equation:

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

The energy equation:

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

where

$$\begin{aligned} \epsilon_{rr} &= \frac{\partial v_r}{\partial r} & \epsilon_{\theta\theta} &= \frac{1}{r} \left(\frac{\partial v_\theta}{\partial \theta} + v_r \right) \\ \epsilon_{zz} &= \frac{\partial v_z}{\partial z} & \epsilon_{\theta z} &= \frac{1}{r} \frac{\partial v_z}{\partial \theta} + \frac{\partial v_\theta}{\partial z} \\ \epsilon_{rz} &= \frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r} & \epsilon_{r\theta} &= \frac{1}{r} \left(\frac{\partial v_r}{\partial \theta} - v_\theta \right) + \frac{\partial v_\theta}{\partial r} \end{aligned} \quad (\text{D.9})$$

Viscous stress components:

$$\begin{aligned} \tau_{rr} &= 2\mu\epsilon_{rr} & \tau_{\theta\theta} &= 2\mu\epsilon_{\theta\theta} & \tau_{zz} &= 2\mu\epsilon_{zz} \\ \tau_{r\theta} &= \mu\epsilon_{r\theta} & \tau_{\theta z} &= \mu\epsilon_{\theta z} & \tau_{rz} &= \mu\epsilon_{rz} \end{aligned} \quad (\text{D.10})$$

Angular velocity components:

$$\begin{aligned} 2\omega_r &= \frac{1}{r} \frac{\partial v_z}{\partial \theta} - \frac{\partial v_\theta}{\partial z} \\ 2\omega_\theta &= \frac{\partial v_r}{\partial z} - \frac{\partial v_z}{\partial r} \\ 2\omega_z &= \frac{1}{r} \frac{\partial}{\partial r} (rv_\theta) - \frac{1}{r} \frac{\partial v_r}{\partial \theta} \end{aligned} \quad (\text{D.11})$$

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, combustion gases, and others. 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 that adopt this text by McGraw-Hill. If you need more information, contact your local McGraw-Hill representative, call 1-800-338-3987, or visit the McGraw-Hill website at <http://www.mhhe.com>. A commercial or professional version of EES can be obtained from

F-Chart Software

Box 444042

Madison, WI 53744

Phone: (608) 836-8531

Fax: (608) 836-8536

<http://fchart.com> e-mail: info@fchart.com

Background Information

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



To start EES, double-click on the **EES** program icon shown at left or on any file created by EES having the .EES filename extension. You can also start EES from the Windows **Run** command in the **Start** menu by entering EES and clicking the **OK** button. 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.

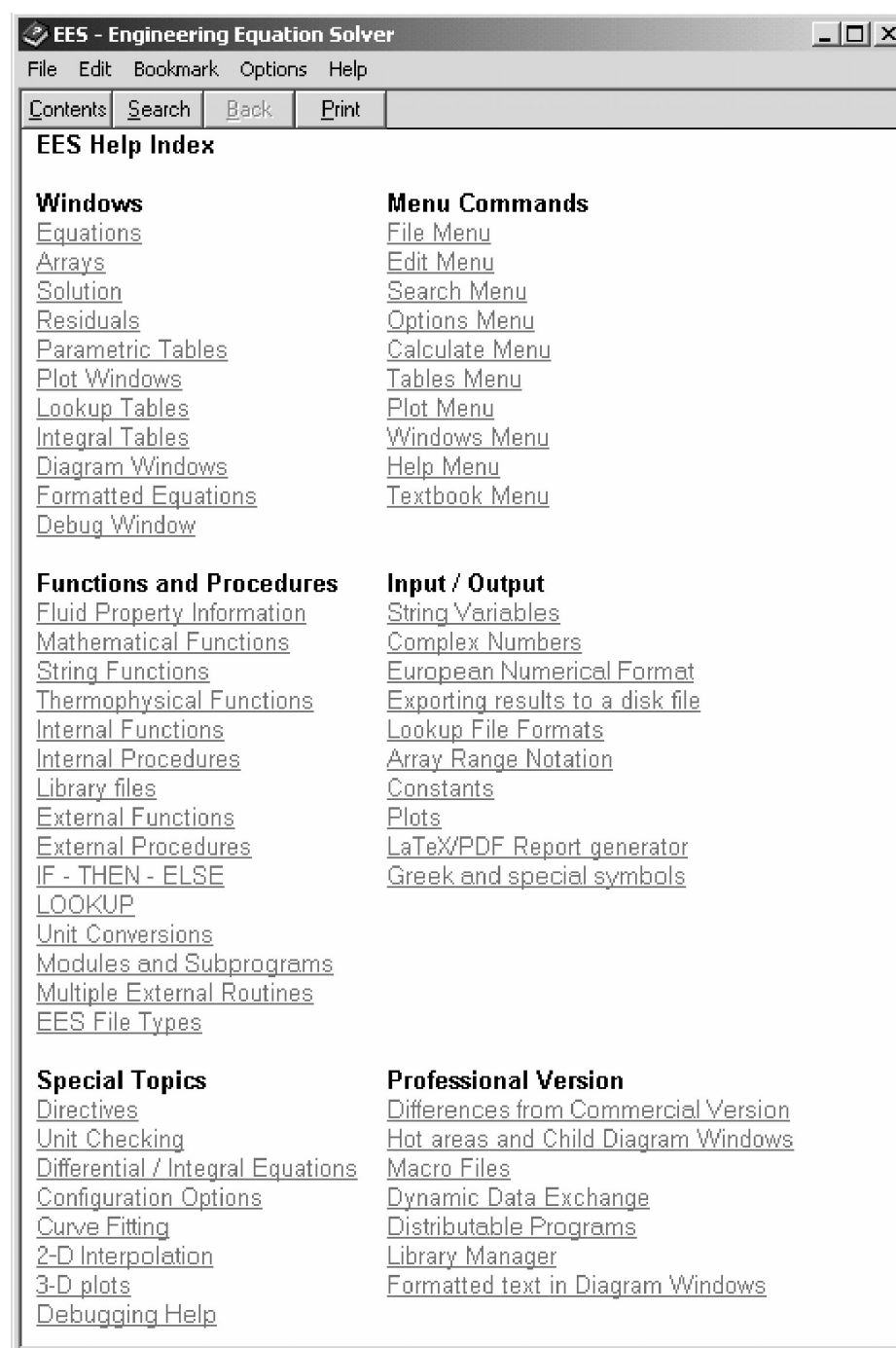


Fig. E.1 EES Help Index.

Detailed help is available at any point in EES. Pressing the **F1** key will bring up a Help window relating to the foremost window. Clicking the **Contents** button will present the **Help Index** shown in Fig. E.1. Clicking on an underlined word (shown in green on color monitors) will provide help relating to that subject.

EES commands are distributed among 11 pull-down menus. A brief summary of their functions follows:



The **System** menu is accessible by clicking on the **EES** icon above the file menu. The **System** menu is not part of EES, but rather a feature of the Windows operating system. It holds commands that allow window moving, resizing, and switching to other applications.

The **File** menu provides commands for loading, merging, and saving work files and 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. A command to check the units of the equations is also provided.

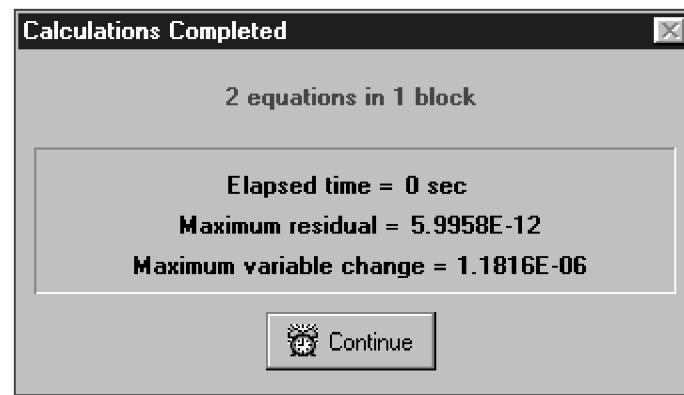
The **Tables** menu contains commands to set up and alter the contents of the **Parametric Table** and **Lookup Table** and to do linear regression on the data in these tables. The **Parametric Table**, which is similar to a spreadsheet, allows the equation set to be solved repeatedly while varying the 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 **Plots** menu provides commands to prepare a new plot of data in the **Parametric**, **Lookup**, **Array**, or **Integral Tables** or to modify an existing plot. Curve-fitting capability and thermodynamic property plots are 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 online help documentation.

The **Fluid Mechanics** menu provides access to EES solutions to problems in this text.



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



A Pipe Friction Example Problem

Let us now solve Prob. P6.55 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:

P6.55 As shown in Fig. E.2, 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/hr if $\Delta z = 100$ m?

This is a representative problem in pipe flow; and with water in a reasonably large (noncapillary) pipe, it will probably be turbulent ($\text{Re} > 4000$). The steady flow energy

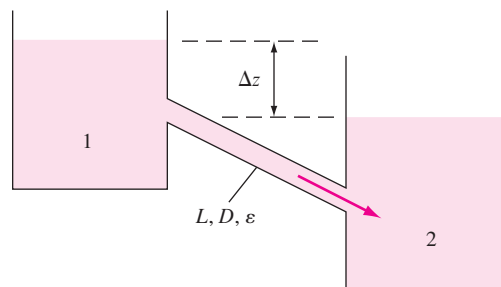


Fig. E.2 Sketch of the flow system.

equation (3.71) may be written between the surfaces of reservoirs 1 and 2:

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

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

$$\Delta z = f \frac{L}{D} \frac{V^2}{2g} \quad (\text{E.1})$$

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. (6.48):

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

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

$$\text{Re} = \rho V D / \mu \quad (\text{E.3}) \quad \text{and} \quad Q = V \frac{\pi}{4} D^2 \quad (\text{E.4})$$

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

There are a total of 11 variables involved in this problem: ($L, D, \Delta z, \epsilon, g, \mu, \rho, V, \text{Re}, f, Q$). Of these, seven can be specified at the start ($L, D, \Delta z, \epsilon, g, \mu, \rho$), while four (V, Re, f, Q) must be calculated from Equations (E.1–4). 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; Always set the unit system immediately: Select **Unit System** from the **Options** menu (Fig. E.3). Select *SI* and *Mass* units and trig *Degrees*, although we do not actually have trig functions this time. We select *kPa* for pressure and *Celsius* for temperature, *kJ* energy units that will be handy for using the EES built-in physical properties of water.

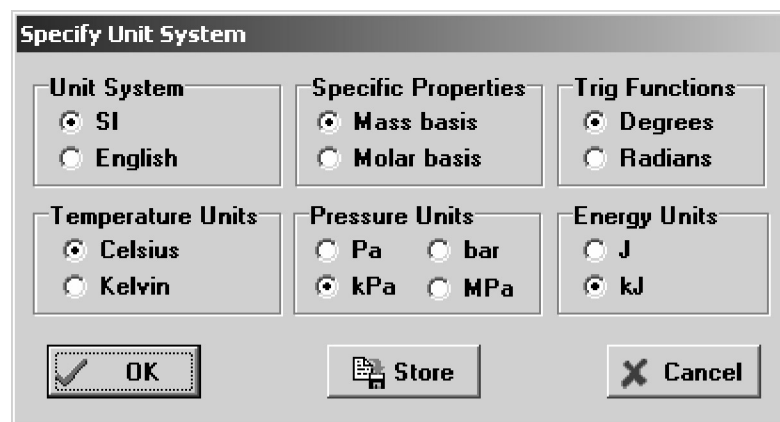


Fig. E.3 Unit selection dialog window.

Now, on the blank screen, enter the equations for this problem (Fig. E.4), five of which are known input values, two are property evaluations, and four are Equations (E.1–4).

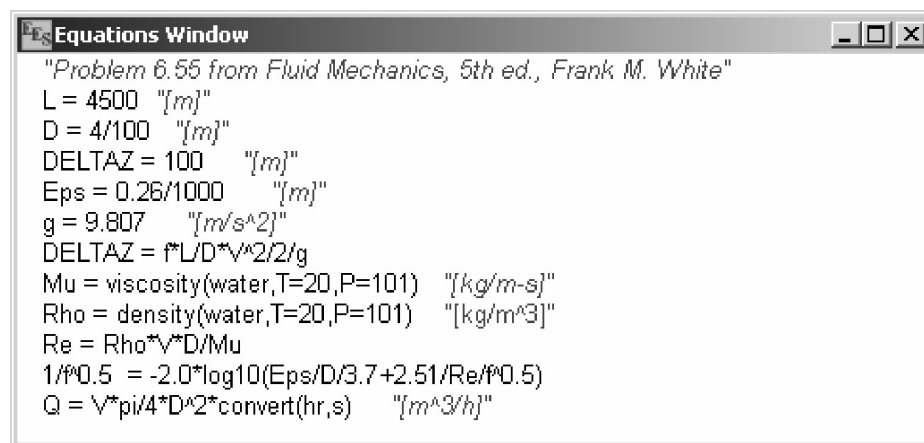


Fig. E.4 Equations window.

Notice several things in Fig. E.4. First, quantities in quotes, such as “[m]”, indicate the units of the variable on the left of the equal sign. There are other ways to enter the units of variables. Unit specifications do not affect the numerical results, but they are used in the unit checking that EES provides. You do not have to enter units in EES; but it is a good idea to do so since EES cannot check the units if you do not enter them, and unit conversions are a likely source of errors. Second, we changed *Eps* and *D* to meters right away to keep the SI units consistent. We could have used the **Convert** function to convert units as used in the last equation. 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, go for it: Choose 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 $+\infty$, too broad. Enter (as already shown in Fig. E.6) guesses for $f = 0.02$

Variable Information

☒ Show array variables Module **Main**

☐ Show string variables

Variable	Guess	Lower	Upper	Display	Units
D	0.04	-infinity	infinity	A 3 N	m
DELTAZ	100	-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	0.001002	-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	998.2	-infinity	infinity	A 3 N	kg/m^3
V	1.0000	0.0000E+00	infinity	F 4 N	m/s

OK Print Update Cancel

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

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

EES Solution

Main

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

D = 0.04 [m]	$\Delta Z = 100$ [m]	Eps = 0.00026 [m]
f = 0.03558	g = 9.807 [m/s^2]	L = 4500 [m]
$\mu = 0.001002$ [kg/m-s]	Q = 3.1666 [m^3/h]	Re = 27891
$\rho = 998.2$ [kg/m^3]	V = 0.7000 [m/s]	

No unit consistency or conversion problems were detected.

Calculation time = .0 sec

Fig. E.6 The Solution window for Problem P6.55.

places. The “units” column shows the units that were set within comments and square braces in the **Equations** window. Units can also be set in this dialog window.

Our guesses and limits are excellent, and the **Solve** command now iterates and reports success: “max residual = $2\text{E}-10$ ”, a negligible error. (The default runs for 100 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). Note that EES also checked the unit consistency of all the equations and found no problems.

This is the correct solution to Prob. P6.55: this cast iron pipe, when subjected to a 100 m elevation difference, will deliver $Q = 3.17 \text{ m}^3/\text{hr}$ 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 wish 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, a menu will appear with **Comment** as its first item. If you select that menu item, 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 .

Click the **Add** button and then the **OK** button and the new table will be displayed (Fig. E.8). Enter 10 values of Δz that cover the range of interest; we have selected the linear range $10 < \Delta z < 500 \text{ m}$. Note that it is not necessary to type these values in, although you can if you wish. Clicking the triangular icon at the upper right of each column header cell brings up a dialog that allows values to be automatically entered into the table.

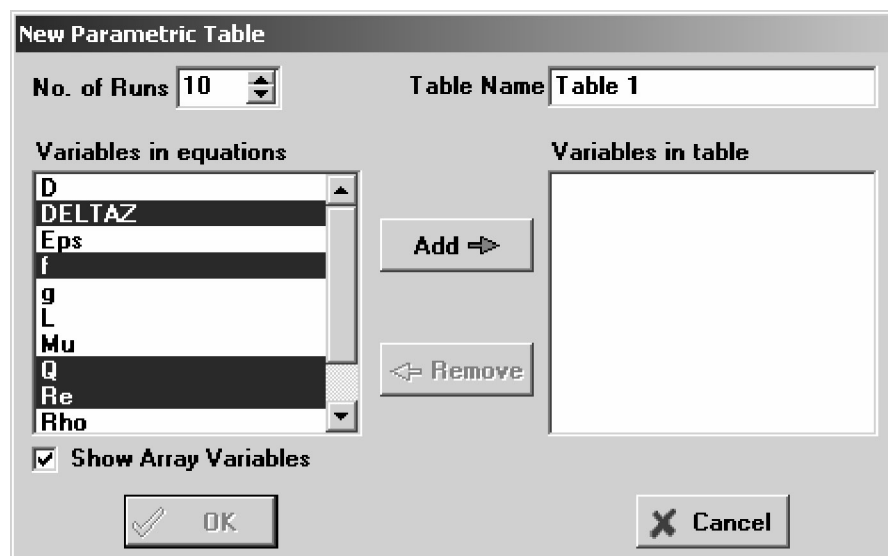
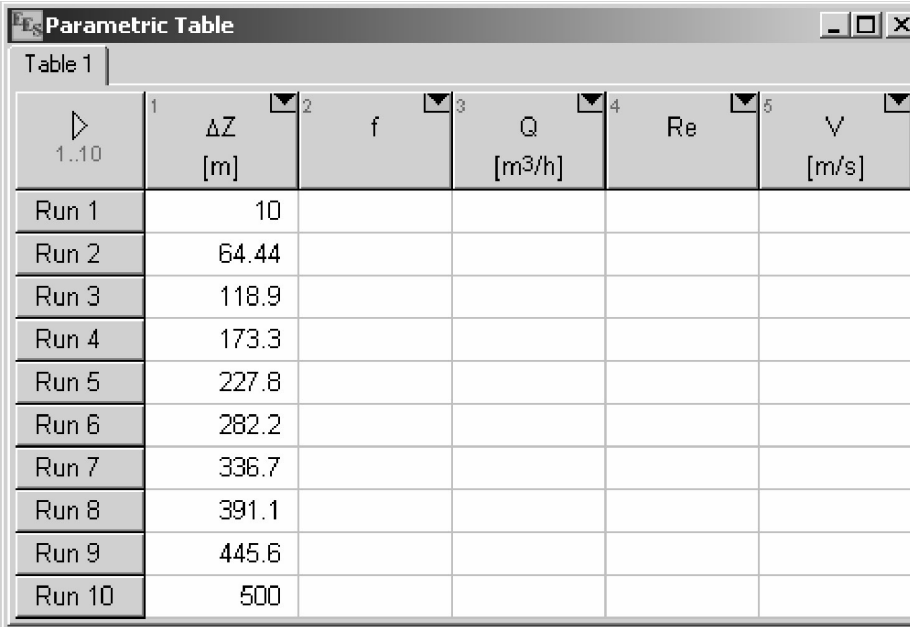


Fig. E.7 New Parametric Table showing selected variables (V is not shown).



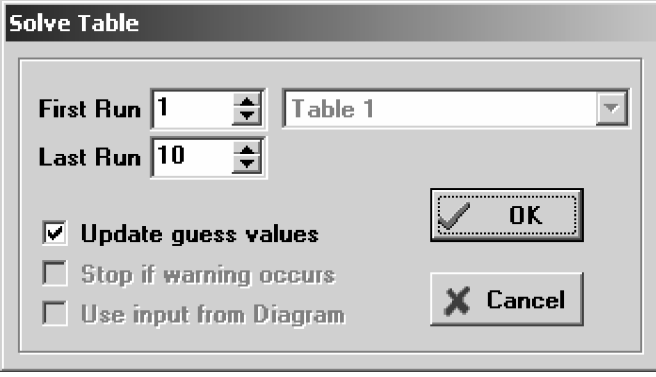
1..10	1 ΔZ [m]	2 f	3 Q [m ³ /h]	4 Re	5 V [m/s]
Run 1	10				
Run 2	64.44				
Run 3	118.9				
Run 4	173.3				
Run 5	227.8				
Run 6	282.2				
Run 7	336.7				
Run 8	391.1				
Run 9	445.6				
Run 10	500				

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 writer 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.

The flow rates are there to see in Fig. E.10, but as always, in the writer's experience, a plot is more illuminating. Select **New Plot Window** from the **Plot** menu. The **New Plot Setup** dialog box (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 .



Solve Table	
First Run	1
Last Run	10
Table 1	
<input checked="" type="checkbox"/> Update guess values	<input checked="" type="checkbox"/> OK
<input type="checkbox"/> Stop if warning occurs	<input type="checkbox"/> Cancel
<input type="checkbox"/> Use input from Diagram	

Fig. E.9 Solve Table dialog.

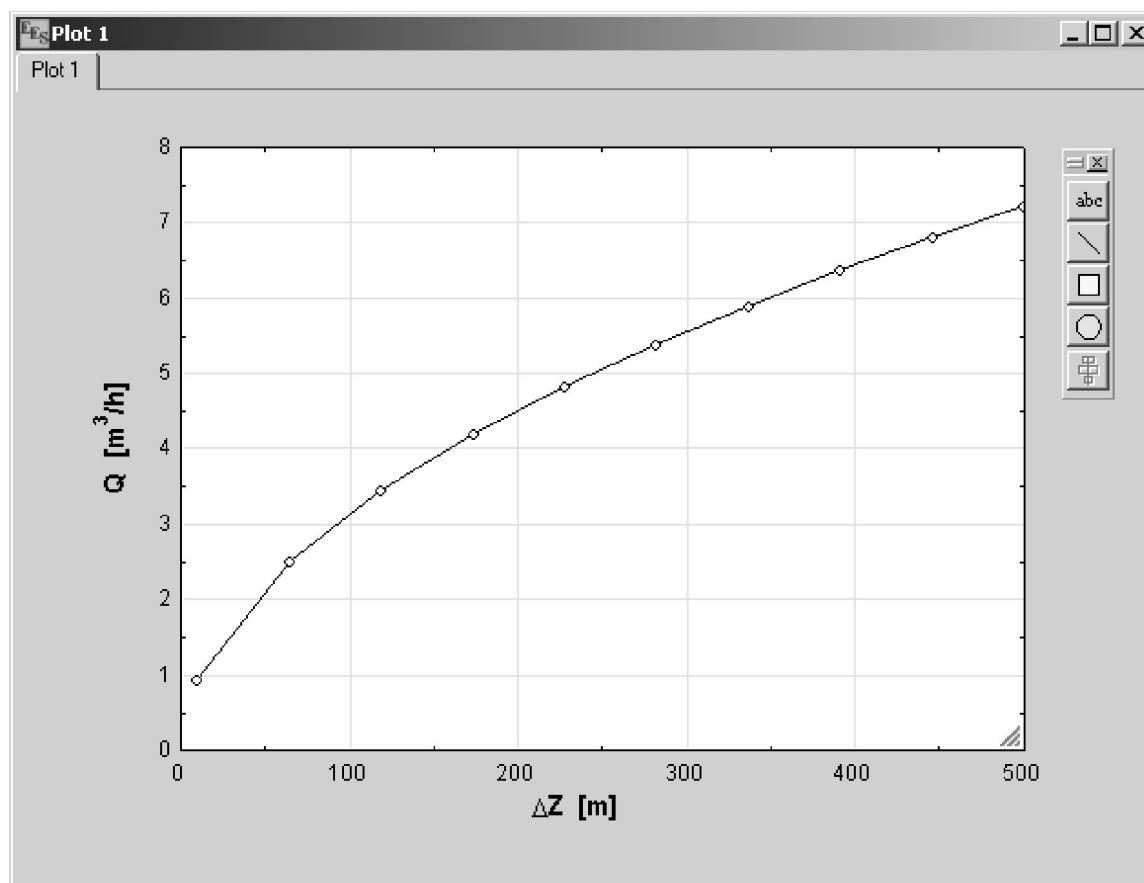


Fig. E.12 Plot window for flow rate versus elevation difference.

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. The toolbar at the right of the **Plot** window can be used to place text or graphics on the plot.

Fluid Dynamics Example Problems

A number of fluid dynamics problems developed for EES have been included with this textbook. In the menu bar at the top of the screen, you should see a menu called **Fluid Mechanics** to the right of the **Help** menu. This menu will provide access to all of the EES problem solutions developed for this book, organized by chapter. As an example, select **Chapter 6** from the **White Fluid Mechanics** menu. A dialog window will appear listing the problems in Chapter 6. Select **Problem P6.55–Flow Between Reservoirs**. This problem is a smooth wall alternative to the problem you just entered. It provides a **Diagram** window in which you can enter the Δz and other information. Enter values, and then select the **Solve** command in the **Calculate** menu to see their effect.

At this point, you should explore. Try whatever you wish. You can't hurt anything. The online 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.