Student Number _____

PhD Written Qualifying Exam 2011

Aerothermodynamics

Aerothermodynamics Ph. D. Qualifying Examination

June 2011

READ THESE INSTRUCTIONS.

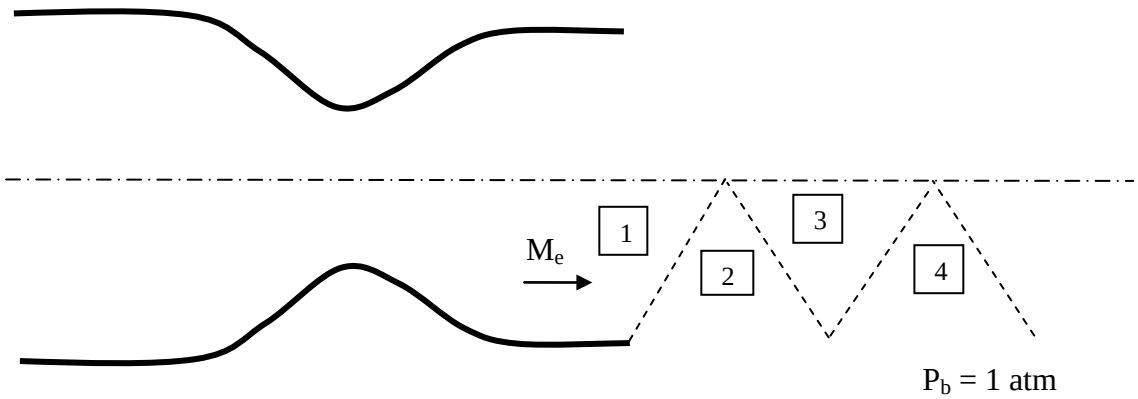
*Answer all **five** questions. Please write on one side of the paper only and put your Code Number and appropriate question number on every sheet.* ***Begin each question on a separate sheet of paper.*** *To obtain complete credit, your work must be neat and your complete procedure shown. Draw neat sketches and list your assumptions. Ask for clarification if the meaning of a question is unclear to you.*

Problem 1:

A supersonic nozzle is operated off the design condition (either over- or under-expanded), which causes the unspecified wave system shown. We know the following:

(i) the Mach number in region 4 is $M_4=3$
(ii) $P_3=3$ atm
(iii) The slipline angle in region 2 has a magnitude of 10 degrees (but whether it is up or down is not specified)

Determine the Mach number in region 2.



Problem 2:

Air enters a constant area burner of a SCRAMJET moving at Mach 3 with static temperature and static pressure of 700 K and 50 kPa respectively (state 1). The stagnation temperature of the combustion products leaving the burner is 2486 K (state 2).

(i) Calculate the Mach number and pressure of the combustion products assuming that the gases have $\gamma = 1.4$ and the same gas constant as air ($R_{\text{air}} = 287$ J/kg-K).

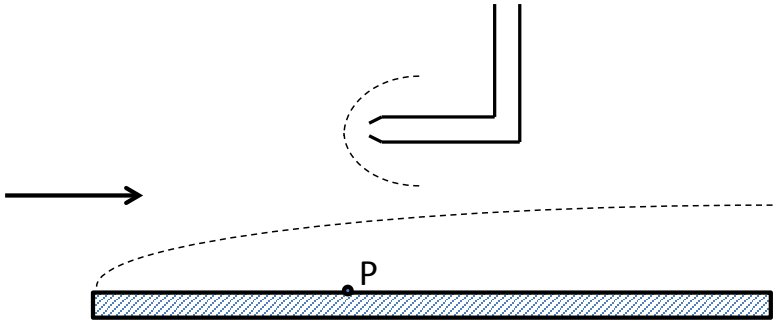
(ii) The combustion products are expanded adiabatically to a pressure of 1.50 kPa in a nozzle. Calculate the Mach number and exit velocity for an ideal nozzle.

(iii) The nozzle efficiency η_n is defined by $\eta_n = \dfrac{u_{e,a}^2/2}{u_{e,s}^2/2}$, where $u_{e,a}$ is the actual exit velocity, and $u_{e,s}$ is the exit velocity of an ideal nozzle. If the true nozzle efficiency is 0.98, calculate the actual velocity of the gas at the exit plane of the nozzle, and the exit gas temperature.

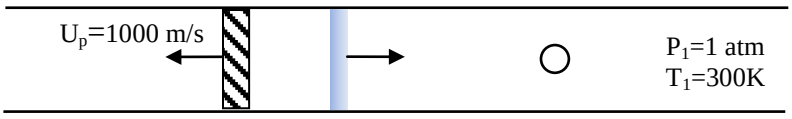
(iv) Sketch the expansion process in the nozzle on a *T*-*s* diagram. Clearly identify the nozzle inlet state **2**, ideal outlet state **3s**, and actual outlet state **3a**, and the stagnation states **o2** and **o3**. Draw the appropriate constant pressure lines p_{o2}, p_{o3a}, p_2, and p_3.

Problem 3:

Consider a Mach 3 flow of air past a flat plate as shown. The plate is insulated and the air can be treated as a calorically perfect gas with Pr=1. Also shown is a Pitot tube in the free stream flow. Compare the dissipation suffered by a fluid particle brought to rest at the plate surface (location P) and at the mouth of the Pitot tube. Obtain a numerical result for $\Delta s/R$, where s is the entropy per unit mass and R is the gas constant. Comment on your result.



Problem 4:
A tube is filled with stagnant air with pressure and temperature of P_1=1atm and T_1=300K. A piston is instantaneously accelerated to 1000 m/s to the left, which produces a wave traveling to the right. Once the wave passes the sphere shown, determine the maximum pressure and temperature on the surface of the sphere. You may neglect viscous effects. Assume the flow 1D and the air can be treated as a calorically perfect gas with γ=1.4.



Problem 5:
Consider the following partial differential equation

$$\frac{\partial u}{\partial t} = \mu \frac{\partial^2 u}{\partial x^2} + S,$$

where, *u* is the dependent variable, μ is a positive constant, and $S = S(u, x, t)$.

a) Suggest an implicit numerical discretization for the above equation assuming $S = 0$.

b) Discuss how you would solve this discretized equation. If the approach involves inverting a matrix for a linear system of equation, discuss what options are available solve this linear system.

c) If $S = Au^2$, where A is a constant, how would you cast the implicit discrete form. Discuss the solution approach for this discrete equation.

Supplementary Equations:

$J_+ = u + 2a/(\gamma-1)$

$J_- = u - 2a/(\gamma-1)$

$K_+ = \theta - \nu$

$K_- = \theta + \nu$

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma+1)M_1^2}{(\gamma-1)M_1^2+2}$$

$$\frac{P_2}{P_1} = \frac{2\gamma M_1^2 - (\gamma-1)}{\gamma+1}$$

Isentropic Flow Table for $\gamma = 1.4$

M	p/p_o	T/T_o	ρ/ρ_o	A/A^*	$\frac{A}{A^*}\frac{p}{p_o}$	M	p/p_o	T/T_o	ρ/ρ_o	A/A^*	$\frac{A}{A^*}\frac{p}{p_o}$
0.00	1.0000	1.0000	1.0000	∞	∞	1.00	0.5283	0.8333	0.6339	1.0000	0.5283
0.02	0.9997	0.9999	0.9998	28.942	128.9340	1.02	0.5160	0.8278	0.6234	1.0003	0.5162
0.04	0.9989	0.9997	0.9992	14.4815	14.4653	1.04	0.5039	0.8222	0.6129	1.0013	0.5045
0.06	0.9975	0.9993	0.9982	9.6659	9.6416	1.06	0.4919	0.8165	0.6024	1.0029	0.4933
0.08	0.9955	0.9987	0.9968	7.2616	7.2292	1.08	0.4800	0.8108	0.5920	1.0051	0.4825
0.10	0.9930	0.9980	0.9950	5.8218	5.7813	1.10	0.4684	0.8052	0.5817	1.0079	0.4721
0.12	0.9900	0.9971	0.9928	4.8643	4.8156	1.12	0.4568	0.7994	0.5714	1.0113	0.4620
0.14	0.9864	0.9961	0.9903	4.1824	4.1255	1.14	0.4455	0.7937	0.5612	1.0153	0.4523
0.16	0.9823	0.9949	0.9873	3.6727	3.6077	1.16	0.4343	0.7879	0.5511	1.0198	0.4428
0.18	0.9776	0.9936	0.9840	3.2779	3.2047	1.18	0.4232	0.7822	0.5411	1.0248	0.4337
0.20	0.9725	0.9921	0.9803	2.9635	2.8820	1.20	0.4124	0.7764	0.5311	1.0304	0.4249
0.22	0.9668	0.9904	0.9762	2.7076	2.6178	1.22	0.4017	0.7706	0.5213	1.0366	0.4164
0.24	0.9607	0.9886	0.9718	2.4956	2.3975	1.24	0.3912	0.7648	0.5115	1.0432	0.4081
0.26	0.9541	0.9867	0.9670	2.3173	2.2109	1.26	0.3809	0.7590	0.5019	1.0504	0.4001
0.28	0.9470	0.9846	0.9619	2.1656	2.0508	1.28	0.3708	0.7532	0.4923	1.0581	0.3924
0.30	0.9395	0.9823	0.9564	2.0351	1.9119	1.30	0.3609	0.7474	0.4829	1.0663	0.3848
0.32	0.9315	0.9799	0.9506	1.9219	1.7902	1.32	0.3512	0.7416	0.4736	1.0750	0.3775
0.34	0.9231	0.9774	0.9445	1.8229	1.6827	1.34	0.3417	0.7358	0.4644	1.0842	0.3704
0.36	0.9143	0.9747	0.9380	1.7358	1.5871	1.36	0.3323	0.7300	0.4553	1.0940	0.3636
0.38	0.9052	0.9719	0.9313	1.6587	1.5014	1.38	0.3232	0.7242	0.4463	1.1042	0.3569
0.40	0.8956	0.9690	0.9243	1.5901	1.4242	1.40	0.3142	0.7184	0.4374	1.1149	0.3504
0.42	0.8857	0.9659	0.9170	1.5289	1.3542	1.42	0.3055	0.7126	0.4287	1.1262	0.3440
0.44	0.8755	0.9627	0.9094	1.4740	1.2905	1.44	0.2969	0.7069	0.4201	1.1379	0.3379
0.46	0.8650	0.9594	0.9016	1.4246	1.2322	1.46	0.2886	0.7011	0.4116	1.1501	0.3319
0.48	0.8541	0.9559	0.8935	1.3801	1.1788	1.48	0.2804	0.6954	0.4032	1.1629	0.3261
0.50	0.8430	0.9524	0.8852	1.3398	1.1295	1.50	0.2724	0.6897	0.3950	1.1762	0.3204
0.52	0.8317	0.9487	0.8766	1.3034	1.0840	1.52	0.2646	0.6840	0.3869	1.1899	0.3149
0.54	0.8201	0.9449	0.8679	1.2703	1.0417	1.54	0.2570	0.6783	0.3789	1.2042	0.3095
0.56	0.8082	0.9410	0.8589	1.2403	1.0024	1.56	0.2496	0.6726	0.3710	1.2190	0.3042
0.58	0.7962	0.9370	0.8498	1.2130	0.9658	1.58	0.2423	0.6670	0.3633	1.2344	0.2991
0.60	0.7840	0.9328	0.8405	1.1882	0.9316	1.60	0.2353	0.6614	0.3557	1.2502	0.2941
0.62	0.7716	0.9286	0.8310	1.1656	0.8995	1.62	0.2284	0.6558	0.3483	1.2666	0.2893
0.64	0.7591	0.9243	0.8213	1.1451	0.8693	1.64	0.2217	0.6502	0.3409	1.2836	0.2845
0.66	0.7465	0.9199	0.8115	1.1265	0.8410	1.66	0.2151	0.6447	0.3337	1.3010	0.2799
0.68	0.7338	0.9153	0.8016	1.1097	0.8142	1.68	0.2088	0.6392	0.3266	1.3190	0.2754
0.70	0.7209	0.9107	0.7916	1.0944	0.7890	1.70	0.2026	0.6337	0.3197	1.3376	0.2710
0.72	0.7080	0.9061	0.7814	1.0806	0.7651	1.72	0.1966	0.6283	0.3129	1.3567	0.2667
0.74	0.6951	0.9013	0.7712	1.0681	0.7424	1.74	0.1907	0.6229	0.3062	1.3764	0.2625
0.76	0.6821	0.8964	0.7609	1.0570	0.7209	1.76	0.1850	0.6175	0.2996	1.3967	0.2584
0.78	0.6691	0.8915	0.7505	1.0471	0.7005	1.78	0.1794	0.6121	0.2931	1.4175	0.2544
0.80	0.6560	0.8865	0.7400	1.0382	0.6811	1.80	0.1740	0.6068	0.2868	1.4390	0.2504
0.82	0.6430	0.8815	0.7295	1.0305	0.6626	1.82	0.1688	0.6015	0.2806	1.4610	0.2466
0.84	0.6300	0.8763	0.7189	1.0237	0.6449	1.84	0.1637	0.5963	0.2745	1.4836	0.2429
0.86	0.6170	0.8711	0.7083	1.0179	0.6281	1.86	0.1587	0.5910	0.2686	1.5069	0.2392
0.88	0.6041	0.8659	0.6977	1.0129	0.6119	1.88	0.1539	0.5859	0.2627	1.5308	0.2356
0.90	0.5913	0.8606	0.6870	1.0089	0.5965	1.90	0.1492	0.5807	0.2570	1.5553	0.2321
0.92	0.5785	0.8552	0.6764	1.0056	0.5817	1.92	0.1447	0.5756	0.2514	1.5804	0.2287
0.94	0.5658	0.8498	0.6658	1.0031	0.5675	1.94	0.1403	0.5705	0.2459	1.6062	0.2253
0.96	0.5532	0.8444	0.6551	1.0014	0.5539	1.96	0.1360	0.5655	0.2405	1.6326	0.2220
0.98	0.5407	0.8389	0.6445	1.0003	0.5409	1.98	0.1318	0.5605	0.2352	1.6597	0.2188
1.00	0.5283	0.8333	0.6339	1.0000	0.5283	2.00	0.1278	0.5556	0.2300	1.6875	0.2157

Isentropic Flow Table for $\gamma = 1.4$

M	p/p_o	T/T_o	ρ/ρ_o	A/A^*	$\frac{A}{A^*}\frac{p}{p_o}$	M	p/p_o	T/T_o	ρ/ρ_o	A/A^*	$\frac{A}{A^*}\frac{p}{p_o}$
2.00	0.1278	0.5556	0.2300	1.6875	0.2157	3.00	2.722 E-2	0.3571	7.623 E-2	4.2346	0.1153
2.02	0.1239	0.5506	0.2250	1.7160	0.2126	3.05	2.526 E-2	0.3496	7.226 E-2	4.4410	0.1122
2.04	0.1201	0.5458	0.2200	1.7451	0.2096	3.10	2.345 E-2	0.3422	6.852 E-2	4.6573	0.1092
2.06	0.1164	0.5409	0.2152	1.7750	0.2066	3.15	2.177 E-2	0.3351	6.499 E-2	4.8838	0.1063
2.08	0.1128	0.5361	0.2104	1.8056	0.2037	3.20	2.023 E-2	0.3281	6.165 E-2	5.1210	0.1036
2.10	0.1094	0.5313	0.2058	1.8369	0.2009	3.25	1.880 E-2	0.3213	5.851 E-2	5.3691	0.1009
2.12	0.1060	0.5266	0.2013	1.8690	0.1981	3.30	1.748 E-2	0.3147	5.554 E-2	5.6286	9.837 E-2
2.14	0.1027	0.5219	0.1968	1.9018	0.1954	3.35	1.625 E-2	0.3082	5.274 E-2	5.9000	9.590 E-2
2.16	9.956 E-2	0.5173	0.1925	1.9354	0.1927	3.40	1.512 E-2	0.3019	5.009 E-2	6.1837	9.353 E-2
2.18	9.649 E-2	0.5127	0.1882	1.9698	0.1901	3.45	1.408 E-2	0.2958	4.759 E-2	6.4801	9.123 E-2
2.20	9.352 E-2	0.5081	0.1841	2.0050	0.1875	3.50	1.311 E-2	0.2899	4.523 E-2	6.7896	8.902 E-2
2.22	9.064 E-2	0.5036	0.1800	2.0409	0.1850	3.55	1.221 E-2	0.2841	4.300 E-2	7.1128	8.688 E-2
2.24	8.785 E-2	0.4991	0.1760	2.0777	0.1825	3.60	1.138 E-2	0.2784	4.089 E-2	7.4501	8.482 E-2
2.26	8.514 E-2	0.4947	0.1721	2.1153	0.1801	3.65	1.062 E-2	0.2729	3.890 E-2	7.8020	8.282 E-2
2.28	8.251 E-2	0.4903	0.1683	2.1538	0.1777	3.70	9.903 E-3	0.2675	3.702 E-2	8.1691	8.090 E-2
2.30	7.997 E-2	0.4859	0.1646	2.1931	0.1754	3.75	9.242 E-3	0.2623	3.524 E-2	8.5517	7.904 E-2
2.32	7.751 E-2	0.4816	0.1609	2.2333	0.1731	3.80	8.629 E-3	0.2572	3.355 E-2	8.9506	7.723 E-2
2.34	7.512 E-2	0.4773	0.1574	2.2744	0.1709	3.85	8.060 E-3	0.2522	3.195 E-2	9.3661	7.549 E-2
2.36	7.281 E-2	0.4731	0.1539	2.3164	0.1687	3.90	7.532 E-3	0.2474	3.044 E-2	9.7990	7.381 E-2
2.38	7.057 E-2	0.4688	0.1505	2.3593	0.1665	3.95	7.042 E-3	0.2427	2.902 E-2	10.2496	7.217 E-2
2.40	6.840 E-2	0.4647	0.1472	2.4031	0.1644	4.00	6.586 E-3	0.2381	2.766 E-2	10.7188	7.059 E-2
2.42	6.630 E-2	0.4606	0.1439	2.4479	0.1623	4.05	6.163 E-3	0.2336	2.638 E-2	11.2069	6.906 E-2
2.44	6.426 E-2	0.4565	0.1408	2.4936	0.1602	4.10	5.769 E-3	0.2293	2.516 E-2	11.7147	6.758 E-2
2.46	6.229 E-2	0.4524	0.1377	2.5403	0.1582	4.15	5.403 E-3	0.2250	2.401 E-2	12.2427	6.614 E-2
2.48	6.038 E-2	0.4484	0.1346	2.5880	0.1563	4.20	5.062 E-3	0.2208	2.292 E-2	12.7916	6.475 E-2
2.50	5.853 E-2	0.4444	0.1317	2.6367	0.1543	4.25	4.745 E-3	0.2168	2.189 E-2	13.3622	6.340 E-2
2.52	5.674 E-2	0.4405	0.1288	2.6865	0.1524	4.30	4.449 E-3	0.2129	2.090 E-2	13.9549	6.209 E-2
2.54	5.500 E-2	0.4366	0.1260	2.7372	0.1505	4.35	4.174 E-3	0.2090	1.997 E-2	14.5706	6.082 E-2
2.56	5.332 E-2	0.4328	0.1232	2.7891	0.1487	4.40	3.918 E-3	0.2053	1.909 E-2	15.2099	5.959 E-2
2.58	5.169 E-2	0.4289	0.1205	2.8420	0.1469	4.45	3.678 E-3	0.2016	1.825 E-2	15.8735	5.839 E-2
2.60	5.012 E-2	0.4252	0.1179	2.8960	0.1451	4.50	3.455 E-3	0.1980	1.745 E-2	16.5622	5.723 E-2
2.62	4.859 E-2	0.4214	0.1153	2.9511	0.1434	4.55	3.247 E-3	0.1945	1.669 E-2	17.2767	5.610 E-2
2.64	4.711 E-2	0.4177	0.1128	3.0073	0.1417	4.60	3.053 E-3	0.1911	1.597 E-2	18.0178	5.500 E-2
2.66	4.568 E-2	0.4141	0.1103	3.0647	0.1400	4.65	2.871 E-3	0.1878	1.529 E-2	18.7862	5.393 E-2
2.68	4.429 E-2	0.4104	0.1079	3.1233	0.1383	4.70	2.701 E-3	0.1846	1.464 E-2	19.5828	5.290 E-2
2.70	4.295 E-2	0.4068	0.1056	3.1830	0.1367	4.75	2.543 E-3	0.1814	1.402 E-2	20.4084	5.189 E-2
2.72	4.165 E-2	0.4033	0.1033	3.2440	0.1351	4.80	2.394 E-3	0.1783	1.343 E-2	21.2637	5.091 E-2
2.74	4.039 E-2	0.3998	0.1010	3.3061	0.1335	4.85	2.255 E-3	0.1753	1.287 E-2	22.1497	4.996 E-2
2.76	3.917 E-2	0.3963	9.885 E-2	3.3695	0.1320	4.90	2.126 E-3	0.1724	1.233 E-2	23.0671	4.903 E-2
2.78	3.799 E-2	0.3928	9.671 E-2	3.4342	0.1305	4.95	2.004 E-3	0.1695	1.182 E-2	24.0169	4.813 E-2
2.80	3.685 E-2	0.3894	9.463 E-2	3.5001	0.1290	5.00	1.890 E-3	0.1667	1.134 E-2	25.0000	4.725 E-2
2.82	3.574 E-2	0.3860	9.259 E-2	3.5674	0.1275	5.10	1.683 E-3	0.1612	1.044 E-2	27.0696	4.640 E-2
2.84	3.467 E-2	0.3827	9.059 E-2	3.6359	0.1261	5.20	1.501 E-3	0.1561	9.620 E-3	29.2833	4.556 E-2
2.86	3.363 E-2	0.3794	8.865 E-2	3.7058	0.1246	5.30	1.341 E-3	0.1511	8.875 E-3	31.6491	4.475 E-2
2.88	3.263 E-2	0.3761	8.675 E-2	3.7771	0.1232	5.40	1.200 E-3	0.1464	8.197 E-3	34.1748	4.396 E-2
2.90	3.165 E-2	0.3729	8.489 E-2	3.8498	0.1219	5.50	1.075 E-3	0.1418	7.578 E-3	36.8690	4.319 E-2
2.92	3.071 E-2	0.3696	8.307 E-2	3.9238	0.1205	5.60	9.643 E-4	0.1375	7.012 E-3	39.7402	4.244 E-2
2.94	2.980 E-2	0.3665	8.130 E-2	3.9993	0.1192	5.70	8.663 E-4	0.1334	6.496 E-3	42.7974	4.171 E-2
2.96	2.891 E-2	0.3633	7.957 E-2	4.0763	0.1178	5.80	7.794 E-4	0.1294	6.023 E-3	46.0500	4.100 E-2
2.98	2.805 E-2	0.3602	7.788 E-2	4.1547	0.1166	5.90	7.021 E-4	0.1256	5.590 E-3	49.5075	4.031 E-2
3.00	2.722 E-2	0.3571	7.623 E-2	4.2346	0.1153	6.00	6.334 E-4	0.1220	5.194 E-3	53.1798	3.963 E-2

Isentropic Flow Table for $\gamma = 1.4$

M	p/p_o	T/T_o	ρ/ρ_o	A/A^*	$\frac{A\ p}{A^* p_o}$
6.00	6.334 E-4	0.1220	5.194 E-3	53.1798	3.368 E-2
6.10	5.721 E-4	0.1185	4.829 E-3	57.0772	3.265 E-2
6.20	5.173 E-4	0.1151	4.495 E-3	61.2102	3.167 E-2
6.30	4.684 E-4	0.1119	4.187 E-3	65.5899	3.073 E-2
6.40	4.247 E-4	0.1088	3.904 E-3	70.2274	2.982 E-2
6.50	3.855 E-4	0.1058	3.643 E-3	75.1343	2.896 E-2
6.60	3.503 E-4	0.1030	3.402 E-3	80.3227	2.814 E-2
6.70	3.187 E-4	0.1002	3.180 E-3	85.8049	2.734 E-2
6.80	2.902 E-4	9.758 E-2	2.974 E-3	91.5935	2.658 E-2
6.90	2.646 E-4	9.504 E-2	2.785 E-3	97.7017	2.586 E-2
7.00	2.416 E-4	9.259 E-2	2.609 E-3	104.1429	2.516 E-2
7.10	2.207 E-4	9.024 E-2	2.446 E-3	110.9309	2.448 E-2
7.20	2.019 E-4	8.797 E-2	2.295 E-3	118.0799	2.384 E-2
7.30	1.848 E-4	8.578 E-2	2.155 E-3	125.6046	2.322 E-2
7.40	1.694 E-4	8.367 E-2	2.025 E-3	133.5200	2.262 E-2
7.50	1.554 E-4	8.163 E-2	1.904 E-3	141.8415	2.205 E-2
7.60	1.427 E-4	7.967 E-2	1.792 E-3	150.5849	2.149 E-2
7.70	1.312 E-4	7.777 E-2	1.687 E-3	159.7665	2.096 E-2
7.80	1.207 E-4	7.594 E-2	1.589 E-3	169.4030	2.045 E-2
7.90	1.111 E-4	7.417 E-2	1.498 E-3	179.5114	1.995 E-2
8.00	1.024 E-4	7.246 E-2	1.414 E-3	190.1094	1.947 E-2
8.10	9.449 E-5	7.081 E-2	1.334 E-3	201.2148	1.901 E-2
8.20	8.723 E-5	6.921 E-2	1.260 E-3	212.8461	1.857 E-2
8.30	8.060 E-5	6.767 E-2	1.191 E-3	225.0221	1.814 E-2
8.40	7.454 E-5	6.617 E-2	1.126 E-3	237.7622	1.772 E-2
8.50	6.898 E-5	6.472 E-2	1.066 E-3	251.0862	1.732 E-2
8.60	6.390 E-5	6.332 E-2	1.009 E-3	265.0142	1.693 E-2
8.70	5.923 E-5	6.197 E-2	9.558 E-4	279.5672	1.656 E-2
8.80	5.494 E-5	6.065 E-2	9.059 E-4	294.7661	1.620 E-2
8.90	5.101 E-5	5.938 E-2	8.590 E-4	310.6328	1.584 E-2
9.00	4.739 E-5	5.814 E-2	8.150 E-4	327.1893	1.550 E-2
9.10	4.405 E-5	5.694 E-2	7.737 E-4	344.4584	1.517 E-2
9.20	4.099 E-5	5.578 E-2	7.348 E-4	362.4632	1.486 E-2
9.30	3.816 E-5	5.465 E-2	6.982 E-4	381.2275	1.455 E-2
9.40	3.555 E-5	5.356 E-2	6.638 E-4	400.7753	1.425 E-2
9.50	3.314 E-5	5.249 E-2	6.313 E-4	421.1314	1.396 E-2
9.60	3.092 E-5	5.146 E-2	6.008 E-4	442.3210	1.367 E-2
9.70	2.886 E-5	5.046 E-2	5.719 E-4	464.3698	1.340 E-2
9.80	2.696 E-5	4.949 E-2	5.447 E-4	487.3042	1.314 E-2
9.90	2.520 E-5	4.854 E-2	5.191 E-4	511.1510	1.288 E-2
10.00	2.356 E-5	4.762 E-2	4.948 E-4	535.9375	1.263 E-2

Normal Shock Table for $\gamma = 1.4$

For oblique shocks tabulated values are M_{n1}, M_{n2}

M_1	M_2	p_2/p_1	T_2/T_1	ρ_2/ρ_1	p_{O2}/p_{O1}	A_2^*/A_1^*
1.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.02	0.9805	1.0471	1.0132	1.0334	1.0000	1.0000
1.04	0.9620	1.0952	1.0263	1.0671	0.9999	1.0001
1.06	0.9444	1.1442	1.0393	1.1009	0.9998	1.0002
1.08	0.9277	1.1941	1.0522	1.1349	0.9994	1.0006
1.10	0.9118	1.2450	1.0649	1.1691	0.9989	1.0011
1.12	0.8966	1.2968	1.0776	1.2034	0.9982	1.0018
1.14	0.8820	1.3495	1.0903	1.2378	0.9973	1.0027
1.16	0.8682	1.4032	1.1029	1.2723	0.9961	1.0040
1.18	0.8549	1.4578	1.1154	1.3069	0.9946	1.0055
1.20	0.8422	1.5133	1.1280	1.3416	0.9928	1.0073
1.22	0.8300	1.5698	1.1405	1.3764	0.9907	1.0094
1.24	0.8183	1.6272	1.1531	1.4112	0.9884	1.0118
1.26	0.8071	1.6855	1.1657	1.4460	0.9857	1.0145
1.28	0.7963	1.7448	1.1783	1.4808	0.9827	1.0176
1.30	0.7860	1.8050	1.1909	1.5157	0.9794	1.0211
1.32	0.7760	1.8661	1.2035	1.5505	0.9758	1.0249
1.34	0.7664	1.9282	1.2162	1.5854	0.9718	1.0290
1.36	0.7572	1.9912	1.2290	1.6202	0.9676	1.0335
1.38	0.7483	2.0551	1.2418	1.6549	0.9630	1.0384
1.40	0.7397	2.1200	1.2547	1.6897	0.9582	1.0436
1.42	0.7314	2.1858	1.2676	1.7243	0.9531	1.0492
1.44	0.7235	2.2525	1.2807	1.7589	0.9476	1.0552
1.46	0.7157	2.3202	1.2938	1.7934	0.9420	1.0616
1.48	0.7083	2.3888	1.3069	1.8278	0.9360	1.0684
1.50	0.7011	2.4583	1.3202	1.8621	0.9298	1.0755
1.52	0.6941	2.5288	1.3336	1.8963	0.9233	1.0830
1.54	0.6874	2.6002	1.3470	1.9303	0.9166	1.0910
1.56	0.6809	2.6725	1.3606	1.9643	0.9097	1.0993
1.58	0.6746	2.7458	1.3742	1.9981	0.9026	1.1080
1.60	0.6684	2.8200	1.3880	2.0317	0.8952	1.1171
1.62	0.6625	2.8951	1.4018	2.0653	0.8877	1.1266
1.64	0.6568	2.9712	1.4158	2.0986	0.8799	1.1365
1.66	0.6512	3.0482	1.4299	2.1318	0.8720	1.1468
1.68	0.6458	3.1261	1.4440	2.1649	0.8639	1.1575
1.70	0.6405	3.2050	1.4583	2.1977	0.8557	1.1686
1.72	0.6355	3.2848	1.4727	2.2304	0.8474	1.1801
1.74	0.6305	3.3655	1.4873	2.2629	0.8389	1.1921
1.76	0.6257	3.4472	1.5019	2.2952	0.8302	1.2045
1.78	0.6210	3.5298	1.5167	2.3273	0.8215	1.2173
1.80	0.6165	3.6133	1.5316	2.3592	0.8127	1.2305
1.82	0.6121	3.6978	1.5466	2.3909	0.8038	1.2441
1.84	0.6078	3.7832	1.5617	2.4224	0.7948	1.2582
1.86	0.6036	3.8695	1.5770	2.4537	0.7857	1.2728
1.88	0.5996	3.9568	1.5924	2.4848	0.7765	1.2877
1.90	0.5956	4.0450	1.6079	2.5157	0.7674	1.3032
1.92	0.5918	4.1341	1.6236	2.5463	0.7581	1.3191
1.94	0.5880	4.2242	1.6394	2.5767	0.7488	1.3354
1.96	0.5844	4.3152	1.6553	2.6069	0.7395	1.3522
1.98	0.5808	4.4071	1.6713	2.6369	0.7302	1.3695
2.00	0.5774	4.5000	1.6875	2.6667	0.7209	1.3872

Normal Shock Table for $\gamma = 1.4$

For oblique shocks tabulated values are M_{n1}, M_{n2}

M_1	M_2	p_2/p_1	T_2/T_1	ρ_2/ρ_1	p_{O2}/p_{O1}	A_2^*/A_1^*
2.00	0.5774	4.5000	1.6875	2.6667	0.7209	1.3872
2.02	0.5740	4.5938	1.7038	2.6962	0.7115	1.4054
2.04	0.5707	4.6885	1.7203	2.7255	0.7022	1.4241
2.06	0.5675	4.7842	1.7369	2.7545	0.6928	1.4433
2.08	0.5643	4.8808	1.7536	2.7833	0.6835	1.4630
2.10	0.5613	4.9783	1.7705	2.8119	0.6742	1.4832
2.12	0.5583	5.0768	1.7875	2.8402	0.6649	1.5039
2.14	0.5554	5.1762	1.8046	2.8683	0.6557	1.5252
2.16	0.5525	5.2765	1.8219	2.8962	0.6464	1.5469
2.18	0.5498	5.3778	1.8393	2.9238	0.6373	1.5692
2.20	0.5471	5.4800	1.8569	2.9512	0.6281	1.5920
2.22	0.5444	5.5831	1.8746	2.9784	0.6191	1.6154
2.24	0.5418	5.6872	1.8924	3.0053	0.6100	1.6393
2.26	0.5393	5.7922	1.9104	3.0319	0.6011	1.6638
2.28	0.5368	5.8981	1.9285	3.0584	0.5921	1.6888
2.30	0.5344	6.0050	1.9468	3.0845	0.5833	1.7144
2.32	0.5321	6.1128	1.9652	3.1105	0.5745	1.7406
2.34	0.5297	6.2215	1.9838	3.1362	0.5658	1.7674
2.36	0.5275	6.3312	2.0025	3.1617	0.5572	1.7948
2.38	0.5253	6.4418	2.0213	3.1869	0.5486	1.8228
2.40	0.5231	6.5533	2.0403	3.2119	0.5401	1.8514
2.42	0.5210	6.6658	2.0595	3.2367	0.5317	1.8806
2.44	0.5189	6.7792	2.0788	3.2612	0.5234	1.9105
2.46	0.5169	6.8935	2.0982	3.2855	0.5152	1.9410
2.48	0.5149	7.0088	2.1178	3.3095	0.5071	1.9721
2.50	0.5130	7.1250	2.1375	3.3333	0.4990	2.0039
2.52	0.5111	7.2421	2.1574	3.3569	0.4911	2.0364
2.54	0.5092	7.3602	2.1774	3.3803	0.4832	2.0696
2.56	0.5074	7.4792	2.1976	3.4034	0.4754	2.1035
2.58	0.5056	7.5991	2.2179	3.4263	0.4677	2.1381
2.60	0.5039	7.7200	2.2383	3.4490	0.4601	2.1733
2.62	0.5022	7.8418	2.2590	3.4714	0.4526	2.2093
2.64	0.5005	7.9645	2.2797	3.4937	0.4452	2.2461
2.66	0.4988	8.0882	2.3006	3.5157	0.4379	2.2835
2.68	0.4972	8.2128	2.3217	3.5374	0.4307	2.3218
2.70	0.4956	8.3383	2.3429	3.5590	0.4236	2.3608
2.72	0.4941	8.4648	2.3642	3.5803	0.4166	2.4005
2.74	0.4926	8.5922	2.3858	3.6015	0.4097	2.4411
2.76	0.4911	8.7205	2.4074	3.6224	0.4028	2.4825
2.78	0.4896	8.8498	2.4292	3.6431	0.3961	2.5246
2.80	0.4882	8.9800	2.4512	3.6636	0.3895	2.5676
2.82	0.4868	9.1111	2.4733	3.6838	0.3829	2.6115
2.84	0.4854	9.2432	2.4955	3.7039	0.3765	2.6561
2.86	0.4840	9.3762	2.5179	3.7238	0.3701	2.7017
2.88	0.4827	9.5101	2.5405	3.7434	0.3639	2.7481
2.90	0.4814	9.6450	2.5632	3.7629	0.3577	2.7954
2.92	0.4801	9.7808	2.5861	3.7821	0.3517	2.8436
2.94	0.4788	9.9175	2.6091	3.8012	0.3457	2.8927
2.96	0.4776	10.0552	2.6322	3.8200	0.3398	2.9427
2.98	0.4764	10.1938	2.6555	3.8387	0.3340	2.9937
3.00	0.4752	10.3333	2.6790	3.8571	0.3283	3.0456

Normal Shock Table for $\gamma = 1.4$

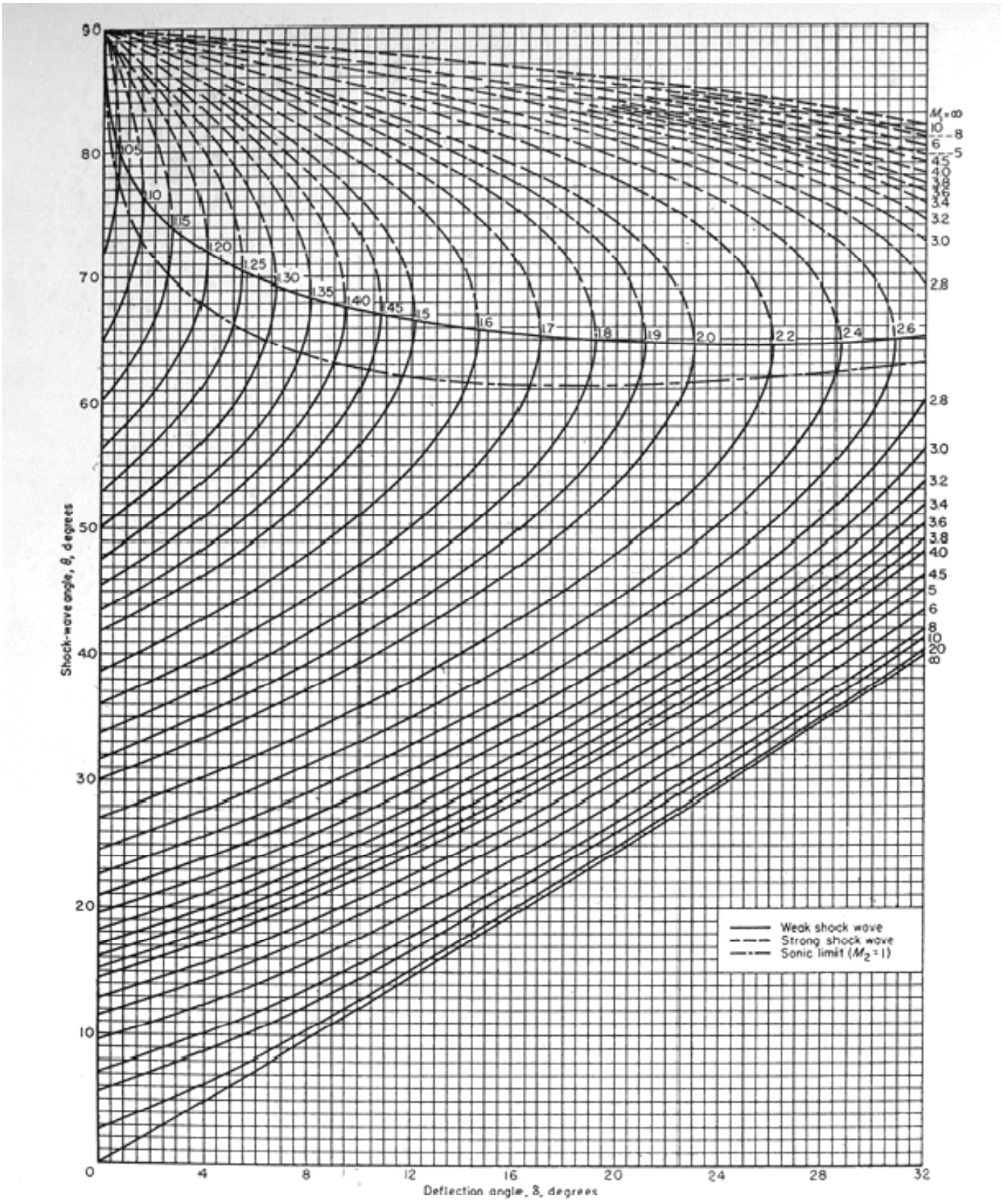
For oblique shocks tabulated values are M_{n1}, M_{n2}

M_1	M_2	p_2/p_1	T_2/T_1	ρ_2/ρ_1	p_{O2}/p_{O1}	A_2^*/A_1^*
3.00	0.4752	10.3333	2.6790	3.8571	0.3283	3.0456
3.02	0.4740	10.4738	2.7026	3.8754	0.3227	3.0985
3.04	0.4729	10.6152	2.7264	3.8935	0.3172	3.1523
3.06	0.4717	10.7575	2.7503	3.9114	0.3118	3.2072
3.08	0.4706	10.9008	2.7744	3.9291	0.3065	3.2630
3.10	0.4695	11.0450	2.7986	3.9466	0.3012	3.3199
3.12	0.4685	11.1901	2.8230	3.9639	0.2960	3.3778
3.14	0.4674	11.3362	2.8475	3.9811	0.2910	3.4368
3.16	0.4664	11.4832	2.8722	3.9981	0.2860	3.4969
3.18	0.4654	11.6311	2.8970	4.0149	0.2811	3.5580
3.20	0.4643	11.7800	2.9220	4.0315	0.2762	3.6202
3.22	0.4634	11.9298	2.9471	4.0479	0.2715	3.6835
3.24	0.4624	12.0805	2.9724	4.0642	0.2668	3.7480
3.26	0.4614	12.2322	2.9979	4.0803	0.2622	3.8136
3.28	0.4605	12.3848	3.0234	4.0963	0.2577	3.8803
3.30	0.4596	12.5383	3.0492	4.1120	0.2533	3.9483
3.32	0.4587	12.6928	3.0751	4.1276	0.2489	4.0174
3.34	0.4578	12.8482	3.1011	4.1431	0.2446	4.0877
3.36	0.4569	13.0045	3.1273	4.1583	0.2404	4.1593
3.38	0.4560	13.1618	3.1537	4.1734	0.2363	4.2321
3.40	0.4552	13.3200	3.1802	4.1884	0.2322	4.3062
3.42	0.4544	13.4791	3.2069	4.2032	0.2282	4.3815
3.44	0.4535	13.6392	3.2337	4.2179	0.2243	4.4581
3.46	0.4527	13.8002	3.2607	4.2323	0.2205	4.5361
3.48	0.4519	13.9621	3.2878	4.2467	0.2167	4.6154
3.50	0.4512	14.1250	3.3151	4.2609	0.2129	4.6960
3.52	0.4504	14.2888	3.3425	4.2749	0.2093	4.7780
3.54	0.4496	14.4535	3.3701	4.2888	0.2057	4.8614
3.56	0.4489	14.6192	3.3978	4.3026	0.2022	4.9461
3.58	0.4481	14.7858	3.4257	4.3162	0.1987	5.0324
3.60	0.4474	14.9533	3.4537	4.3296	0.1953	5.1200
3.62	0.4467	15.1218	3.4819	4.3429	0.1920	5.2091
3.64	0.4460	15.2912	3.5103	4.3561	0.1887	5.2997
3.66	0.4453	15.4615	3.5388	4.3692	0.1855	5.3918
3.68	0.4446	15.6328	3.5674	4.3821	0.1823	5.4854
3.70	0.4439	15.8050	3.5962	4.3949	0.1792	5.5806
3.72	0.4433	15.9781	3.6252	4.4075	0.1761	5.6773
3.74	0.4426	16.1522	3.6543	4.4200	0.1731	5.7756
3.76	0.4420	16.3272	3.6836	4.4324	0.1702	5.8755
3.78	0.4414	16.5031	3.7130	4.4447	0.1673	5.9770
3.80	0.4407	16.6800	3.7426	4.4568	0.1645	6.0801
3.82	0.4401	16.8578	3.7723	4.4688	0.1617	6.1849
3.84	0.4395	17.0365	3.8022	4.4807	0.1589	6.2915
3.86	0.4389	17.2162	3.8323	4.4924	0.1563	6.3997
3.88	0.4383	17.3968	3.8625	4.5041	0.1536	6.5096
3.90	0.4377	17.5783	3.8928	4.5156	0.1510	6.6213
3.92	0.4372	17.7608	3.9233	4.5270	0.1485	6.7348
3.94	0.4366	17.9442	3.9540	4.5383	0.1460	6.8501
3.96	0.4360	18.1285	3.9848	4.5494	0.1435	6.9672
3.98	0.4355	18.3138	4.0158	4.5605	0.1411	7.0861
4.00	0.4350	18.5000	4.0469	4.5714	0.1388	7.2069

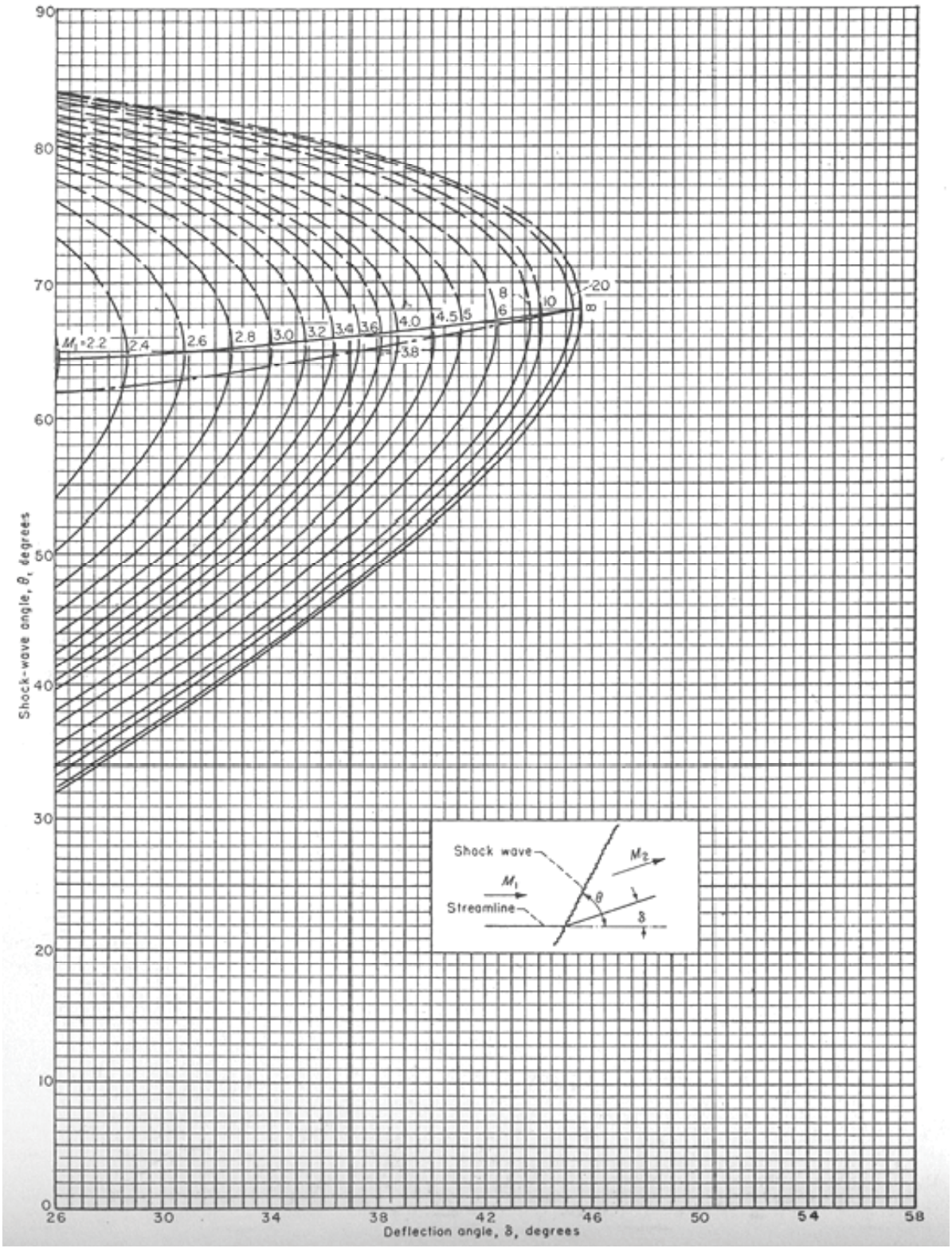
Normal Shock Table for $\gamma = 1.4$

For oblique shocks tabulated values are M_{n1}, M_{n2}

M_1	M_2	p_2/p_1	T_2/T_1	ρ_2/ρ_1	p_{O2}/p_{O1}	A_2^*/A_1^*
4.00	0.4350	18.5000	4.0469	4.5714	0.1388	7.2069
4.05	0.4336	18.9696	4.1254	4.5983	0.1330	7.5172
4.10	0.4324	19.4450	4.2048	4.6245	0.1276	7.8397
4.15	0.4311	19.9263	4.2852	4.6500	0.1223	8.1747
4.20	0.4299	20.4133	4.3666	4.6749	0.1173	8.5227
4.25	0.4288	20.9063	4.4489	4.6992	0.1126	8.8840
4.30	0.4277	21.4050	4.5322	4.7229	0.1080	9.2591
4.35	0.4266	21.9096	4.6165	4.7460	0.1036	9.6484
4.40	0.4255	22.4200	4.7017	4.7685	9.948 E-02	10.0522
4.45	0.4245	22.9363	4.7879	4.7904	9.550 E-02	10.4711
4.50	0.4236	23.4583	4.8751	4.8119	9.170 E-02	10.9054
4.55	0.4226	23.9862	4.9632	4.8328	8.806 E-02	11.3556
4.60	0.4217	24.5200	5.0523	4.8532	8.459 E-02	11.8222
4.65	0.4208	25.0596	5.1424	4.8731	8.126 E-02	12.3057
4.70	0.4199	25.6050	5.2334	4.8926	7.809 E-02	12.8065
4.75	0.4191	26.1563	5.3254	4.9116	7.505 E-02	13.3251
4.80	0.4183	26.7133	5.4184	4.9301	7.214 E-02	13.8620
4.85	0.4175	27.2762	5.5124	4.9482	6.936 E-02	14.4177
4.90	0.4167	27.8450	5.6073	4.9659	6.670 E-02	14.9928
4.95	0.4160	28.4196	5.7032	4.9831	6.415 E-02	15.5878
5.00	0.4152	29.0000	5.8000	5.0000	6.172 E-02	16.2032
5.10	0.4138	30.1783	5.9966	5.0326	5.715 E-02	17.4974
5.20	0.4125	31.3800	6.1971	5.0637	5.297 E-02	18.8801
5.30	0.4113	32.6050	6.4014	5.0934	4.913 E-02	20.3558
5.40	0.4101	33.8533	6.6097	5.1218	4.560 E-02	21.9296
5.50	0.4090	35.1250	6.8218	5.1489	4.236 E-02	23.6064
5.60	0.4079	36.4200	7.0378	5.1749	3.938 E-02	25.3915
5.70	0.4069	37.7383	7.2577	5.1998	3.664 E-02	27.2902
5.80	0.4059	39.0800	7.4814	5.2236	3.412 E-02	29.3083
5.90	0.4050	40.4450	7.7091	5.2464	3.179 E-02	31.4515
6.00	0.4042	41.8333	7.9406	5.2683	2.965 E-02	33.7257
6.20	0.4025	44.6800	8.4153	5.3094	2.584 E-02	38.6924
6.40	0.4011	47.6200	8.9055	5.3473	2.259 E-02	44.2603
6.60	0.3997	50.6533	9.4113	5.3822	1.981 E-02	50.4846
6.80	0.3985	53.7800	9.9326	5.4145	1.741 E-02	57.4238
7.00	0.3974	57.0000	10.4694	5.4444	1.535 E-02	65.1403
7.20	0.3963	60.3133	11.0218	5.4722	1.357 E-02	73.6997
7.40	0.3954	63.7200	11.5897	5.4980	1.202 E-02	83.1716
7.60	0.3945	67.2200	12.1732	5.5220	1.068 E-02	93.6294
7.80	0.3937	70.8133	12.7722	5.5443	9.510 E-03	105.1503
8.00	0.3929	74.5000	13.3867	5.5652	8.488 E-03	117.8157
8.20	0.3922	78.2800	14.0168	5.5847	7.592 E-03	131.7112
8.40	0.3915	82.1533	14.6625	5.6030	6.806 E-03	146.9266
8.60	0.3909	86.1200	15.3237	5.6201	6.114 E-03	163.5560
8.80	0.3903	90.1800	16.0004	5.6361	5.504 E-03	181.6981
9.00	0.3898	94.3333	16.6927	5.6512	4.964 E-03	201.4562
9.20	0.3893	98.5800	17.4006	5.6653	4.486 E-03	222.9381
9.40	0.3888	102.9200	18.1240	5.6787	4.061 E-03	246.2567
9.60	0.3884	107.3533	18.8629	5.6912	3.683 E-03	271.5295
9.80	0.3880	111.8800	19.6174	5.7031	3.346 E-03	298.8794
10.00	0.3876	116.5000	20.3875	5.7143	3.045 E-03	328.4339


Shock-wave angle, β, degrees
Deflection angle, δ, degrees
0
10
20
30
40
50
60
70
80
90
4
8
12
16
20
24
28
32
1.05
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.5
1.6
1.7
1.8
1.9
2.0
2.2
2.4
2.6
M1=∞
10
8
6
5
4.5
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.5
5
6
8
10
20
∞
Weak shock wave
Strong shock wave
Sonic limit (M2 = 1)

OBLIQUE SHOCK PROPERTIES: $\gamma = 1.4$



Prandtl-Meyer Table for $\gamma = 1.4$

M	ν	α	M	ν	α	M	ν	α
1.00	0.0000	90.000	2.00	26.380	30.000	3.00	49.757	19.471
1.02	0.1257	78.635	2.02	26.930	29.673	3.05	50.713	19.139
1.04	0.3510	74.058	2.04	27.476	29.353	3.10	51.650	18.819
1.06	0.6367	70.630	2.06	28.020	29.041	3.15	52.569	18.509
1.08	0.9680	67.808	2.08	28.560	28.736	3.20	53.470	18.210
1.10	1.3362	65.380	2.10	29.097	28.437	3.25	54.355	17.920
1.12	1.7350	63.234	2.12	29.631	28.145	3.30	55.222	17.640
1.14	2.1600	61.306	2.14	30.161	27.859	3.35	56.073	17.368
1.16	2.6073	59.550	2.16	30.688	27.578	3.40	56.908	17.105
1.18	3.0743	57.936	2.18	31.212	27.304	3.45	57.726	16.849
1.20	3.5582	56.443	2.20	31.732	27.036	3.50	58.530	16.602
1.22	4.0572	55.052	2.22	32.249	26.773	3.55	59.318	16.361
1.24	4.5694	53.751	2.24	32.763	26.515	3.60	60.091	16.128
1.26	5.0931	52.528	2.26	33.273	26.262	3.65	60.850	15.901
1.28	5.6272	51.375	2.28	33.780	26.014	3.70	61.595	15.680
1.30	6.1703	50.285	2.30	34.283	25.771	3.75	62.326	15.466
1.32	6.7213	49.251	2.32	34.782	25.533	3.80	63.044	15.258
1.34	7.2794	48.268	2.34	35.279	25.300	3.85	63.748	15.055
1.36	7.8435	47.332	2.36	35.771	25.070	3.90	64.440	14.857
1.38	8.4130	46.439	2.38	36.261	24.845	3.95	65.118	14.665
1.40	8.9870	45.585	2.40	36.747	24.624	4.00	65.785	14.478
1.42	9.5650	44.767	2.42	37.229	24.407	4.05	66.439	14.295
1.44	10.146	43.983	2.44	37.708	24.195	4.10	67.082	14.117
1.46	10.731	43.230	2.46	38.183	23.985	4.15	67.713	13.943
1.48	11.317	42.507	2.48	38.655	23.780	4.20	68.333	13.774
1.50	11.905	41.810	2.50	39.124	23.578	4.25	68.942	13.609
1.52	12.495	41.140	2.52	39.589	23.380	4.30	69.541	13.448
1.54	13.086	40.493	2.54	40.050	23.185	4.35	70.129	13.290
1.56	13.677	39.868	2.56	40.508	22.993	4.40	70.706	13.137
1.58	14.269	39.265	2.58	40.963	22.805	4.45	71.274	12.986
1.60	14.860	38.682	2.60	41.415	22.620	4.50	71.832	12.840
1.62	15.452	38.118	2.62	41.863	22.438	4.55	72.380	12.696
1.64	16.043	37.572	2.64	42.307	22.259	4.60	72.919	12.556
1.66	16.633	37.043	2.66	42.749	22.082	4.65	73.449	12.419
1.68	17.222	36.530	2.68	43.187	21.909	4.70	73.970	12.284
1.70	17.810	36.032	2.70	43.621	21.738	4.75	74.482	12.153
1.72	18.396	35.549	2.72	44.053	21.571	4.80	74.986	12.025
1.74	18.981	35.080	2.74	44.481	21.405	4.85	75.482	11.899
1.76	19.565	34.624	2.76	44.906	21.243	4.90	75.969	11.776
1.78	20.146	34.180	2.78	45.327	21.083	4.95	76.449	11.655
1.80	20.725	33.749	2.80	45.746	20.925	5.00	76.920	11.537
1.82	21.302	33.329	2.82	46.161	20.770	5.10	77.841	11.308
1.84	21.877	32.921	2.84	46.573	20.617	5.20	78.732	11.087
1.86	22.449	32.523	2.86	46.982	20.466	5.30	79.596	10.876
1.88	23.019	32.135	2.88	47.388	20.318	5.40	80.433	10.672
1.90	23.586	31.757	2.90	47.790	20.171	5.50	81.245	10.476
1.92	24.151	31.388	2.92	48.190	20.027	5.60	82.032	10.287
1.94	24.712	31.028	2.94	48.586	19.885	5.70	82.796	10.104
1.96	25.271	30.677	2.96	48.980	19.745	5.80	83.537	9.928
1.98	25.827	30.335	2.98	49.370	19.607	5.90	84.256	9.758
2.00	26.380	30.000	3.00	49.757	19.471	6.00	84.955	9.594

Rayleigh Flow Table for $\gamma = 1.4$

Philip L. Varghese

Frictionless Flow with exoergic or endoergic reactions or heat transfer

Note: $\rho/\rho^* = V^*/V = \frac{p/p^*}{T/T^*}$

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*
0.00	0.000 E+00	0.000 E+00	2.4000	1.2679	1.00	1.0000	1.0000	1.0000	1.0000
0.02	1.918 E-03	2.301 E-03	2.3987	1.2675	1.02	0.9997	0.9930	0.9770	1.0002
0.04	7.648 E-03	9.175 E-03	2.3946	1.2665	1.04	0.9989	0.9855	0.9546	1.0008
0.06	1.712 E-02	2.053 E-02	2.3880	1.2647	1.06	0.9977	0.9776	0.9327	1.0017
0.08	3.022 E-02	3.621 E-02	2.3787	1.2623	1.08	0.9960	0.9691	0.9115	1.0031
0.10	4.678 E-02	5.602 E-02	2.3669	1.2591	1.10	0.9939	0.9603	0.8909	1.0049
0.12	6.661 E-02	7.970 E-02	2.3526	1.2554	1.12	0.9915	0.9512	0.8708	1.0070
0.14	8.947 E-02	0.1069	2.3359	1.2510	1.14	0.9887	0.9417	0.8512	1.0095
0.16	0.1151	0.1374	2.3170	1.2461	1.16	0.9856	0.9320	0.8322	1.0124
0.18	0.1432	0.1708	2.2959	1.2406	1.18	0.9823	0.9220	0.8137	1.0157
0.20	0.1736	0.2066	2.2727	1.2346	1.20	0.9787	0.9118	0.7958	1.0194
0.22	0.2057	0.2445	2.2477	1.2281	1.22	0.9749	0.9015	0.7783	1.0235
0.24	0.2395	0.2841	2.2209	1.2213	1.24	0.9709	0.8911	0.7613	1.0279
0.26	0.2745	0.3250	2.1925	1.2140	1.26	0.9668	0.8805	0.7447	1.0328
0.28	0.3104	0.3667	2.1626	1.2064	1.28	0.9624	0.8699	0.7287	1.0380
0.30	0.3469	0.4089	2.1314	1.1985	1.30	0.9580	0.8592	0.7130	1.0437
0.32	0.3837	0.4512	2.0991	1.1904	1.32	0.9534	0.8484	0.6978	1.0497
0.34	0.4206	0.4933	2.0657	1.1822	1.34	0.9487	0.8377	0.6830	1.0561
0.36	0.4572	0.5348	2.0314	1.1737	1.36	0.9440	0.8269	0.6686	1.0629
0.38	0.4935	0.5755	1.9964	1.1652	1.38	0.9391	0.8161	0.6546	1.0701
0.40	0.5290	0.6151	1.9608	1.1566	1.40	0.9343	0.8054	0.6410	1.0777
0.42	0.5638	0.6535	1.9247	1.1480	1.42	0.9293	0.7947	0.6278	1.0856
0.44	0.5975	0.6903	1.8882	1.1394	1.44	0.9243	0.7840	0.6149	1.0940
0.46	0.6301	0.7254	1.8515	1.1308	1.46	0.9193	0.7735	0.6024	1.1028
0.48	0.6614	0.7587	1.8147	1.1224	1.48	0.9143	0.7629	0.5902	1.1120
0.50	0.6914	0.7901	1.7778	1.1141	1.50	0.9093	0.7525	0.5783	1.1215
0.52	0.7199	0.8196	1.7409	1.1059	1.52	0.9042	0.7422	0.5668	1.1315
0.54	0.7470	0.8469	1.7043	1.0979	1.54	0.8992	0.7319	0.5555	1.1419
0.56	0.7725	0.8723	1.6678	1.0901	1.56	0.8942	0.7217	0.5446	1.1527
0.58	0.7965	0.8955	1.6316	1.0826	1.58	0.8892	0.7117	0.5339	1.1640
0.60	0.8189	0.9167	1.5957	1.0753	1.60	0.8842	0.7017	0.5236	1.1756
0.62	0.8398	0.9358	1.5603	1.0682	1.62	0.8792	0.6919	0.5135	1.1877
0.64	0.8592	0.9530	1.5253	1.0615	1.64	0.8743	0.6822	0.5036	1.2002
0.66	0.8771	0.9682	1.4908	1.0550	1.66	0.8694	0.6726	0.4940	1.2131
0.68	0.8935	0.9814	1.4569	1.0489	1.68	0.8645	0.6631	0.4847	1.2264
0.70	0.9085	0.9929	1.4235	1.0431	1.70	0.8597	0.6538	0.4756	1.2402
0.72	0.9221	1.0026	1.3907	1.0376	1.72	0.8549	0.6445	0.4668	1.2545
0.74	0.9344	1.0106	1.3585	1.0325	1.74	0.8502	0.6355	0.4581	1.2692
0.76	0.9455	1.0171	1.3270	1.0278	1.76	0.8455	0.6265	0.4497	1.2843
0.78	0.9553	1.0220	1.2961	1.0234	1.78	0.8409	0.6176	0.4415	1.2999
0.80	0.9639	1.0255	1.2658	1.0193	1.80	0.8363	0.6089	0.4335	1.3159
0.82	0.9715	1.0276	1.2362	1.0157	1.82	0.8317	0.6004	0.4257	1.3324
0.84	0.9781	1.0285	1.2073	1.0124	1.84	0.8273	0.5919	0.4181	1.3494
0.86	0.9836	1.0283	1.1791	1.0095	1.86	0.8228	0.5836	0.4107	1.3669
0.88	0.9883	1.0269	1.1515	1.0070	1.88	0.8185	0.5754	0.4035	1.3849
0.90	0.9921	1.0245	1.1246	1.0049	1.90	0.8141	0.5673	0.3964	1.4033
0.92	0.9951	1.0212	1.0984	1.0031	1.92	0.8099	0.5594	0.3895	1.4222
0.94	0.9973	1.0170	1.0728	1.0017	1.94	0.8057	0.5516	0.3828	1.4417
0.96	0.9988	1.0121	1.0479	1.0008	1.96	0.8015	0.5439	0.3763	1.4616
0.98	0.9997	1.0064	1.0236	1.0002	1.98	0.7974	0.5364	0.3699	1.4821
1.00	1.0000	1.0000	1.0000	1.0000	2.00	0.7934	0.5289	0.3636	1.5031

Rayleigh Flow Table for $\gamma = 1.4$

Frictionless Flow with exoergic or endoergic reactions or heat transfer

Note: $\rho/\rho^* = V^*/V = \dfrac{p/p^*}{T/T^*}$

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*
2.00	0.7934	0.5289	0.3636	1.5031	3.00	0.6540	0.2803	0.1765	3.4245
2.02	0.7894	0.5216	0.3575	1.5246	3.02	0.6522	0.2771	0.1743	3.4854
2.04	0.7855	0.5144	0.3516	1.5467	3.04	0.6504	0.2740	0.1722	3.5476
2.06	0.7816	0.5074	0.3458	1.5693	3.06	0.6486	0.2709	0.1701	3.6108
2.08	0.7778	0.5004	0.3401	1.5924	3.08	0.6469	0.2679	0.1681	3.6752
2.10	0.7741	0.4936	0.3345	1.6162	3.10	0.6452	0.2650	0.1660	3.7408
2.12	0.7704	0.4868	0.3291	1.6404	3.12	0.6435	0.2620	0.1641	3.8076
2.14	0.7667	0.4802	0.3238	1.6653	3.14	0.6418	0.2592	0.1621	3.8756
2.16	0.7631	0.4737	0.3186	1.6908	3.16	0.6402	0.2563	0.1602	3.9449
2.18	0.7596	0.4673	0.3136	1.7168	3.18	0.6386	0.2535	0.1583	4.0154
2.20	0.7561	0.4611	0.3086	1.7434	3.20	0.6370	0.2508	0.1565	4.0871
2.22	0.7527	0.4549	0.3038	1.7707	3.22	0.6354	0.2481	0.1547	4.1602
2.24	0.7493	0.4488	0.2991	1.7986	3.24	0.6339	0.2454	0.1529	4.2345
2.26	0.7460	0.4428	0.2945	1.8271	3.26	0.6324	0.2428	0.1511	4.3101
2.28	0.7428	0.4370	0.2899	1.8562	3.28	0.6309	0.2402	0.1494	4.3871
2.30	0.7395	0.4312	0.2855	1.8860	3.30	0.6294	0.2377	0.1477	4.4655
2.32	0.7364	0.4256	0.2812	1.9165	3.32	0.6280	0.2352	0.1461	4.5452
2.34	0.7333	0.4200	0.2769	1.9476	3.34	0.6265	0.2327	0.1444	4.6263
2.36	0.7302	0.4145	0.2728	1.9794	3.36	0.6251	0.2303	0.1428	4.7089
2.38	0.7272	0.4091	0.2688	2.0119	3.38	0.6237	0.2279	0.1412	4.7929
2.40	0.7242	0.4038	0.2648	2.0451	3.40	0.6224	0.2255	0.1397	4.8783
2.42	0.7213	0.3986	0.2609	2.0789	3.42	0.6210	0.2232	0.1381	4.9652
2.44	0.7184	0.3935	0.2571	2.1136	3.44	0.6197	0.2209	0.1366	5.0536
2.46	0.7156	0.3885	0.2534	2.1489	3.46	0.6184	0.2186	0.1351	5.1435
2.48	0.7128	0.3836	0.2497	2.1850	3.48	0.6171	0.2164	0.1337	5.2350
2.50	0.7101	0.3787	0.2462	2.2218	3.50	0.6158	0.2142	0.1322	5.3280
2.52	0.7074	0.3739	0.2427	2.2594	3.52	0.6145	0.2120	0.1308	5.4226
2.54	0.7047	0.3692	0.2392	2.2978	3.54	0.6133	0.2099	0.1294	5.5188
2.56	0.7021	0.3646	0.2359	2.3370	3.56	0.6121	0.2078	0.1280	5.6167
2.58	0.6995	0.3601	0.2326	2.3770	3.58	0.6109	0.2057	0.1267	5.7162
2.60	0.6970	0.3556	0.2294	2.4177	3.60	0.6097	0.2037	0.1254	5.8173
2.62	0.6945	0.3512	0.2262	2.4593	3.62	0.6085	0.2017	0.1241	5.9201
2.64	0.6921	0.3469	0.2231	2.5018	3.64	0.6074	0.1997	0.1228	6.0247
2.66	0.6896	0.3427	0.2201	2.5451	3.66	0.6062	0.1977	0.1215	6.1310
2.68	0.6873	0.3385	0.2171	2.5892	3.68	0.6051	0.1958	0.1202	6.2390
2.70	0.6849	0.3344	0.2142	2.6343	3.70	0.6040	0.1939	0.1190	6.3488
2.72	0.6826	0.3304	0.2113	2.6802	3.72	0.6029	0.1920	0.1178	6.4605
2.74	0.6804	0.3264	0.2085	2.7270	3.74	0.6018	0.1902	0.1166	6.5739
2.76	0.6781	0.3225	0.2058	2.7748	3.76	0.6008	0.1884	0.1154	6.6893
2.78	0.6760	0.3186	0.2030	2.8235	3.78	0.5997	0.1866	0.1143	6.8065
2.80	0.6738	0.3149	0.2004	2.8731	3.80	0.5987	0.1848	0.1131	6.9256
2.82	0.6717	0.3111	0.1978	2.9237	3.82	0.5977	0.1830	0.1120	7.0466
2.84	0.6696	0.3075	0.1953	2.9752	3.84	0.5967	0.1813	0.1109	7.1696
2.86	0.6675	0.3039	0.1927	3.0278	3.86	0.5957	0.1796	0.1098	7.2945
2.88	0.6655	0.3004	0.1903	3.0813	3.88	0.5947	0.1779	0.1087	7.4215
2.90	0.6635	0.2969	0.1879	3.1359	3.90	0.5937	0.1763	0.1077	7.5505
2.92	0.6615	0.2934	0.1855	3.1914	3.92	0.5928	0.1746	0.1066	7.6816
2.94	0.6596	0.2901	0.1832	3.2481	3.94	0.5918	0.1730	0.1056	7.8147
2.96	0.6577	0.2868	0.1809	3.3058	3.96	0.5909	0.1714	0.1046	7.9499
2.98	0.6558	0.2835	0.1787	3.3646	3.98	0.5900	0.1699	0.1036	8.0873
3.00	0.6540	0.2803	0.1765	3.4245	4.00	0.5891	0.1683	0.1026	8.2268