Mechanical Engineering

MCEN90008 Fluid Dynamics

End of semester 2 2020

Exam Commencement Time:

- This exam starts on 23/11/2020 15:00 and ends on 23/11/2020 18:15 (Melbourne time)

Exam Duration:

- **Recommended Reading Time:** [15] minutes
- **Recommended Writing Time:** [180] minutes

Submission Time: [30] minutes to scan and upload

Exam Submission:

- You must upload your examination answer scripts by 23/11/2020 18:45 (Melbourne time)

All students must connect to the Zoom meeting. All exam-related announcements will be made via zoom. If you experience internet problems, you must inform the examiner via zoom using the phone option.

Zoom meeting detail:

Link: https://unimelb.zoom.us/j/84868893609?pwd=MUgvdm8rbm05aGlWc08zSDRyU3hzUT09

Zoom meeting ID: 848 6889 3609 with password MCEN90008

Or join by phone:

Dial (Australia): +61 3 7018 2005 or +61 2 8015 6011
Dial (US): +1 669 900 6833 or +1 646 876 9923
Dial (Hong Kong, China): +852 5808 6088 or +852 5803 3730
Dial (UK): +44 203 481 5240 or +44 131 460 1196
International numbers available: https://unimelb.zoom.us/u/azLaaCtom

Examiner availability:

Your examiner and exam supervisor team will be available online via **Zoom** for the duration of the exam.

Issues & Concerns:

If you run into any issues uploading your responses, inform the lecturer / exam supervising team immediately**, before the end of the Submission time**.

Exam format and instructions:

There will be three questions for unit 1 (potential flow) and three questions for unit 2 (compressible flow). Students should attempt all questions. Each question is worth 10 marks.

- Total marks available for this exam is [60]
- Attempt all questions.
- All answers must be hand-written and show your own working for each question.
- Write legibly, preferably in blue or black pen
- Ensure your student number is written on each answer page that you upload
- Number each page prior to submission to indicate the order of the pages
- Responses should be compiled into a single PDF document

Authorised Materials

This is an Open Book exam, which means that you will be allowed to use notes or textbooks during the exam. However, interaction with other persons outside of the teaching staff supervising the exam is strictly prohibited during the examination and is a breach of the University's Academic Integrity Policy. Any evidence

of collusion will be investigated as potential academic misconduct. The Academic Integrity policy can be found at: https://academicintegrity.unimelb.edu.au/

The following materials are permitted:

- Any material loaded onto Canvas as part of the subject content
- Your own notes (printed, hand-written, and digital/electronic)
- Textbooks
- Online books and materials
- Language dictionaries
- Calculators (any model),
- Computers, electronic tablets, blank paper, pens, rulers, etc.

Academic Integrity

Collusion is not allowed under any circumstances. Collusion includes, but is not limited to, talking to, phoning, emailing, texting or using the internet to communicate with other students. Similarly, you cannot communicate with any other person via any means about the content of this exam during the examination time. If another student contacts you during the examination period, please inform the subject coordinator immediately.

Plagiarism/copying is not allowed under any circumstances. Your answers to the exam must be in your own words and not directly copied from lecture notes, tutorial materials, the internet or study notes you have prepared with your friends. You may refer to sources, but answers should be written in your own words. This also applies to programming (code) related answers. Code must be written on your own displaying originality in the content.

Any similarity detected between your answers, the answers from other students and/or from the internet or other sources will be investigated and may result in severe penalties

Academic Integrity Declaration

By commencing and/or submitting this assessment I agree that I have read and understood the University's policy on academic integrity. Links to an external site.

I also agree that:

1. The work I submit will be original and solely my own work (cheating);
2. I will not use any sources without proper acknowledgment or referencing (plagiarism).
3. Where the work I submit is a computer program or code, I will ensure that:
    1. any code I have copied is clearly noted by identifying the source of that code at the start of the program or in a header file or, that comments inline identify the start and end of the copied code; and
    2. any modifications to code sourced from elsewhere will be commented upon to show the nature of the modification.

Unit A - Potential Flow

Attempt all questions in this section.

Question A1考手微信risepaper

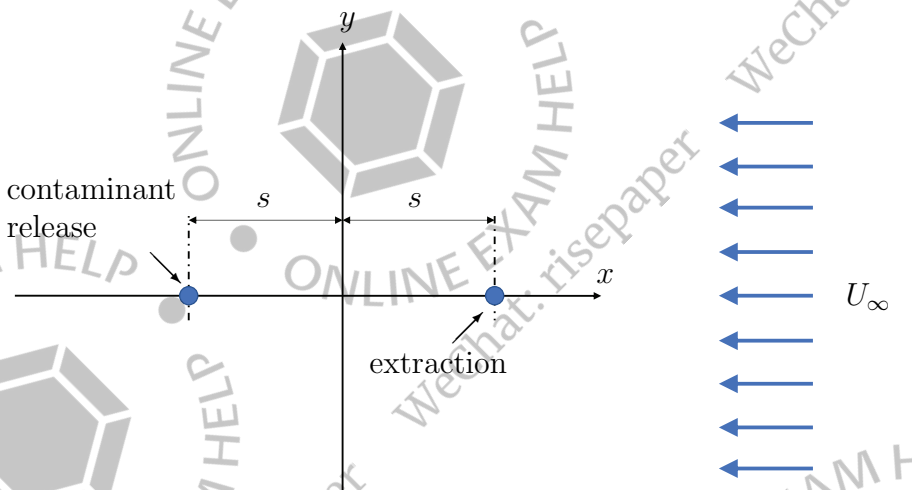

Figure A1

A contaminant is released into a uniform oncoming flow of 0.5 ms^{-1} as depicted in figure A1. Containment is attempted (perhaps unwisely) in the form of an extraction fan located 2m upstream of the contaminant release.

(a) Modelling the contaminant release and extraction using a source and a sink both with volume flow rate $Q = \pi$, derive an expression for the location of the stagnation points **(4 marks)**

(b) If the volume flow rate remains the same as part (a), but the freestream velocity doubles, find the location of the stagnation points. **(1 marks)**

(c) In this case, prove that the equation of the separatrix that contains the contaminant is described by,

$$x = \pm\sqrt{s^2 - y^2 - 2ys\cot\left(\frac{2\pi U_\infty y}{Q}\right)}$$

you may make use of the relationship,

$$\arctan(A) - \arctan(B) = \arctan\left(\frac{A-B}{1+AB}\right)$$

(2 marks)

(d) Compare this to the separatrix for the case with no extraction, but the same Q and U_∞ as parts (b) and (c). By considering the width of the separatrix (in y) at $x = -\infty$, which case has the narrower contamination region?. **(3 marks)**

Question A2

The complex potential function for a Uniform flow (from right to left) and Doublet (anti-clockwise on top, clockwise on bottom) is given by,

$$w = -U_\infty z - \frac{K}{\pi z}$$

Where K is a positive constant.

(a) Working purely in terms of the complex potential function, demonstrate that the stagnation points are located on the x axis at

$$x = \pm\sqrt{\frac{K}{U_\infty \pi}}$$

(3 marks)

(b) Assuming that the separatrix is a circle passing through the stagnation point given above, derive an expression for the pressure coefficient C_p on the separatrix and find the azimuthal locations where $C_p = 0$ and 1. **(3 marks)**

(c) The conformal transformation for rotation in the counter-clockwise direction is given by $z_1 = ze^{i\alpha}$. This transformation will transform the flow over a cylinder with flow from right to left (in the z plane) into the flow over a cylinder with flow from top to bottom (in the z_1 plane) when $\alpha = \pi/2$. Demonstrate that in this case the magnitude of the velocity on the surface of the transformed cylinder is given by,

$$V_1 = 2U_\infty \cos\theta_1$$

(4 marks)

Question A3

(a) Two potential vortices are located at (0,d) and (0,$-d$) with circulation strength Γ, yet opposite signs (see figure A3 over the page). A uniform flow is also imposed from right to left. Given that the streamfunction for this flow is:

$$\psi = \frac{-\Gamma}{2\pi}\log\sqrt{(x^2+(y-d)^2)} + \frac{\Gamma}{2\pi}\log\sqrt{(x^2+(y+d)^2)} - U_\infty y$$

Find the required value of

$$\frac{\Gamma}{\pi U_\infty d}$$

To have stagnation points located at (x,y) = (0,$\pm d/2$)

(3 marks)

(*question continued over page*)

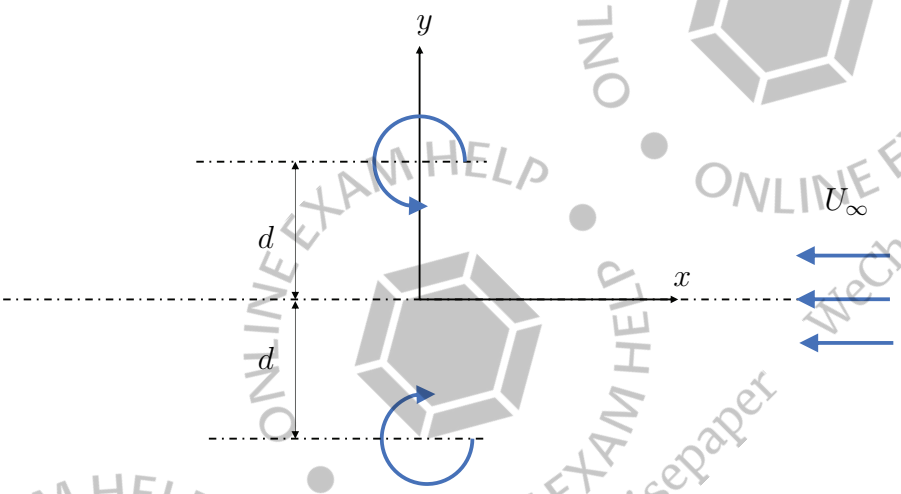

Figure A3

(b) If the relative strength of the vortex is now changed to,

$$\frac{\Gamma}{\pi U_\infty d} > 1$$

Find the location of the stagnation points. **(2 marks)**

(c) Now consider the same case, but where the vortices are free to move due to the flow-field. Derive an expression for the vortex strength Γ in terms of U_∞ and d if the vortices are to migrate upstream at a speed equal (and opposite) to the oncoming freestream flow. **(2 marks)**

(d) For the case considered in part (c), derive an equation for the time dependent closed separatrix (Kelvin oval) with x as a function of y, t, U_∞ and d, and where t is time. You may assume that the vortices are at $x = 0$ at time $t = 0$ **(3 marks)**

Unit B - Compressible Flow

Attempt all questions in this section. You may assume that $\gamma = 7/5$ throughout.

Question B1

Consider the converging-diverging nozzle shown in figure B1, fed from a pressure vessel with stagnation conditions as given and exhausting to atmosphere at sea level with $p_{atm} = 101$ kPa. The nozzle has a throat area of 0.0032 m^2, and an exit to throat area ratio $A_e/A_T = 8$.

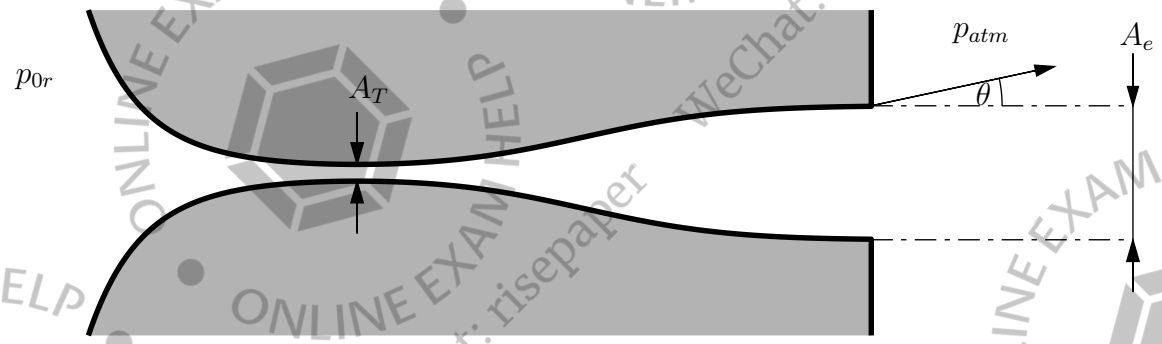

Figure B1

(a) Compute the required stagnation pressure in the vessel p_{0r} for the isentropic sonic solution (sonic conditions at the throat, but subsonic everywhere else) **(1 mark)**

(b) If the stagnation pressure in the vessel is $p_{0r} = 4p_{atm}$, compute which regime that the nozzle is operating in (i.e show whether the nozzle has shock in the nozzle, or is over- or under-expanded **(3 marks)**

(c) If, under the conditions given in (b), we require a mass flow rate of 3 kg s^{-1}, state the required stagnation density in the pressure vessel (ρ_{0r}). **(2 marks)**

State the exit flow angle θ as defined on figure B2 when the stagnation pressure in the pressure vessel is:

(d) $p_{0r} = 9882000$ Pa **(1 mark)**
(e) $p_{0r} = 20$ MPa **(3 marks)**

Question B2

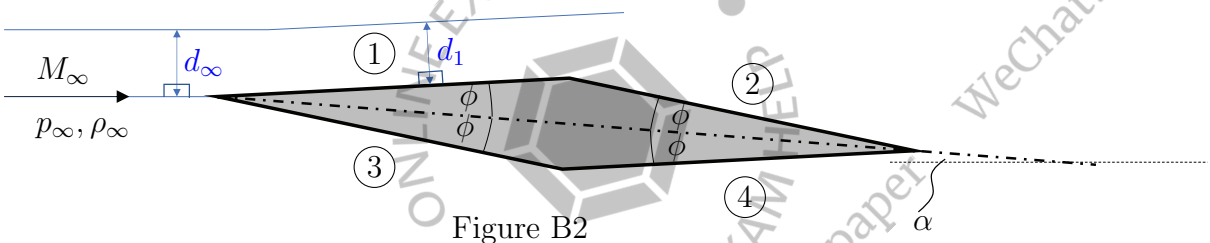

Figure B2

Consider the symmetrical airfoil shown in figure B2 under wind-tunnel testing. Pressure ratios (p/p_∞) are measured on regions 1 to 4, and the Mach number is measured in region 2. These results are given in the table below.

facet#	p/p_∞	M
1	1.3799	-
2	0.4524	3.0163
3	1.9745	-
4	0.7124	-

(a) Based on the measured data in the above table, compute M_1 (the Mach Number in region 1) **(1 mark)**

(b) Hence compute the angles ϕ and α and also the freestream Mach number M_∞ **(3 marks)**

(c) Hence, show that the lift coefficient for the airfoil can be given by $C_L = 0.0957$ **(2 marks)**

(d) Based on the tabulated data it can be shown that $C_D = 0.0403$. Based *only* on these given values of C_D and C_L, what would Ackeret's approximation (given below) suggest α and ϕ would be?

$$C_L = \frac{4\alpha}{\sqrt{M_\infty^2 - 1}}$$

$$C_D = \frac{4}{\sqrt{M_\infty^2 - 1}} \left\{ \alpha^2 + \overline{\left(\frac{dt}{dx}\right)^2} + \overline{\left(\frac{d\xi}{dx}\right)^2} \right\}$$

(3 marks)

(e) Consider the streamline shown in figure B1. Assuming that d_1 and d_2 are measured normal to the local flow direction, show that,

$$d_1 = d_\infty \left(\frac{M_\infty}{M_1}\right) \left(\frac{p_\infty}{p_1}\right)^{\frac{1}{2}} \left(\frac{\rho_\infty}{\rho_1}\right)^{\frac{1}{2}}$$

(1 marks)

Question B3

(a) For the airfoil shown in figure B2, using Ackeret approximation show analytically (i.e not through numerical solution) that the maximum lift-to-drag coefficient is given by,

$$\left.\frac{C_L}{C_D}\right|_{max} = \frac{1}{2\tan\phi}$$

(3 marks)

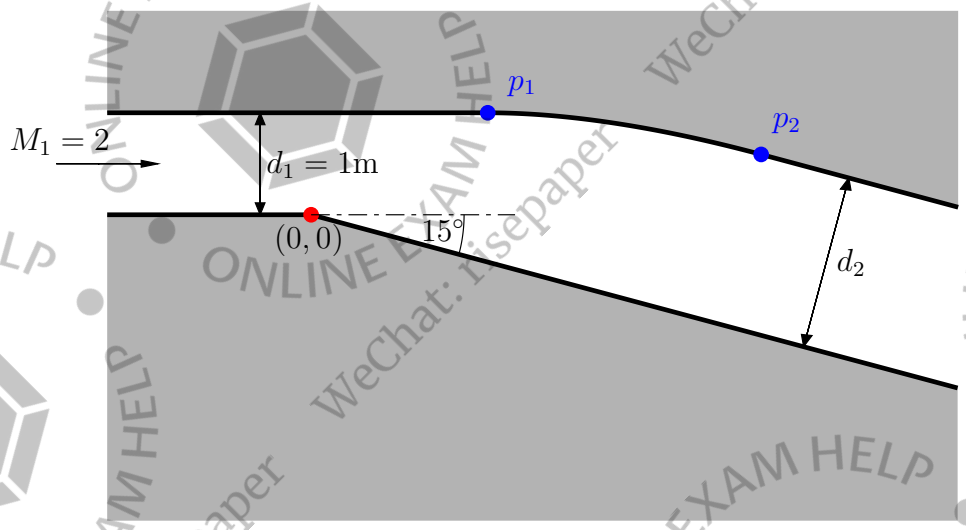

Figure B3

(b) Consider the duct shown above, where the curved upper surface is designed to prevent reflected waves. Show that the (x, y) coordinates of point p_1 (the start of the smooth curve on the upper surface) is given by,

$$p_1 = \left(d_1\sqrt{M_1^2 - 1}, d_1\right)$$

(2 marks)

(c) Hence, find the (x, y) coordinates of point p_2 (the end of the smooth curve on the upper surface) **(5 marks)**

Stagnation Relationships

$$\frac{T_0}{T} = 1 + \frac{\gamma - 1}{2} M^2$$
$$\frac{p_0}{p} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$
$$\frac{\rho_0}{\rho} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{1}{\gamma - 1}}$$

θ-β-M relationship

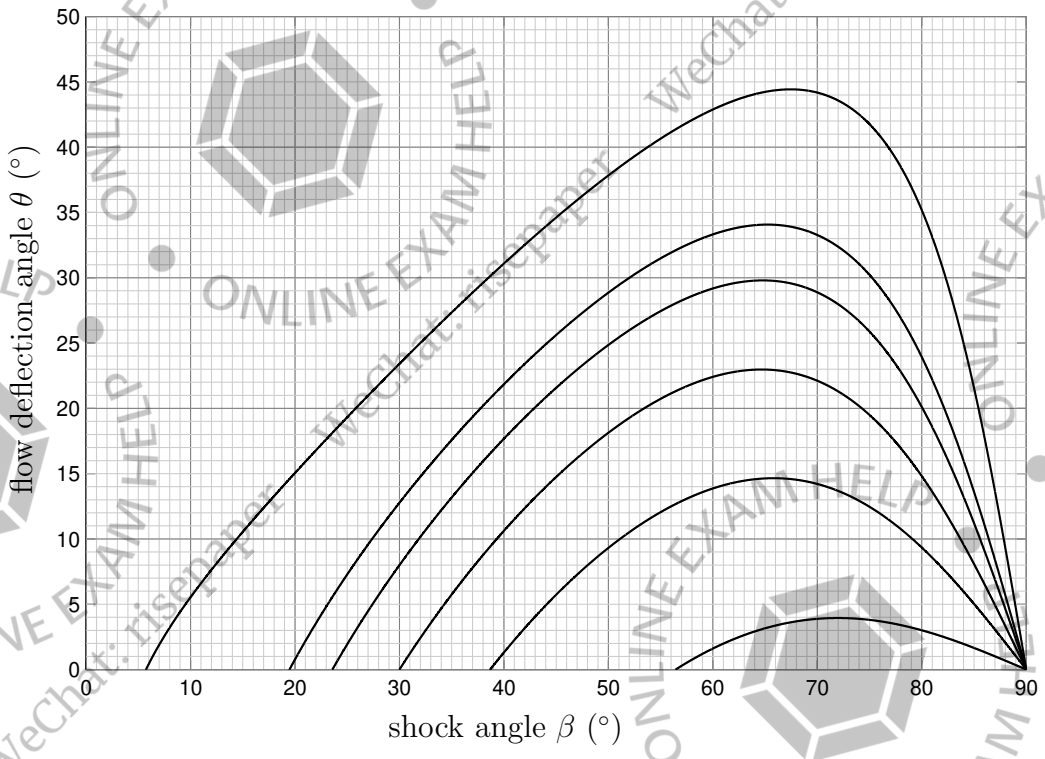

Figure 1: Relationship between shock angle β and flow deflection angle θ for several Mach numbers ($M = 1.2$, 1.5, 2, 2.5, 3, 10)

Isentropic flow properties

M	p_0/p	ρ_0/ρ	T_0/T	A/A^*	M	p_0/p	ρ_0/ρ	T_0/T	A/A^*
0.0100	1.0001	1.0001	1.0000	57.8738	0.5100	1.1942	1.1352	1.0520	1.3212
0.0200	1.0003	1.0002	1.0001	28.9421	0.5200	1.2024	1.1407	1.0541	1.3034
0.0300	1.0006	1.0005	1.0002	19.3005	0.5300	1.2108	1.1464	1.0562	1.2865
0.0400	1.0011	1.0008	1.0003	14.4815	0.5400	1.2194	1.1522	1.0583	1.2703
0.0500	1.0018	1.0013	1.0005	11.5914	0.5500	1.2283	1.1582	1.0605	1.2549
0.0600	1.0025	1.0018	1.0007	9.6659	0.5600	1.2373	1.1643	1.0627	1.2403
0.0700	1.0034	1.0025	1.0010	8.2915	0.5700	1.2465	1.1705	1.0650	1.2263
0.0800	1.0045	1.0032	1.0013	7.2616	0.5800	1.2560	1.1768	1.0673	1.2130
0.0900	1.0057	1.0041	1.0016	6.4613	0.5900	1.2656	1.1832	1.0696	1.2003
0.1000	1.0070	1.0050	1.0020	5.8218	0.6000	1.2755	1.1898	1.0720	1.1882
0.1100	1.0085	1.0061	1.0024	5.2992	0.6100	1.2856	1.1966	1.0744	1.1767
0.1200	1.0101	1.0072	1.0029	4.8643	0.6200	1.2959	1.2034	1.0769	1.1656
0.1300	1.0119	1.0085	1.0034	4.4969	0.6300	1.3065	1.2104	1.0794	1.1552
0.1400	1.0138	1.0098	1.0039	4.1824	0.6400	1.3173	1.2176	1.0819	1.1451
0.1500	1.0158	1.0113	1.0045	3.9103	0.6500	1.3283	1.2248	1.0845	1.1356
0.1600	1.0180	1.0128	1.0051	3.6727	0.6600	1.3396	1.2322	1.0871	1.1265
0.1700	1.0204	1.0145	1.0058	3.4635	0.6700	1.3511	1.2398	1.0898	1.1179
0.1800	1.0229	1.0163	1.0065	3.2779	0.6800	1.3628	1.2475	1.0925	1.1097
0.1900	1.0255	1.0181	1.0072	3.1123	0.6900	1.3748	1.2553	1.0952	1.1018
0.2000	1.0283	1.0201	1.0080	2.9635	0.7000	1.3871	1.2633	1.0980	1.0944
0.2100	1.0312	1.0222	1.0088	2.8293	0.7100	1.3996	1.2714	1.1008	1.0873
0.2200	1.0343	1.0244	1.0097	2.7076	0.7200	1.4124	1.2797	1.1037	1.0806
0.2300	1.0375	1.0267	1.0106	2.5968	0.7300	1.4254	1.2881	1.1066	1.0742
0.2400	1.0409	1.0290	1.0115	2.4956	0.7400	1.4387	1.2967	1.1095	1.0681
0.2500	1.0444	1.0315	1.0125	2.4027	0.7500	1.4523	1.3054	1.1125	1.0624
0.2600	1.0481	1.0341	1.0135	2.3173	0.7600	1.4661	1.3143	1.1155	1.0570
0.2700	1.0520	1.0368	1.0146	2.2385	0.7700	1.4802	1.3233	1.1186	1.0519
0.2800	1.0560	1.0397	1.0157	2.1656	0.7800	1.4947	1.3325	1.1217	1.0471
0.2900	1.0601	1.0426	1.0168	2.0979	0.7900	1.5094	1.3419	1.1248	1.0425
0.3000	1.0644	1.0456	1.0180	2.0351	0.8000	1.5243	1.3514	1.1280	1.0382
0.3100	1.0689	1.0487	1.0192	1.9765	0.8100	1.5396	1.3610	1.1312	1.0342
0.3200	1.0735	1.0520	1.0205	1.9219	0.8200	1.5552	1.3709	1.1345	1.0305
0.3300	1.0783	1.0553	1.0218	1.8707	0.8300	1.5711	1.3808	1.1378	1.0270
0.3400	1.0833	1.0588	1.0231	1.8229	0.8400	1.5873	1.3910	1.1411	1.0237
0.3500	1.0884	1.0624	1.0245	1.7780	0.8500	1.6038	1.4013	1.1445	1.0207
0.3600	1.0937	1.0661	1.0259	1.7358	0.8600	1.6207	1.4118	1.1479	1.0179
0.3700	1.0992	1.0699	1.0274	1.6961	0.8700	1.6378	1.4225	1.1514	1.0153
0.3800	1.1048	1.0738	1.0289	1.6587	0.8800	1.6553	1.4333	1.1549	1.0129
0.3900	1.1106	1.0778	1.0304	1.6234	0.8900	1.6731	1.4443	1.1584	1.0108
0.4000	1.1166	1.0819	1.0320	1.5901	0.9000	1.6913	1.4555	1.1620	1.0089
0.4100	1.1227	1.0862	1.0336	1.5587	0.9100	1.7098	1.4669	1.1656	1.0071
0.4200	1.1290	1.0905	1.0353	1.5289	0.9200	1.7287	1.4784	1.1693	1.0056
0.4300	1.1355	1.0950	1.0370	1.5007	0.9300	1.7479	1.4901	1.1730	1.0043
0.4400	1.1422	1.0996	1.0387	1.4740	0.9400	1.7675	1.5020	1.1767	1.0031
0.4500	1.1491	1.1043	1.0405	1.4487	0.9500	1.7874	1.5141	1.1805	1.0021
0.4600	1.1561	1.1092	1.0423	1.4246	0.9600	1.8078	1.5264	1.1843	1.0014
0.4700	1.1634	1.1141	1.0442	1.4018	0.9700	1.8285	1.5389	1.1882	1.0008
0.4800	1.1708	1.1192	1.0461	1.3801	0.9800	1.8496	1.5515	1.1921	1.0003
0.4900	1.1784	1.1244	1.0480	1.3595	0.9900	1.8710	1.5644	1.1960	1.0001
0.5000	1.1862	1.1297	1.0500	1.3398	1.0000	1.8929	1.5774	1.2000	1.0000

Isentropic flow properties (continued)

M	p_0/p	ρ_0/ρ	T_0/T	A/A^*	M	p_0/p	ρ_0/ρ	T_0/T	A/A^*
1.0100	1.9152	1.5907	1.2040	1.0001	1.5100	3.7247	2.5581	1.4560	1.1830
1.0200	1.9379	1.6041	1.2081	1.0003	1.5200	3.7792	2.5848	1.4621	1.1899
1.0300	1.9610	1.6178	1.2122	1.0007	1.5300	3.8347	2.6119	1.4682	1.1970
1.0400	1.9846	1.6316	1.2163	1.0013	1.5400	3.8911	2.6392	1.4743	1.2042
1.0500	2.0085	1.6457	1.2205	1.0020	1.5500	3.9485	2.6670	1.4805	1.2116
1.0600	2.0330	1.6599	1.2247	1.0029	1.5600	4.0068	2.6951	1.4867	1.2190
1.0700	2.0578	1.6744	1.2290	1.0039	1.5700	4.0662	2.7235	1.4930	1.2266
1.0800	2.0831	1.6891	1.2333	1.0051	1.5800	4.1266	2.7524	1.4993	1.2344
1.0900	2.1089	1.7040	1.2376	1.0064	1.5900	4.1880	2.7816	1.5056	1.2422
1.1000	2.1351	1.7191	1.2420	1.0079	1.6000	4.2504	2.8111	1.5120	1.2502
1.1100	2.1618	1.7344	1.2464	1.0095	1.6100	4.3139	2.8411	1.5184	1.2584
1.1200	2.1890	1.7500	1.2509	1.0113	1.6200	4.3785	2.8714	1.5249	1.2666
1.1300	2.2167	1.7658	1.2554	1.0132	1.6300	4.4442	2.9021	1.5314	1.2750
1.1400	2.2449	1.7818	1.2599	1.0153	1.6400	4.5110	2.9332	1.5379	1.2836
1.1500	2.2736	1.7980	1.2645	1.0175	1.6500	4.5789	2.9646	1.5445	1.2922
1.1600	2.3028	1.8145	1.2691	1.0198	1.6600	4.6479	2.9965	1.5511	1.3010
1.1700	2.3325	1.8312	1.2738	1.0222	1.6700	4.7181	3.0288	1.5578	1.3100
1.1800	2.3628	1.8481	1.2785	1.0248	1.6800	4.7896	3.0614	1.5645	1.3190
1.1900	2.3936	1.8653	1.2832	1.0276	1.6900	4.8622	3.0945	1.5712	1.3283
1.2000	2.4250	1.8827	1.2880	1.0304	1.7000	4.9360	3.1280	1.5780	1.3376
1.2100	2.4569	1.9004	1.2928	1.0334	1.7100	5.0111	3.1619	1.5848	1.3471
1.2200	2.4894	1.9183	1.2977	1.0366	1.7200	5.0874	3.1962	1.5917	1.3567
1.2300	2.5224	1.9365	1.3026	1.0398	1.7300	5.1650	3.2310	1.5986	1.3665
1.2400	2.5560	1.9549	1.3075	1.0432	1.7400	5.2439	3.2662	1.6055	1.3764
1.2500	2.5903	1.9736	1.3125	1.0468	1.7500	5.3241	3.3018	1.6125	1.3865
1.2600	2.6251	1.9925	1.3175	1.0504	1.7600	5.4057	3.3378	1.6195	1.3967
1.2700	2.6606	2.0117	1.3226	1.0542	1.7700	5.4886	3.3743	1.6266	1.4070
1.2800	2.6967	2.0311	1.3277	1.0581	1.7800	5.5729	3.4113	1.6337	1.4175
1.2900	2.7334	2.0508	1.3328	1.0621	1.7900	5.6587	3.4487	1.6408	1.4282
1.3000	2.7707	2.0708	1.3380	1.0663	1.8000	5.7458	3.4865	1.6480	1.4390
1.3100	2.8088	2.0911	1.3432	1.0706	1.8100	5.8344	3.5248	1.6552	1.4499
1.3200	2.8474	2.1116	1.3485	1.0750	1.8200	5.9244	3.5636	1.6625	1.4610
1.3300	2.8868	2.1324	1.3538	1.0796	1.8300	6.0160	3.6029	1.6698	1.4723
1.3400	2.9269	2.1535	1.3591	1.0842	1.8400	6.1091	3.6426	1.6771	1.4836
1.3500	2.9676	2.1749	1.3645	1.0890	1.8500	6.2037	3.6828	1.6845	1.4952
1.3600	3.0091	2.1965	1.3699	1.0940	1.8600	6.2998	3.7235	1.6919	1.5069
1.3700	3.0513	2.2185	1.3754	1.0990	1.8700	6.3976	3.7647	1.6994	1.5187
1.3800	3.0942	2.2407	1.3809	1.1042	1.8800	6.4970	3.8063	1.7069	1.5308
1.3900	3.1378	2.2633	1.3864	1.1095	1.8900	6.5980	3.8485	1.7144	1.5429
1.4000	3.1823	2.2861	1.3920	1.1149	1.9000	6.7006	3.8912	1.7220	1.5553
1.4100	3.2275	2.3093	1.3976	1.1205	1.9100	6.8050	3.9344	1.7296	1.5677
1.4200	3.2734	2.3327	1.4033	1.1262	1.9200	6.9111	3.9781	1.7373	1.5804
1.4300	3.3202	2.3565	1.4090	1.1320	1.9300	7.0189	4.0223	1.7450	1.5932
1.4400	3.3678	2.3805	1.4147	1.1379	1.9400	7.1284	4.0671	1.7527	1.6062
1.4500	3.4162	2.4049	1.4205	1.1440	1.9500	7.2398	4.1124	1.7605	1.6193
1.4600	3.4654	2.4296	1.4263	1.1501	1.9600	7.3530	4.1582	1.7683	1.6326
1.4700	3.5155	2.4547	1.4322	1.1565	1.9700	7.4680	4.2045	1.7762	1.6461
1.4800	3.5665	2.4800	1.4381	1.1629	1.9800	7.5849	4.2514	1.7841	1.6597
1.4900	3.6183	2.5057	1.4440	1.1695	1.9900	7.7037	4.2989	1.7920	1.6735
1.5000	3.6710	2.5317	1.4500	1.1762	2.0000	7.8244	4.3469	1.8000	1.6875

Isentropic flow properties (continued)

M	p_0/p	ρ_0/ρ	T_0/T	A/A^*	M	p_0/p	ρ_0/ρ	T_0/T	A/A^*
2.0100	7.9471	4.3955	1.8080	1.7016	2.5100	17.3537	7.6786	2.2600	2.6615
2.0200	8.0718	4.4446	1.8161	1.7160	2.5200	17.6256	7.7643	2.2701	2.6865
2.0300	8.1985	4.4944	1.8242	1.7305	2.5300	17.9016	7.8510	2.2802	2.7117
2.0400	8.3273	4.5447	1.8323	1.7451	2.5400	18.1818	7.9385	2.2903	2.7372
2.0500	8.4581	4.5956	1.8405	1.7600	2.5500	18.4662	8.0270	2.3005	2.7630
2.0600	8.5911	4.6471	1.8487	1.7750	2.5600	18.7549	8.1165	2.3107	2.7891
2.0700	8.7262	4.6991	1.8570	1.7902	2.5700	19.0480	8.2069	2.3210	2.8154
2.0800	8.8635	4.7518	1.8653	1.8056	2.5800	19.3455	8.2982	2.3313	2.8420
2.0900	9.0030	4.8051	1.8736	1.8212	2.5900	19.6475	8.3906	2.3416	2.8688
2.1000	9.1447	4.8590	1.8820	1.8369	2.6000	19.9540	8.4839	2.3520	2.8960
2.1100	9.2887	4.9136	1.8904	1.8529	2.6100	20.2652	8.5781	2.3624	2.9234
2.1200	9.4350	4.9687	1.8989	1.8690	2.6200	20.5809	8.6734	2.3729	2.9511
2.1300	9.5836	5.0245	1.9074	1.8853	2.6300	20.9015	8.7697	2.3834	2.9791
2.1400	9.7347	5.0809	1.9159	1.9018	2.6400	21.2268	8.8669	2.3939	3.0073
2.1500	9.8881	5.1380	1.9245	1.9185	2.6500	21.5569	8.9652	2.4045	3.0359
2.1600	10.0440	5.1957	1.9331	1.9354	2.6600	21.8920	9.0646	2.4151	3.0647
2.1700	10.2023	5.2541	1.9418	1.9525	2.6700	22.2321	9.1649	2.4258	3.0938
2.1800	10.3632	5.3132	1.9505	1.9698	2.6800	22.5772	9.2663	2.4365	3.1233
2.1900	10.5267	5.3729	1.9592	1.9873	2.6900	22.9274	9.3688	2.4472	3.1530
2.2000	10.6927	5.4333	1.9680	2.0050	2.7000	23.2829	9.4723	2.4580	3.1830
2.2100	10.8614	5.4944	1.9768	2.0229	2.7100	23.6436	9.5769	2.4688	3.2133
2.2200	11.0327	5.5561	1.9857	2.0409	2.7200	24.0096	9.6825	2.4797	3.2440
2.2300	11.2068	5.6186	1.9946	2.0592	2.7300	24.3810	9.7893	2.4906	3.2749
2.2400	11.3836	5.6818	2.0035	2.0777	2.7400	24.7579	9.8971	2.5015	3.3061
2.2500	11.5631	5.7457	2.0125	2.0964	2.7500	25.1403	10.0061	2.5125	3.3377
2.2600	11.7455	5.8103	2.0215	2.1153	2.7600	25.5284	10.1162	2.5235	3.3695
2.2700	11.9308	5.8756	2.0306	2.1345	2.7700	25.9221	10.2274	2.5346	3.4017
2.2800	12.1190	5.9416	2.0397	2.1538	2.7800	26.3217	10.3397	2.5457	3.4342
2.2900	12.3101	6.0084	2.0488	2.1734	2.7900	26.7270	10.4532	2.5568	3.4670
2.3000	12.5043	6.0759	2.0580	2.1931	2.8000	27.1383	10.5679	2.5680	3.5001
2.3100	12.7015	6.1442	2.0672	2.2131	2.8100	27.5556	10.6837	2.5792	3.5336
2.3200	12.9017	6.2133	2.0765	2.2333	2.8200	27.9789	10.8007	2.5905	3.5674
2.3300	13.1051	6.2831	2.0858	2.2538	2.8300	28.4084	10.9188	2.6018	3.6015
2.3400	13.3116	6.3536	2.0951	2.2744	2.8400	28.8441	11.0382	2.6131	3.6359
2.3500	13.5214	6.4250	2.1045	2.2953	2.8500	29.2862	11.1588	2.6245	3.6707
2.3600	13.7344	6.4971	2.1139	2.3164	2.8600	29.7346	11.2806	2.6359	3.7058
2.3700	13.9507	6.5701	2.1234	2.3377	2.8700	30.1896	11.4036	2.6474	3.7413
2.3800	14.1704	6.6438	2.1329	2.3593	2.8800	30.6511	11.5278	2.6589	3.7771
2.3900	14.3935	6.7183	2.1424	2.3811	2.8900	31.1192	11.6533	2.6704	3.8133
2.4000	14.6200	6.7937	2.1520	2.4031	2.9000	31.5941	11.7800	2.6820	3.8498
2.4100	14.8500	6.8699	2.1616	2.4254	2.9100	32.0758	11.9081	2.6936	3.8866
2.4200	15.0836	6.9469	2.1713	2.4479	2.9200	32.5644	12.0373	2.7053	3.9238
2.4300	15.3208	7.0247	2.1810	2.4706	2.9300	33.0600	12.1679	2.7170	3.9614
2.4400	15.5616	7.1034	2.1907	2.4936	2.9400	33.5627	12.2998	2.7287	3.9993
2.4500	15.8061	7.1830	2.2005	2.5168	2.9500	34.0725	12.4330	2.7405	4.0376
2.4600	16.0544	7.2634	2.2103	2.5403	2.9600	34.5897	12.5675	2.7523	4.0763
2.4700	16.3064	7.3446	2.2202	2.5640	2.9700	35.1141	12.7033	2.7642	4.1153
2.4800	16.5623	7.4268	2.2301	2.5880	2.9800	35.6461	12.8404	2.7761	4.1547
2.4900	16.8222	7.5098	2.2400	2.6122	2.9900	36.1856	12.9790	2.7880	4.1944
2.5000	17.0859	7.5938	2.2500	2.6367	3.0000	36.7327	13.1188	2.8000	4.2346

Isentropic flow properties (continued)

M	p_0/p	ρ_0/ρ	T_0/T	A/A^*	M	p_0/p	ρ_0/ρ	T_0/T	A/A^*
3.0100	37.2876	13.2601	2.8120	4.2751	3.5100	77.3627	22.3332	3.4640	6.8532
3.0200	37.8503	13.4027	2.8241	4.3160	3.5200	78.4673	22.5605	3.4781	6.9172
3.0300	38.4210	13.5467	2.8362	4.3573	3.5300	79.5863	22.7899	3.4922	6.9819
3.0400	38.9997	13.6922	2.8483	4.3989	3.5400	80.7199	23.0212	3.5063	7.0471
3.0500	39.5865	13.8390	2.8605	4.4410	3.5500	81.8682	23.2547	3.5205	7.1128
3.0600	40.1815	13.9873	2.8727	4.4835	3.5600	83.0314	23.4902	3.5347	7.1791
3.0700	40.7849	14.1370	2.8850	4.5263	3.5700	84.2098	23.7279	3.5490	7.2460
3.0800	41.3968	14.2882	2.8973	4.5696	3.5800	85.4033	23.9676	3.5633	7.3135
3.0900	42.0172	14.4408	2.9096	4.6132	3.5900	86.6123	24.2095	3.5776	7.3815
3.1000	42.6462	14.5949	2.9220	4.6573	3.6000	87.8369	24.4535	3.5920	7.4501
3.1100	43.2841	14.7505	2.9344	4.7018	3.6100	89.0773	24.6996	3.6064	7.5193
3.1200	43.9307	14.9075	2.9469	4.7467	3.6200	90.3336	24.9480	3.6209	7.5891
3.1300	44.5864	15.0661	2.9594	4.7920	3.6300	91.6061	25.1985	3.6354	7.6595
3.1400	45.2512	15.2262	2.9719	4.8377	3.6400	92.8949	25.4512	3.6499	7.7305
3.1500	45.9251	15.3879	2.9845	4.8838	3.6500	94.2001	25.7061	3.6645	7.8020
3.1600	46.6084	15.5511	2.9971	4.9304	3.6600	95.5221	25.9633	3.6791	7.8742
3.1700	47.3011	15.7158	3.0098	4.9774	3.6700	96.8609	26.2227	3.6938	7.9470
3.1800	48.0034	15.8821	3.0225	5.0248	3.6800	98.2168	26.4844	3.7085	8.0204
3.1900	48.7153	16.0500	3.0352	5.0727	3.6900	99.5899	26.7483	3.7232	8.0944
3.2000	49.4370	16.2195	3.0480	5.1210	3.7000	100.9805	27.0146	3.7380	8.1691
3.2100	50.1686	16.3906	3.0608	5.1697	3.7100	102.3887	27.2831	3.7528	8.2443
3.2200	50.9103	16.5633	3.0737	5.2189	3.7200	103.8147	27.5540	3.7677	8.3202
3.2300	51.6620	16.7376	3.0866	5.2685	3.7300	105.2588	27.8273	3.7826	8.3968
3.2400	52.4240	16.9136	3.0995	5.3186	3.7400	106.7211	28.1028	3.7975	8.4739
3.2500	53.1965	17.0912	3.1125	5.3691	3.7500	108.2018	28.3808	3.8125	8.5517
3.2600	53.9794	17.2705	3.1255	5.4201	3.7600	109.7011	28.6612	3.8275	8.6302
3.2700	54.7730	17.4515	3.1386	5.4715	3.7700	111.2193	28.9439	3.8426	8.7093
3.2800	55.5773	17.6342	3.1517	5.5234	3.7800	112.7565	29.2291	3.8577	8.7891
3.2900	56.3925	17.8186	3.1648	5.5758	3.7900	114.3130	29.5167	3.8728	8.8695
3.3000	57.2188	18.0047	3.1780	5.6286	3.8000	115.8889	29.8068	3.8880	8.9506
3.3100	58.0562	18.1925	3.1912	5.6820	3.8100	117.4845	30.0994	3.9032	9.0323
3.3200	58.9049	18.3820	3.2045	5.7358	3.8200	119.1000	30.3944	3.9185	9.1148
3.3300	59.7650	18.5734	3.2178	5.7900	3.8300	120.7356	30.6920	3.9338	9.1979
3.3400	60.6367	18.7665	3.2311	5.8448	3.8400	122.3915	30.9921	3.9491	9.2817
3.3500	61.5201	18.9614	3.2445	5.9000	3.8500	124.0679	31.2947	3.9645	9.3661
3.3600	62.4154	19.1580	3.2579	5.9558	3.8600	125.7651	31.5999	3.9799	9.4513
3.3700	63.3226	19.3565	3.2714	6.0120	3.8700	127.4833	31.9077	3.9954	9.5372
3.3800	64.2419	19.5568	3.2849	6.0687	3.8800	129.2227	32.2180	4.0109	9.6237
3.3900	65.1735	19.7590	3.2984	6.1260	3.8900	130.9836	32.5310	4.0264	9.7110
3.4000	66.1175	19.9630	3.3120	6.1837	3.9000	132.7661	32.8466	4.0420	9.7990
3.4100	67.0740	20.1689	3.3256	6.2419	3.9100	134.5705	33.1649	4.0576	9.8877
3.4200	68.0432	20.3766	3.3393	6.3007	3.9200	136.3970	33.4858	4.0733	9.9771
3.4300	69.0253	20.5863	3.3530	6.3600	3.9300	138.2460	33.8094	4.0890	10.0672
3.4400	70.0204	20.7978	3.3667	6.4198	3.9400	140.1175	34.1357	4.1047	10.1581
3.4500	71.0286	21.0113	3.3805	6.4801	3.9500	142.0119	34.4647	4.1205	10.2496
3.4600	72.0501	21.2267	3.3943	6.5409	3.9600	143.9294	34.7965	4.1363	10.3420
3.4700	73.0851	21.4440	3.4082	6.6023	3.9700	145.8702	35.1310	4.1522	10.4350
3.4800	74.1337	21.6633	3.4221	6.6642	3.9800	147.8346	35.4683	4.1681	10.5289
3.4900	75.1960	21.8846	3.4360	6.7266	3.9900	149.8229	35.8084	4.1840	10.6234
3.5000	76.2723	22.1079	3.4500	6.7896	4.0000	151.8352	36.1512	4.2000	10.7188

Isentropic flow properties (continued)

M	p_0/p	ρ_0/ρ	T_0/T	A/A^*	M	p_0/p	ρ_0/ρ	T_0/T	A/A^*
4.0100	153.8719	36.4970	4.2160	10.8148	4.5100	293.0449	57.8224	5.0680	16.7030
4.0200	155.9332	36.8455	4.2321	10.9117	4.5200	296.7161	58.3389	5.0861	16.8449
4.0300	158.0193	37.1969	4.2482	11.0093	4.5300	300.4284	58.8593	5.1042	16.9878
4.0400	160.1306	37.5513	4.2643	11.1077	4.5400	304.1820	59.3836	5.1223	17.1317
4.0500	162.2672	37.9085	4.2805	11.2069	4.5500	307.9773	59.9119	5.1405	17.2767
4.0600	164.4295	38.2686	4.2967	11.3068	4.5600	311.8149	60.4442	5.1587	17.4228
4.0700	166.6177	38.6317	4.3130	11.4076	4.5700	315.6950	60.9805	5.1770	17.5699
4.0800	168.8320	38.9977	4.3293	11.5091	4.5800	319.6181	61.5209	5.1953	17.7181
4.0900	171.0729	39.3667	4.3456	11.6115	4.5900	323.5846	62.0652	5.2136	17.8674
4.1000	173.3404	39.7387	4.3620	11.7147	4.6000	327.5949	62.6137	5.2320	18.0178
4.1100	175.6350	40.1138	4.3784	11.8186	4.6100	331.6494	63.1663	5.2504	18.1693
4.1200	177.9568	40.4918	4.3949	11.9234	4.6200	335.7485	63.7229	5.2689	18.3218
4.1300	180.3062	40.8730	4.4114	12.0290	4.6300	339.8927	64.2838	5.2874	18.4755
4.1400	182.6834	41.2572	4.4279	12.1354	4.6400	344.0824	64.8488	5.3059	18.6303
4.1500	185.0888	41.6445	4.4445	12.2427	4.6500	348.3180	65.4180	5.3245	18.7862
4.1600	187.5226	42.0349	4.4611	12.3508	4.6600	352.6000	65.9914	5.3431	18.9433
4.1700	189.9851	42.4284	4.4778	12.4597	4.6700	356.9287	66.5691	5.3618	19.1015
4.1800	192.4767	42.8251	4.4945	12.5695	4.6800	361.3047	67.1510	5.3805	19.2608
4.1900	194.9975	43.2250	4.5112	12.6801	4.6900	365.7283	67.7372	5.3992	19.4212
4.2000	197.5479	43.6281	4.5280	12.7916	4.7000	370.2001	68.3278	5.4180	19.5828
4.2100	200.1283	44.0344	4.5448	12.9040	4.7100	374.7204	68.9227	5.4368	19.7456
4.2200	202.7388	44.4439	4.5617	13.0172	4.7200	379.2898	69.5220	5.4557	19.9095
4.2300	205.3798	44.8567	4.5786	13.1313	4.7300	383.9086	70.1257	5.4746	20.0746
4.2400	208.0517	45.2727	4.5955	13.2463	4.7400	388.5774	70.7338	5.4935	20.2409
4.2500	210.7547	45.6921	4.6125	13.3622	4.7500	393.2965	71.3463	5.5125	20.4084
4.2600	213.4892	46.1148	4.6295	13.4789	4.7600	398.0666	71.9633	5.5315	20.5770
4.2700	216.2554	46.5408	4.6466	13.5965	4.7700	402.8880	72.5848	5.5506	20.7469
4.2800	219.0537	46.9701	4.6637	13.7151	4.7800	407.7612	73.2109	5.5697	20.9179
4.2900	221.8844	47.4029	4.6808	13.8345	4.7900	412.6867	73.8415	5.5888	21.0902
4.3000	224.7478	47.8390	4.6980	13.9549	4.8000	417.6649	74.4766	5.6080	21.2637
4.3100	227.6443	48.2786	4.7152	14.0762	4.8100	422.6965	75.1164	5.6272	21.4384
4.3200	230.5742	48.7216	4.7325	14.1984	4.8200	427.7818	75.7608	5.6465	21.6144
4.3300	233.5378	49.1681	4.7498	14.3215	4.8300	432.9213	76.4098	5.6658	21.7916
4.3400	236.5355	49.6181	4.7671	14.4456	4.8400	438.1156	77.0636	5.6851	21.9700
4.3500	239.5675	50.0716	4.7845	14.5706	4.8500	443.3651	77.7220	5.7045	22.1497
4.3600	242.6343	50.5286	4.8019	14.6965	4.8600	448.6704	78.3852	5.7239	22.3306
4.3700	245.7362	50.9892	4.8194	14.8234	4.8700	454.0320	79.0531	5.7434	22.5128
4.3800	248.8735	51.4533	4.8369	14.9513	4.8800	459.4503	79.7258	5.7629	22.6963
4.3900	252.0465	51.9210	4.8544	15.0801	4.8900	464.9259	80.4033	5.7824	22.8811
4.4000	255.2557	52.3924	4.8720	15.2099	4.9000	470.4593	81.0857	5.8020	23.0671
4.4100	258.5014	52.8674	4.8896	15.3406	4.9100	476.0510	81.7729	5.8216	23.2545
4.4200	261.7839	53.3460	4.9073	15.4724	4.9200	481.7016	82.4651	5.8413	23.4431
4.4300	265.1036	53.8284	4.9250	15.6051	4.9300	487.4116	83.1621	5.8610	23.6331
4.4400	268.4609	54.3144	4.9427	15.7388	4.9400	493.1815	83.8641	5.8807	23.8243
4.4500	271.8561	54.8042	4.9605	15.8735	4.9500	499.0118	84.5711	5.9005	24.0169
4.4600	275.2896	55.2977	4.9783	16.0092	4.9600	504.9032	85.2831	5.9203	24.2109
4.4700	278.7618	55.7950	4.9962	16.1459	4.9700	510.8561	86.0001	5.9402	24.4061
4.4800	282.2730	56.2961	5.0141	16.2837	4.9800	516.8712	86.7222	5.9601	24.6027
4.4900	285.8237	56.8010	5.0320	16.4224	4.9900	522.9489	87.4494	5.9800	24.8007
4.5000	289.4142	57.3097	5.0500	16.5622	5.0000	529.0898	88.1816	6.0000	25.0000

Normal shock relations

$$\frac{p_2}{p_1} = \frac{2\gamma M_1^2 - \gamma + 1}{\gamma + 1}$$

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

$$M_2^2 = \frac{2 + (\gamma - 1)M_1^2}{2\gamma M_1^2 - \gamma + 1}$$

$$\frac{s_2 - s_1}{c_v} = \ln\left(\left[\frac{2 + \gamma M_1^2 - M_1^2}{M_1^2(\gamma + 1)}\right]^\gamma \left[\frac{2\gamma M_1^2 - \gamma + 1}{\gamma + 1}\right]\right)$$

Normal shock relations

M_1	p_2/p_1	p_{02}/p_{01}	ρ_2/ρ_1	M_2	M_1	p_2/p_1	p_{02}/p_{01}	ρ_2/ρ_1	M_2
1.0200	1.0471	1.0000	1.0334	0.9805	1.5200	2.5288	0.9233	1.8963	0.6941
1.0300	1.0711	1.0000	1.0502	0.9712	1.5300	2.5644	0.9200	1.9133	0.6907
1.0400	1.0952	0.9999	1.0671	0.9620	1.5400	2.6002	0.9166	1.9303	0.6874
1.0500	1.1196	0.9999	1.0840	0.9531	1.5500	2.6363	0.9132	1.9473	0.6841
1.0600	1.1442	0.9998	1.1009	0.9444	1.5600	2.6725	0.9097	1.9643	0.6809
1.0700	1.1690	0.9996	1.1179	0.9360	1.5700	2.7091	0.9062	1.9812	0.6777
1.0800	1.1941	0.9994	1.1349	0.9277	1.5800	2.7458	0.9026	1.9981	0.6746
1.0900	1.2195	0.9992	1.1520	0.9196	1.5900	2.7828	0.8989	2.0149	0.6715
1.1000	1.2450	0.9989	1.1691	0.9118	1.6000	2.8200	0.8952	2.0317	0.6684
1.1100	1.2708	0.9986	1.1862	0.9041	1.6100	2.8574	0.8915	2.0485	0.6655
1.1200	1.2968	0.9982	1.2034	0.8966	1.6200	2.8951	0.8877	2.0653	0.6625
1.1300	1.3231	0.9978	1.2206	0.8892	1.6300	2.9330	0.8838	2.0820	0.6596
1.1400	1.3495	0.9973	1.2378	0.8820	1.6400	2.9712	0.8799	2.0986	0.6568
1.1500	1.3762	0.9967	1.2550	0.8750	1.6500	3.0096	0.8760	2.1152	0.6540
1.1600	1.4032	0.9961	1.2723	0.8682	1.6600	3.0482	0.8720	2.1318	0.6512
1.1700	1.4304	0.9953	1.2896	0.8615	1.6700	3.0871	0.8680	2.1484	0.6485
1.1800	1.4578	0.9946	1.3069	0.8549	1.6800	3.1261	0.8639	2.1649	0.6458
1.1900	1.4854	0.9937	1.3243	0.8485	1.6900	3.1654	0.8599	2.1813	0.6431
1.2000	1.5133	0.9928	1.3416	0.8422	1.7000	3.2050	0.8557	2.1977	0.6405
1.2100	1.5415	0.9918	1.3590	0.8360	1.7100	3.2448	0.8516	2.2141	0.6380
1.2200	1.5698	0.9907	1.3764	0.8300	1.7200	3.2848	0.8474	2.2304	0.6355
1.2300	1.5984	0.9896	1.3938	0.8241	1.7300	3.3251	0.8431	2.2467	0.6330
1.2400	1.6272	0.9884	1.4112	0.8183	1.7400	3.3655	0.8389	2.2629	0.6305
1.2500	1.6563	0.9871	1.4286	0.8126	1.7500	3.4063	0.8346	2.2791	0.6281
1.2600	1.6855	0.9857	1.4460	0.8071	1.7600	3.4472	0.8302	2.2952	0.6257
1.2700	1.7151	0.9842	1.4634	0.8016	1.7700	3.4884	0.8259	2.3113	0.6234
1.2800	1.7448	0.9827	1.4808	0.7963	1.7800	3.5298	0.8215	2.3273	0.6210
1.2900	1.7748	0.9811	1.4983	0.7911	1.7900	3.5715	0.8171	2.3433	0.6188
1.3000	1.8050	0.9794	1.5157	0.7860	1.8000	3.6133	0.8127	2.3592	0.6165
1.3100	1.8355	0.9776	1.5331	0.7809	1.8100	3.6555	0.8082	2.3751	0.6143
1.3200	1.8661	0.9758	1.5505	0.7760	1.8200	3.6978	0.8038	2.3909	0.6121
1.3300	1.8971	0.9738	1.5680	0.7712	1.8300	3.7404	0.7993	2.4067	0.6099
1.3400	1.9282	0.9718	1.5854	0.7664	1.8400	3.7832	0.7948	2.4224	0.6078
1.3500	1.9596	0.9697	1.6028	0.7618	1.8500	3.8263	0.7902	2.4381	0.6057
1.3600	1.9912	0.9676	1.6202	0.7572	1.8600	3.8695	0.7857	2.4537	0.6036
1.3700	2.0231	0.9653	1.6376	0.7527	1.8700	3.9131	0.7811	2.4693	0.6016
1.3800	2.0551	0.9630	1.6549	0.7483	1.8800	3.9568	0.7765	2.4848	0.5996
1.3900	2.0875	0.9607	1.6723	0.7440	1.8900	4.0008	0.7720	2.5003	0.5976
1.4000	2.1200	0.9582	1.6897	0.7397	1.9000	4.0450	0.7674	2.5157	0.5956
1.4100	2.1528	0.9557	1.7070	0.7355	1.9100	4.0895	0.7627	2.5310	0.5937
1.4200	2.1858	0.9531	1.7243	0.7314	1.9200	4.1341	0.7581	2.5463	0.5918
1.4300	2.2191	0.9504	1.7416	0.7274	1.9300	4.1791	0.7535	2.5616	0.5899
1.4400	2.2525	0.9476	1.7589	0.7235	1.9400	4.2242	0.7488	2.5767	0.5880
1.4500	2.2862	0.9448	1.7761	0.7196	1.9500	4.2696	0.7442	2.5919	0.5862
1.4600	2.3202	0.9420	1.7934	0.7157	1.9600	4.3152	0.7395	2.6069	0.5844
1.4700	2.3544	0.9390	1.8106	0.7120	1.9700	4.3611	0.7349	2.6220	0.5826
1.4800	2.3888	0.9360	1.8278	0.7083	1.9800	4.4071	0.7302	2.6369	0.5808
1.4900	2.4234	0.9329	1.8449	0.7047	1.9900	4.4535	0.7255	2.6518	0.5791
1.5000	2.4583	0.9298	1.8621	0.7011	2.0000	4.5000	0.7209	2.6667	0.5774
1.5100	2.4935	0.9266	1.8792	0.6976	2.0100	4.5468	0.7162	2.6815	0.5757

Normal shock relations (continued)

M_1	p_2/p_1	p_{02}/p_{01}	ρ_2/ρ_1	M_2	M_1	p_2/p_1	p_{02}/p_{01}	ρ_2/ρ_1	M_2
2.0200	4.5938	0.7115	2.6962	0.5740	2.5200	7.2421	0.4911	3.3569	0.5111
2.0300	4.6411	0.7069	2.7109	0.5723	2.5300	7.3010	0.4871	3.3686	0.5102
2.0400	4.6885	0.7022	2.7255	0.5707	2.5400	7.3602	0.4832	3.3803	0.5092
2.0500	4.7363	0.6975	2.7400	0.5691	2.5500	7.4196	0.4793	3.3919	0.5083
2.0600	4.7842	0.6928	2.7545	0.5675	2.5600	7.4792	0.4754	3.4034	0.5074
2.0700	4.8324	0.6882	2.7689	0.5659	2.5700	7.5390	0.4715	3.4149	0.5065
2.0800	4.8808	0.6835	2.7833	0.5643	2.5800	7.5991	0.4677	3.4263	0.5056
2.0900	4.9294	0.6789	2.7976	0.5628	2.5900	7.6594	0.4639	3.4377	0.5047
2.1000	4.9783	0.6742	2.8119	0.5613	2.6000	7.7200	0.4601	3.4490	0.5039
2.1100	5.0275	0.6696	2.8261	0.5598	2.6100	7.7808	0.4564	3.4602	0.5030
2.1200	5.0768	0.6649	2.8402	0.5583	2.6200	7.8418	0.4526	3.4714	0.5022
2.1300	5.1264	0.6603	2.8543	0.5568	2.6300	7.9030	0.4489	3.4826	0.5013
2.1400	5.1762	0.6557	2.8683	0.5554	2.6400	7.9645	0.4452	3.4937	0.5005
2.1500	5.2262	0.6511	2.8823	0.5540	2.6500	8.0263	0.4416	3.5047	0.4996
2.1600	5.2765	0.6464	2.8962	0.5525	2.6600	8.0882	0.4379	3.5157	0.4988
2.1700	5.3270	0.6419	2.9101	0.5511	2.6700	8.1504	0.4343	3.5266	0.4980
2.1800	5.3778	0.6373	2.9238	0.5498	2.6800	8.2128	0.4307	3.5374	0.4972
2.1900	5.4288	0.6327	2.9376	0.5484	2.6900	8.2754	0.4271	3.5482	0.4964
2.2000	5.4800	0.6281	2.9512	0.5471	2.7000	8.3383	0.4236	3.5590	0.4956
2.2100	5.5315	0.6236	2.9648	0.5457	2.7100	8.4015	0.4201	3.5697	0.4949
2.2200	5.5831	0.6191	2.9784	0.5444	2.7200	8.4648	0.4166	3.5803	0.4941
2.2300	5.6351	0.6145	2.9918	0.5431	2.7300	8.5284	0.4131	3.5909	0.4933
2.2400	5.6872	0.6100	3.0053	0.5418	2.7400	8.5922	0.4097	3.6015	0.4926
2.2500	5.7396	0.6055	3.0186	0.5406	2.7500	8.6563	0.4062	3.6119	0.4918
2.2600	5.7922	0.6011	3.0319	0.5393	2.7600	8.7205	0.4028	3.6224	0.4911
2.2700	5.8451	0.5966	3.0452	0.5381	2.7700	8.7851	0.3994	3.6327	0.4903
2.2800	5.8981	0.5921	3.0584	0.5368	2.7800	8.8498	0.3961	3.6431	0.4896
2.2900	5.9515	0.5877	3.0715	0.5356	2.7900	8.9148	0.3928	3.6533	0.4889
2.3000	6.0050	0.5833	3.0845	0.5344	2.8000	8.9800	0.3895	3.6636	0.4882
2.3100	6.0588	0.5789	3.0976	0.5332	2.8100	9.0455	0.3862	3.6737	0.4875
2.3200	6.1128	0.5745	3.1105	0.5321	2.8200	9.1111	0.3829	3.6838	0.4868
2.3300	6.1671	0.5702	3.1234	0.5309	2.8300	9.1771	0.3797	3.6939	0.4861
2.3400	6.2215	0.5658	3.1362	0.5297	2.8400	9.2432	0.3765	3.7039	0.4854
2.3500	6.2763	0.5615	3.1490	0.5286	2.8500	9.3096	0.3733	3.7139	0.4847
2.3600	6.3312	0.5572	3.1617	0.5275	2.8600	9.3762	0.3701	3.7238	0.4840
2.3700	6.3864	0.5529	3.1743	0.5264	2.8700	9.4431	0.3670	3.7336	0.4833
2.3800	6.4418	0.5486	3.1869	0.5253	2.8800	9.5101	0.3639	3.7434	0.4827
2.3900	6.4975	0.5444	3.1994	0.5242	2.8900	9.5775	0.3608	3.7532	0.4820
2.4000	6.5533	0.5401	3.2119	0.5231	2.9000	9.6450	0.3577	3.7629	0.4814
2.4100	6.6095	0.5359	3.2243	0.5221	2.9100	9.7128	0.3547	3.7725	0.4807
2.4200	6.6658	0.5317	3.2367	0.5210	2.9200	9.7808	0.3517	3.7821	0.4801
2.4300	6.7224	0.5276	3.2489	0.5200	2.9300	9.8491	0.3487	3.7917	0.4795
2.4400	6.7792	0.5234	3.2612	0.5189	2.9400	9.9175	0.3457	3.8012	0.4788
2.4500	6.8363	0.5193	3.2733	0.5179	2.9500	9.9863	0.3428	3.8106	0.4782
2.4600	6.8935	0.5152	3.2855	0.5169	2.9600	10.0552	0.3398	3.8200	0.4776
2.4700	6.9510	0.5111	3.2975	0.5159	2.9700	10.1244	0.3369	3.8294	0.4770
2.4800	7.0088	0.5071	3.3095	0.5149	2.9800	10.1938	0.3340	3.8387	0.4764
2.4900	7.0668	0.5030	3.3215	0.5140	2.9900	10.2635	0.3312	3.8479	0.4758
2.5000	7.1250	0.4990	3.3333	0.5130	3.0000	10.3333	0.3283	3.8571	0.4752

Normal shock relations (continued)

M_1	p_2/p_1	p_{02}/p_{01}	ρ_2/ρ_1	M_2	M_1	p_2/p_1	p_{02}/p_{01}	ρ_2/ρ_1	M_2
3.0200	10.4738	0.3227	0.4524	0.4740	3.5200	14.2888	0.2093	0.6256	0.4504
3.0300	10.5444	0.3200	0.4558	0.4734	3.5300	14.3710	0.2075	0.6291	0.4500
3.0400	10.6152	0.3172	0.4593	0.4729	3.5400	14.4535	0.2057	0.6325	0.4496
3.0500	10.6862	0.3145	0.4627	0.4723	3.5500	14.5362	0.2039	0.6360	0.4492
3.0600	10.7575	0.3118	0.4662	0.4717	3.5600	14.6192	0.2022	0.6394	0.4489
3.0700	10.8291	0.3091	0.4696	0.4712	3.5700	14.7024	0.2004	0.6429	0.4485
3.0800	10.9008	0.3065	0.4731	0.4706	3.5800	14.7858	0.1987	0.6464	0.4481
3.0900	10.9728	0.3038	0.4765	0.4701	3.5900	14.8695	0.1970	0.6498	0.4478
3.1000	11.0450	0.3012	0.4800	0.4695	3.6000	14.9533	0.1953	0.6533	0.4474
3.1100	11.1174	0.2986	0.4834	0.4690	3.6100	15.0375	0.1936	0.6567	0.4471
3.1200	11.1901	0.2960	0.4869	0.4685	3.6200	15.1218	0.1920	0.6602	0.4467
3.1300	11.2630	0.2935	0.4904	0.4679	3.6300	15.2064	0.1903	0.6636	0.4463
3.1400	11.3362	0.2910	0.4938	0.4674	3.6400	15.2912	0.1887	0.6671	0.4460
3.1500	11.4096	0.2885	0.4973	0.4669	3.6500	15.3763	0.1871	0.6705	0.4456
3.1600	11.4832	0.2860	0.5007	0.4664	3.6600	15.4615	0.1855	0.6740	0.4453
3.1700	11.5571	0.2835	0.5042	0.4659	3.6700	15.5471	0.1839	0.6774	0.4450
3.1800	11.6311	0.2811	0.5077	0.4654	3.6800	15.6328	0.1823	0.6808	0.4446
3.1900	11.7055	0.2786	0.5111	0.4648	3.6900	15.7188	0.1807	0.6843	0.4443
3.2000	11.7800	0.2762	0.5146	0.4643	3.7000	15.8050	0.1792	0.6877	0.4439
3.2100	11.8548	0.2738	0.5181	0.4639	3.7100	15.8915	0.1777	0.6912	0.4436
3.2200	11.9298	0.2715	0.5215	0.4634	3.7200	15.9781	0.1761	0.6946	0.4433
3.2300	12.0051	0.2691	0.5250	0.4629	3.7300	16.0650	0.1746	0.6980	0.4430
3.2400	12.0805	0.2668	0.5285	0.4624	3.7400	16.1522	0.1731	0.7015	0.4426
3.2500	12.1562	0.2645	0.5320	0.4619	3.7500	16.2396	0.1717	0.7049	0.4423
3.2600	12.2322	0.2622	0.5354	0.4614	3.7600	16.3272	0.1702	0.7083	0.4420
3.2700	12.3084	0.2600	0.5389	0.4610	3.7700	16.4151	0.1687	0.7117	0.4417
3.2800	12.3848	0.2577	0.5424	0.4605	3.7800	16.5031	0.1673	0.7152	0.4414
3.2900	12.4615	0.2555	0.5458	0.4600	3.7900	16.5915	0.1659	0.7186	0.4410
3.3000	12.5383	0.2533	0.5493	0.4596	3.8000	16.6800	0.1645	0.7220	0.4407
3.3100	12.6155	0.2511	0.5528	0.4591	3.8100	16.7688	0.1631	0.7254	0.4404
3.3200	12.6928	0.2489	0.5563	0.4587	3.8200	16.8578	0.1617	0.7288	0.4401
3.3300	12.7704	0.2468	0.5597	0.4582	3.8300	16.9471	0.1603	0.7323	0.4398
3.3400	12.8482	0.2446	0.5632	0.4578	3.8400	17.0365	0.1589	0.7357	0.4395
3.3500	12.9263	0.2425	0.5667	0.4573	3.8500	17.1263	0.1576	0.7391	0.4392
3.3600	13.0045	0.2404	0.5701	0.4569	3.8600	17.2162	0.1563	0.7425	0.4389
3.3700	13.0831	0.2383	0.5736	0.4565	3.8700	17.3064	0.1549	0.7459	0.4386
3.3800	13.1618	0.2363	0.5771	0.4560	3.8800	17.3968	0.1536	0.7493	0.4383
3.3900	13.2408	0.2342	0.5805	0.4556	3.8900	17.4875	0.1523	0.7527	0.4380
3.4000	13.3200	0.2322	0.5840	0.4552	3.9000	17.5783	0.1510	0.7561	0.4377
3.4100	13.3995	0.2302	0.5875	0.4548	3.9100	17.6695	0.1497	0.7595	0.4375
3.4200	13.4791	0.2282	0.5910	0.4544	3.9200	17.7608	0.1485	0.7629	0.4372
3.4300	13.5590	0.2263	0.5944	0.4540	3.9300	17.8524	0.1472	0.7663	0.4369
3.4400	13.6392	0.2243	0.5979	0.4535	3.9400	17.9442	0.1460	0.7697	0.4366
3.4500	13.7196	0.2224	0.6014	0.4531	3.9500	18.0363	0.1448	0.7731	0.4363
3.4600	13.8002	0.2205	0.6048	0.4527	3.9600	18.1285	0.1435	0.7765	0.4360
3.4700	13.8811	0.2186	0.6083	0.4523	3.9700	18.2211	0.1423	0.7799	0.4358
3.4800	13.9621	0.2167	0.6118	0.4519	3.9800	18.3138	0.1411	0.7833	0.4355
3.4900	14.0435	0.2148	0.6152	0.4515	3.9900	18.4068	0.1399	0.7866	0.4352
3.5000	14.1250	0.2129	0.6187	0.4512	4.0000	18.5000	0.1388	0.7900	0.4350

Prandtl-Meyer relationship

M	ω	M	ω	M	ω	M	ω
1.0100	0.0447	1.5100	12.1999	2.0100	26.6550	2.5100	39.3565
1.0200	0.1257	1.5200	12.4949	2.0200	26.9295	2.5200	39.5886
1.0300	0.2294	1.5300	12.7901	2.0300	27.2033	2.5300	39.8199
1.0400	0.3510	1.5400	13.0856	2.0400	27.4762	2.5400	40.0503
1.0500	0.4874	1.5500	13.3812	2.0500	27.7484	2.5500	40.2798
1.0600	0.6367	1.5600	13.6770	2.0600	28.0197	2.5600	40.5085
1.0700	0.7973	1.5700	13.9728	2.0700	28.2903	2.5700	40.7363
1.0800	0.9680	1.5800	14.2686	2.0800	28.5600	2.5800	40.9633
1.0900	1.1479	1.5900	14.5645	2.0900	28.8290	2.5900	41.1894
1.1000	1.3362	1.6000	14.8604	2.1000	29.0971	2.6000	41.4147
1.1100	1.5321	1.6100	15.1561	2.1100	29.3644	2.6100	41.6392
1.1200	1.7350	1.6200	15.4518	2.1200	29.6308	2.6200	41.8628
1.1300	1.9445	1.6300	15.7473	2.1300	29.8965	2.6300	42.0855
1.1400	2.1600	1.6400	16.0427	2.1400	30.1613	2.6400	42.3074
1.1500	2.3810	1.6500	16.3379	2.1500	30.4253	2.6500	42.5285
1.1600	2.6073	1.6600	16.6328	2.1600	30.6884	2.6600	42.7488
1.1700	2.8385	1.6700	16.9276	2.1700	30.9507	2.6700	42.9682
1.1800	3.0743	1.6800	17.2220	2.1800	31.2121	2.6800	43.1868
1.1900	3.3142	1.6900	17.5161	2.1900	31.4727	2.6900	43.4045
1.2000	3.5582	1.7000	17.8099	2.2000	31.7325	2.7000	43.6215
1.2100	3.8060	1.7100	18.1034	2.2100	31.9914	2.7100	43.8376
1.2200	4.0572	1.7200	18.3964	2.2200	32.2494	2.7200	44.0529
1.2300	4.3117	1.7300	18.6891	2.2300	32.5066	2.7300	44.2673
1.2400	4.5694	1.7400	18.9814	2.2400	32.7629	2.7400	44.4810
1.2500	4.8299	1.7500	19.2732	2.2500	33.0184	2.7500	44.6938
1.2600	5.0931	1.7600	19.5646	2.2600	33.2730	2.7600	44.9059
1.2700	5.3590	1.7700	19.8554	2.2700	33.5268	2.7700	45.1171
1.2800	5.6272	1.7800	20.1458	2.2800	33.7796	2.7800	45.3275
1.2900	5.8977	1.7900	20.4357	2.2900	34.0316	2.7900	45.5371
1.3000	6.1703	1.8000	20.7251	2.3000	34.2828	2.8000	45.7459
1.3100	6.4449	1.8100	21.0139	2.3100	34.5331	2.8100	45.9539
1.3200	6.7213	1.8200	21.3021	2.3200	34.7825	2.8200	46.1611
1.3300	6.9995	1.8300	21.5898	2.3300	35.0310	2.8300	46.3675
1.3400	7.2794	1.8400	21.8768	2.3400	35.2787	2.8400	46.5731
1.3500	7.5607	1.8500	22.1633	2.3500	35.5255	2.8500	46.7779
1.3600	7.8435	1.8600	22.4492	2.3600	35.7715	2.8600	46.9820
1.3700	8.1276	1.8700	22.7344	2.3700	36.0165	2.8700	47.1852
1.3800	8.4130	1.8800	23.0190	2.3800	36.2607	2.8800	47.3877
1.3900	8.6995	1.8900	23.3029	2.3900	36.5041	2.8900	47.5894
1.4000	8.9870	1.9000	23.5861	2.4000	36.7465	2.9000	47.7903
1.4100	9.2756	1.9100	23.8687	2.4100	36.9881	2.9100	47.9905
1.4200	9.5650	1.9200	24.1506	2.4200	37.2289	2.9200	48.1898
1.4300	9.8553	1.9300	24.4318	2.4300	37.4687	2.9300	48.3884
1.4400	10.1464	1.9400	24.7123	2.4400	37.7077	2.9400	48.5863
1.4500	10.4381	1.9500	24.9920	2.4500	37.9459	2.9500	48.7833
1.4600	10.7305	1.9600	25.2711	2.4600	38.1831	2.9600	48.9796
1.4700	11.0235	1.9700	25.5494	2.4700	38.4195	2.9700	49.1752
1.4800	11.3169	1.9800	25.8269	2.4800	38.6551	2.9800	49.3700
1.4900	11.6109	1.9900	26.1037	2.4900	38.8897	2.9900	49.5640
1.5000	11.9052	2.0000	26.3798	2.5000	39.1236	3.0000	49.7573

Prandtl-Meyer relationship (continued)

M	ω	M	ω	M	ω	M	ω
3.0100	49.9499	3.5100	58.6886	4.0100	65.9167	4.5100	71.9422
3.0200	50.1417	3.5200	58.8469	4.0200	66.0480	4.5200	72.0522
3.0300	50.3328	3.5300	59.0045	4.0300	66.1789	4.5300	72.1619
3.0400	50.5231	3.5400	59.1616	4.0400	66.3093	4.5400	72.2712
3.0500	50.7127	3.5500	59.3180	4.0500	66.4393	4.5500	72.3801
3.0600	50.9016	3.5600	59.4739	4.0600	66.5688	4.5600	72.4887
3.0700	51.0897	3.5700	59.6291	4.0700	66.6978	4.5700	72.5968
3.0800	51.2771	3.5800	59.7838	4.0800	66.8263	4.5800	72.7046
3.0900	51.4638	3.5900	59.9379	4.0900	66.9544	4.5900	72.8121
3.1000	51.6497	3.6000	60.0915	4.1000	67.0820	4.6000	72.9192
3.1100	51.8350	3.6100	60.2444	4.1100	67.2092	4.6100	73.0259
3.1200	52.0195	3.6200	60.3968	4.1200	67.3359	4.6200	73.1322
3.1300	52.2033	3.6300	60.5486	4.1300	67.4621	4.6300	73.2382
3.1400	52.3864	3.6400	60.6998	4.1400	67.5879	4.6400	73.3438
3.1500	52.5688	3.6500	60.8504	4.1500	67.7132	4.6500	73.4491
3.1600	52.7505	3.6600	61.0005	4.1600	67.8381	4.6600	73.5540
3.1700	52.9315	3.6700	61.1501	4.1700	67.9626	4.6700	73.6586
3.1800	53.1118	3.6800	61.2990	4.1800	68.0866	4.6800	73.7628
3.1900	53.2914	3.6900	61.4474	4.1900	68.2101	4.6900	73.8666
3.2000	53.4703	3.7000	61.5953	4.2000	68.3332	4.7000	73.9701
3.2100	53.6486	3.7100	61.7426	4.2100	68.4559	4.7100	74.0733
3.2200	53.8261	3.7200	61.8893	4.2200	68.5782	4.7200	74.1761
3.2300	54.0029	3.7300	62.0355	4.2300	68.7000	4.7300	74.2786
3.2400	54.1791	3.7400	62.1812	4.2400	68.8213	4.7400	74.3807
3.2500	54.3546	3.7500	62.3263	4.2500	68.9423	4.7500	74.4824
3.2600	54.5294	3.7600	62.4709	4.2600	69.0628	4.7600	74.5839
3.2700	54.7036	3.7700	62.6149	4.2700	69.1829	4.7700	74.6850
3.2800	54.8770	3.7800	62.7584	4.2800	69.3026	4.7800	74.7858
3.2900	55.0498	3.7900	62.9014	4.2900	69.4218	4.7900	74.8862
3.3000	55.2220	3.8000	63.0438	4.3000	69.5406	4.8000	74.9863
3.3100	55.3935	3.8100	63.1857	4.3100	69.6590	4.8100	75.0860
3.3200	55.5643	3.8200	63.3271	4.3200	69.7770	4.8200	75.1855
3.3300	55.7344	3.8300	63.4679	4.3300	69.8946	4.8300	75.2846
3.3400	55.9040	3.8400	63.6083	4.3400	70.0118	4.8400	75.3833
3.3500	56.0728	3.8500	63.7481	4.3500	70.1285	4.8500	75.4818
3.3600	56.2411	3.8600	63.8874	4.3600	70.2449	4.8600	75.5799
3.3700	56.4086	3.8700	64.0262	4.3700	70.3608	4.8700	75.6777
3.3800	56.5756	3.8800	64.1645	4.3800	70.4763	4.8800	75.7752
3.3900	56.7419	3.8900	64.3023	4.3900	70.5914	4.8900	75.8723
3.4000	56.9075	3.9000	64.4395	4.4000	70.7062	4.9000	75.9691
3.4100	57.0725	3.9100	64.5763	4.4100	70.8205	4.9100	76.0657
3.4200	57.2369	3.9200	64.7125	4.4200	70.9344	4.9200	76.1619
3.4300	57.4007	3.9300	64.8483	4.4300	71.0479	4.9300	76.2577
3.4400	57.5639	3.9400	64.9836	4.4400	71.1611	4.9400	76.3533
3.4500	57.7264	3.9500	65.1183	4.4500	71.2738	4.9500	76.4486
3.4600	57.8883	3.9600	65.2526	4.4600	71.3862	4.9600	76.5435
3.4700	58.0496	3.9700	65.3864	4.4700	71.4982	4.9700	76.6382
3.4800	58.2102	3.9800	65.5197	4.4800	71.6097	4.9800	76.7325
3.4900	58.3703	3.9900	65.6525	4.4900	71.7209	4.9900	76.8265
3.5000	58.5298	4.0000	65.7848	4.5000	71.8317	5.0000	76.9202