UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 1997/98

September 1997

EMK 310 - Dinamik Gas & Dorongan Jet

Masa ; [3 jam]

ARAHAN KEPADA CALON:

Sila pastikan bahawa kertas soalan ini mengandungi **LAPAN** mukasurat dan **DUA PULUH TUJUH** halaman lampiran serta **TUJUH** soalan yang bercetak sebelum anda memulakan peperiksaan.

Sila jawab **LIMA** soalan sahaja.

Sekurang-kurangnya satu (1) soalan mestilah dijawab dalam bahasa Malaysia. Soalan-soalan yang lain bolehlah dijawab sama ada dalam bahasa Malaysia atau bahasa Inggeris.

Setiap soalan mestilah dimulakan pada mukasurat yang baru.

Termasuk lampiran-lampiran:

1. "Working Chart and Table for Isentropic Flow." (2 m/s)
2. "Working Chart and Table Flow Across a Normal Shock Wave." (4 m/s)
3. "Working Chart and Table Isothermal Flow of a Perfect Gas." (2 m/s)
4. "Working Chart and Table the Flow of a Perfect Gas on the Rayleigh Line." (2 m/s)
5. "Properties of the Standar Atmosphere." (1 m/s)
6. "Thermodynamic Properties of Common Gases at Standard Temperature and Pressure (15°C, 101.325 kPa)" (1 m/s)
7. "Isentropic Flow of a Perfect Gas (k = 1.4)." (1 m/s)
8. "Flow of a Perfect Gas Across a Normal Shock." (2 m/s)
9. "Flow of a Perfect Gas on a Fanno Line." (4 m/s)
10. "Isothermal Flow of a Perfect Gas." (3 m/s)
11. "Flow of a Perfect Gas on the Rayleigh Line." (2 m/s)

..2/-

S1. [a] **Terbitkan persamaan keselanjaran satu dimensi bagi aliran boleh mampat tak stabil dalam bentuk kebezaan. Apakah pemudahan yang terlibat di dalam persamaan ini jika aliran adalah :-**

[i] stabil

[ii] tak boleh mampatan

Derive the one-dimensional continuity equation for an unsteady compressible flow in differential form. What simplifications are involved in this equation if the flow is :-

[i] steady

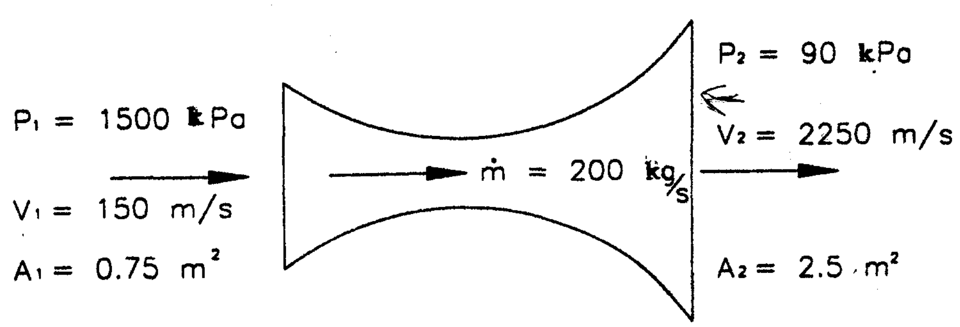
[ii] incompressible

(40 markah)

[b] **Satu muncung menumpu-mencapah mempunyai halaju dan tekanan seperti yang ditunjukkan di dalam Rajah S1[b]. Tentukan nilai daya yang diperlukan untuk memegang muncung pada tempatnya. Kirakan juga nilai tujahan bagi muncung yang ditunjukkan.**

A convergent-divergent nozzle has the velocities and pressure shown in Figure Q1[b]. Find the force required to hold the nozzle in place. Calculate the thrust for the given nozzle.

(60 markah)



Rajah S1[b]
Figure Q1[b]

S2. **[a]** **Dengan bantuan gambaran, tunjukkan zon senyapan tidak wujud bagi aliran subbunyi.**

Show by illustration, zones of silence do not exist for a subsonic flow.

(10 markah)

[b] **Terbitkan persamaan bagi halaju elips prandtl dan tunjukkan secara gambarajah pelbagai rejim bagi aliran boleh mampat seentropi.**

Derive an equation for the Prandtl velocity Ellipse and illustrate the various regimes of isentropic compressible flow.

(30 markah)

[c] **Satu aliran udara mengalir di dalam satu salur penumpuan dari Stesen 1 dengan luas keratan rentas 1176 mm^2 ke Stesen 2 dengan luas keratan rentas 1057 mm^2, yang mana tekanan, suhu dan halaju adalah 150 kPa, 125°C dan 304 m/s masing-masing.**

[i] **Tentukan properti-properti genangan bagi bendalir pada Stesen 2.**

[ii] **Tentukan properti-properti bendalir pada Stesen 1.**

[iii] **Tentukan kadar aliran jisim**

[iv] **Tunjukkan proses ini di atas gambarajah suhu-entropi.**

Anggapkan aliran stabil satu dimensi seentropi.

An air stream flows in a converging duct from a cross-sectional area of 1176 mm^2 at Station 1 to a cross sectional area of 1057 mm^2 at Station 2 where the pressure, temperature and velocity are 150 kPa, 125°C and 304 m/s respectively.

[i] *Determine the stagnation properties of the fluid at Station 2.*

[ii] *Determine the fluid properties at Station 1.*

[iii] *Determine the mass flow rate.*

[iv] *Show the process on a temperature-entropy diagram.*

Assume steady one dimensional isentropic flow.

(60 markah)

..4/-

S3. [a] Tunjukkan bahawa, bagi gas-gas berkalori sempurna, proses kejutan normal mengakibatkan suhu genangan malar.

Show that, for calorically perfect gases, the normal shock process possesses a constant stagnation temperature.

(20 markah)

[b] Tunjukkan bahawa aliran dengan nombor Mach kurang dari satu tidak akan menghasilkan kejutan normal.

Show that a flow with a stream Mach number less than one cannot produce a normal shock wave.

(20 markah)

[c] Aliran udara dengan halaju 500 m/s, tekanan pegun 70 kPa dan suhu pegun 300 K mengalami kejutan normal. Tentukan:-

[i] Nombor Mach dan halaju selepas gelombang kejutan normal.

[ii] Keadaan-keadaan pegun selepas gelombang kejutan normal.

[iii] Perubahan entropi di sepanjang rentasan gelombang kejutan normal.

An air stream with a velocity of 500m/s, a static pressure of 70 kPa and a static temperature of 300 K undergoes a normal shock. Determine:-

[i] Mach number and the velocity after the normal shock wave.

[ii] the static conditions after the normal shockwave.

[iii] the entropy change across the normal shockwave.

(60 markah)

S4. [a] Namakan <u>EMPAT</u> potensi memandu yang selalunya digunakan di dalam kajian aliran boleh mampat satu dimensi.

Name the <u>FOUR</u> driving potentials normally used in the study of one-dimensional compressible flows.

(10 markah)

..5/-

[b] **Tunjukkan bahawa bagi aliran Fanno bagi gas yang sempurna kalorinya, keadaan entropi maksimum terjadi pada ketika keadaan Nombor Mach, M = 1.**

Show that for the Fannoflow of a calorically perfect gas, the state of maximum entropy is the sonic state, M = 1.

(20 markah)

[c] **Gas asli dibekalkan ke Stesen Janakuasa Turbin Gas melalui paip berdiameter 50 sm (Faktor geseran Fanning 0.004). Kirakan jarak antara stesen-stesen pengepam apabila tekanan di dalam paip berkurangan dari 500 kPa pada keluaran satu pemampat ke 150 kPa pada masukan bagi pemampat berikutnya. Gas asli berkenaan mengalir secara sesuhu pada 300°K. Halaju pada masukan ialah 13.59 m/s. Ambil nilai $\gamma = 1.32$; $C_p = 2223$ J/kgK; R = 518.2 J/kgK.**

Natural gas is supplied to a Gas Turbine Power Station through a 50 cm diameter pipe (Fanning friction factor 0.004). Calculate distance between the pumping stations when the pressure in the pipe reduces from 500 kPa at exit of compressor to 150 kPa at inlet of next compressor. The natural gas flows isothermally at 300°K. The velocity at inlet is 13.59 m/s. $\gamma = 1.32$; $C_p = 2223$ J/kgK; R = 518.2 J/kgK.

(70 markah)

S5. [a] **Tunjukkan bagi satu proses Rayleigh, nombor Mach pada nisbah suhu maksimum diberi oleh** $M^2 = \frac{1}{\gamma}$. **Mulakan dengan persamaan**

$$\frac{T}{T^*} = \frac{(1+\gamma)^2 M^2}{(1+\gamma M^2)^2}.$$

Starting from $\frac{T}{T^*} = \frac{(1+\gamma)^2 M^2}{(1+\gamma M^2)^2}$ *show that, for a Rayleigh Process, the Mach number associated with the maximum value of the temperature ratio is given by* $M^2 = \frac{1}{\gamma}$.

(20 markah)

..6/-

[b] **Dengan berbantukan gambarajah enthalpi-entropi, tunjukkan bahawa lokus bagi keadaan-keadaan sebelum dan selepas kejutan normal terletak pada garisan-garisan Rayleigh dan Fanno.**

Illustrate with an enthalpy-entropy diagram that the locus of states before and after a normal shock appears on Rayleigh and Fanno lines.

(20 markah)

[c] **Satu salur dengan keluasan tetap disambungkan kepada satu tangki bertekanan tinggi melalui sebuah muncung mencapah. Dinding bagi salur yang berkeluasan tetap berkenaan dipanaskan, agar udara yang melalui saluran itu mendapat 250 kJ/kg. Tekanan dan suhu bagi tangki adalah 750 kPa dan 300 K masing-masing. Tekanan balik bagi sistem ialah 300 kPa. Tentukan samada saluran itu dicekik atau tidak. Kirakan juga kadar aliran jisim bagi udara yang melalui saluran berkenaan jika diameternya ialah 5 sm dan panjangnya 1.2 m. Nyatakan anggapan-anggapan yang dibuat di dalam penyelesaian masalah ini.**

A constant-area duct is connected to a high pressure air reservoir through a converging nozzle. The walls of the constant-area duct are heated so as to supply 250 kJ/kg to the air passing through the duct. The reservoir pressure and temperature are 750 kPa and 300 K respectively. The system back pressure is 300 kPa. Determine whether or not the duct is choked. Also find the mass flow rate of air passing through the duct if the duct diameter is 5 cm and duct length is 1.2 m.. Mention the assumptions made in the solution of the problem.

(60 markah)

S6. [a] **Terangkan prinsip kerja bagi enjin jet turbo dengan bantuan gambarajah skima. Tunjukkan proses-proses termodinamik yang berlaku di atas gambarajah suhu-entropi dan bezakan antara kitar unggul dan kitar sebenar.**

Explain the working of a turbo jet engine with the help of a schematic diagram and represent the thermodynamic processes taking place on an temperature-entropy diagram bringing out the differences between ideal and actual cycles.

(40 markah)

..7/-

[b] **Sebuah kapalterbang berenjin jet turbo terbang pada ketinggian 11,00 meter (tekanan dan suhu adalah 22.6 kPa dan 216.65 K) masing-masing pada kelajuan 222 m/s. Luas bagi saluran masukan dan jet adalah 0.6 m^2 dan 0.4 m^2 masing-masing dan halaju jet ialah 550 m/s. Nisbah bahanapi ke udara ialah 0.018 dan tekanan jet ialah 23.0 kPa. Jika tenaga yang benar-benar dipindahkan kepada bendalir kerja hasil dari pembakaran bahanapi ialah 729 kJ/kg (nilai pemanasan bagi bahanapi ialah 45,000 kJ/kg). Tentukan:-**

[i] **Tujahan bersih bagi enjin**

[ii] **Kecekapan dorongan**

[iii] **Kecekapan terma keseluruhan**

[iv] **Penggunaan bahanapi tentu tujah bersih**

[v] **Penggunaan bahanapi tentu tujah kasar**

A turbojet driven aircraft flies at an altitude of 11,000 meters (pressure and temperature are 22.6 kPa and 216.65 K) at a speed of 222 m/s. The inlet and jet areas are 0.6 m^2 and 0.4 m^2 respectively and the jet velocity is 550 m/s. The fuel to air ratio is 0.018 and the jet pressure is 23.0 kPa. If the energy actually transferred to the working fluid by the combustion of the fuel is 729 kJ/kg (when the heating value of the fuel is 45000 kJ/kg). Determine:-

[i] *net thrust of the engine*

[ii] *propulsive efficiency*

[iii] *overall thermal efficiency*

[iv] *net thrust specific fuel consumption*

[v] *gross thrust specific fuel consumption*

(60 markah)

S7. [a] **Bezakan prinsip kerja bagi sistem kipas turbo dan prop turbo. Tunjukkan proses-proses termodinamik yang terlibat di atas gambarajah suhu-entropi.**

Distinguish between the turboprop and turbofan systems in terms of their working. Represent the thermodynamic processes on temperature-entropy diagram.

(30 markah)

[b] **Sebuah enjin turbofan mengunakan muncung sejuk dan panas secara berasingan. Kejatuhan suhu di dalam muncung panas ialah 80 K dan muncung sejuk 40 K. Nisbah pirau ialah 2.5 dan jumlah kadar alir jisim udara ialah 100 kg/s. Haba tentu bagi udara dan gas ialah 1.005 kJ/kgK dan 1.15 kJ/kgK masing-masing. Tentukan tujahan-tujahan yang dihasilkan oleh setiap jet dan daya seretan jika kelajuan enjin ketika berlepas ialah 100 m/s.**

The following details refer to a turbofan engine in which separate hot and cold nozzles are used. Temperature drop in the hot nozzle is 80 K and in cold nozzle it is 40 K. The by pass ratio is 2.5 and the total air mass flow rate is 100 kg/s. The specific heats of air and gas are 1.005 kJ/kgK and 1.15 kJ/kgK respectively. Determine the thrusts produced by individual jets and the drag force if the take off speed of the engine is 100 m/s.

(50 markah)

[c] **Tuliskan sedikit nota ringkas tentang imbuhan tujahan di dalam enjin jet.**

Write a brief note on thrust augmentation in jet engines.

(20 markah)

oooOooo

WORKING CHART AND WORKING TABLE FOR ISENTROPIC FLOW

Formulas derived thus far introduce quite tedious numerical calculations, and their solutions often involve a trial-and-error procedure. The numerical calculations can be facilitated by introducing a working chart and a working table. The following equations are the property ratios for the steady, isentropic and one-dimensional flow of a perfect gas that were derived in the previous sections.

$$M^{*2} = \frac{[(k+1)/2]M^2}{1+[(k-1)/2]M^2}$$

$$\frac{T_0}{T} = 1 + \frac{k-1}{2}M^2$$

$$\frac{p_0}{p} = \left(1 + \frac{k-1}{2}M^2\right)^{k/(k-1)}$$

$$\frac{\rho_0}{\rho} = \left(1 + \frac{k-1}{2}M^2\right)^{1/(k-1)}$$

$$\frac{A}{A^*} = \frac{1}{M}\left[\frac{2}{k+1}\left(1 + \frac{k-1}{2}M^2\right)\right]^{(k+1)/[2(k-1)]}$$

$$\frac{I}{I^*} = \frac{1+kM^2}{M\sqrt{2(k+1)[1+\frac{1}{2}(k-1)M^2]}}$$

$$\frac{\dot{m}\sqrt{RT_0}}{Ap_0} = \sqrt{k}\,M\left(1 + \frac{k-1}{2}M^2\right)^{-(k+1)/[2(k-1)]}$$

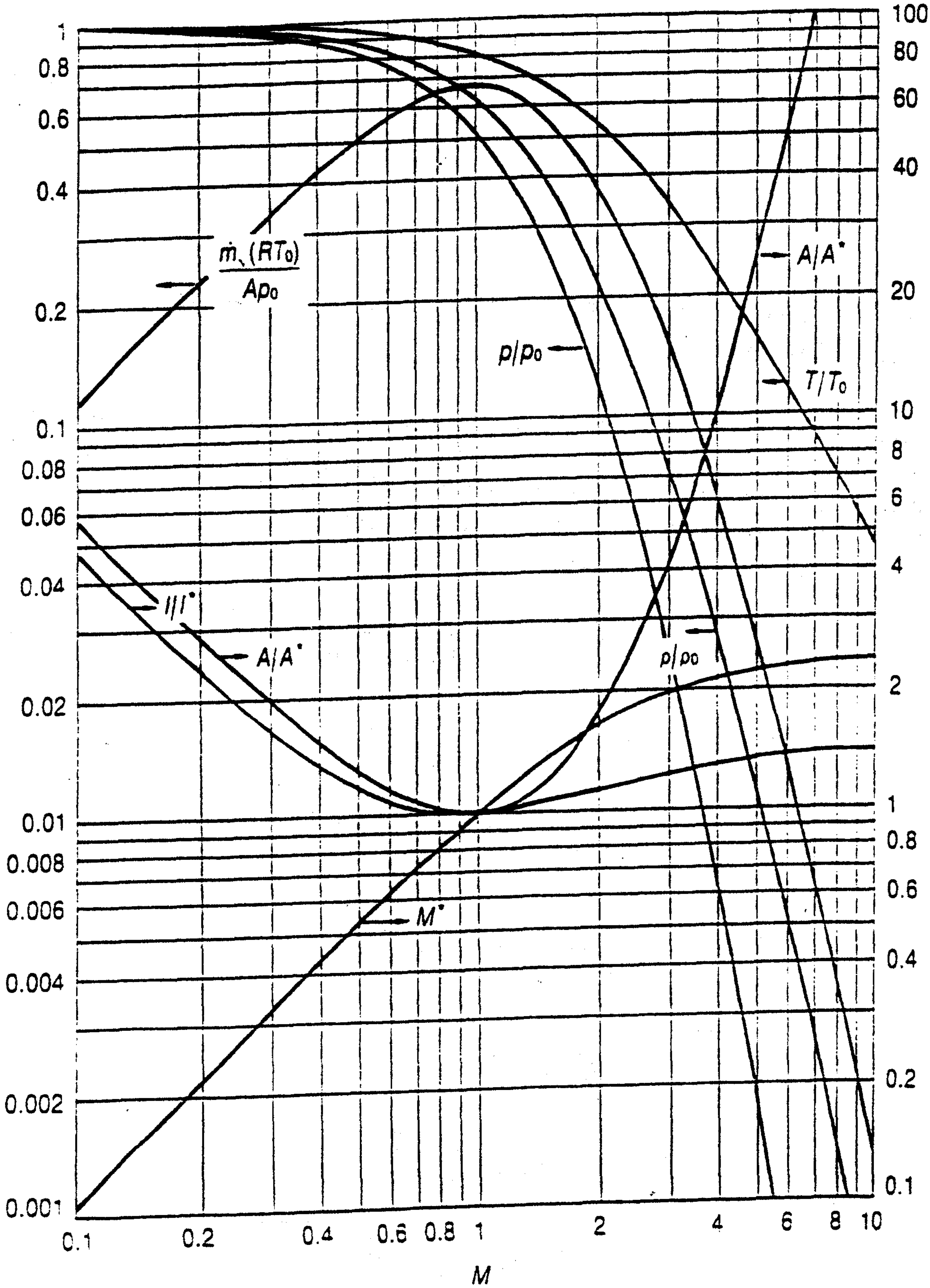


Figure 4.19 Working chart for isentropic flow ($k = 1.4$)

WORKING CHART AND WORKING TABLE FOR FLOW ACROSS A NORMAL SHOCK WAVE

The formulas derived thus far introduce quite extensive numerical calculations, and their solutions often involve a trial-and-error procedure. The numerical computations may be facilitated by introducing a working chart and a working table. The following equations are the property ratios for flow across a normal shock wave:

$$M_y = \sqrt{\left(\frac{(k-1)M_x^2 + 2}{2kM_x^2 - (k-1)}\right)}$$

$$\frac{T_y}{T_x} = \left(1 + \frac{k-1}{2} M_x^2\right)\left(\frac{2k}{k-1} M_x^2 - 1\right) \Big/ \left(\frac{(k+1)^2}{2(k-1)} M_x^2\right)$$

$$\frac{p_y}{p_x} = \frac{2k}{k+1} M_x^2 - \frac{k-1}{k+1}$$

$$\frac{\rho_y}{\rho_x} = \frac{(k+1)M_x^2}{2 + (k-1)M_x^2}$$

$$\frac{V_y}{V_x} = \frac{2 + (k-1)M_x^2}{(k+1)M_x^2}$$

$$\frac{p_{0y}}{p_{0x}} = \frac{A_x^*}{A_y^*} = \left(\frac{\frac{1}{2}(k+1)M_x^2}{1 + \frac{1}{2}(k-1)M_x^2}\right)^{k/(k-1)} \left(\frac{2k}{k+1} M_x^2 - \frac{k-1}{k+1}\right)^{1/(1-k)}$$

$$\frac{s_y - s_x}{R} = \frac{k}{k-1} \ln\left(\frac{2}{(k+1)M_x^2} + \frac{k-1}{k+1}\right) + \frac{1}{k-1} \ln\left(\frac{2k}{k+1} M_x^2 - \frac{k-1}{k+1}\right)$$

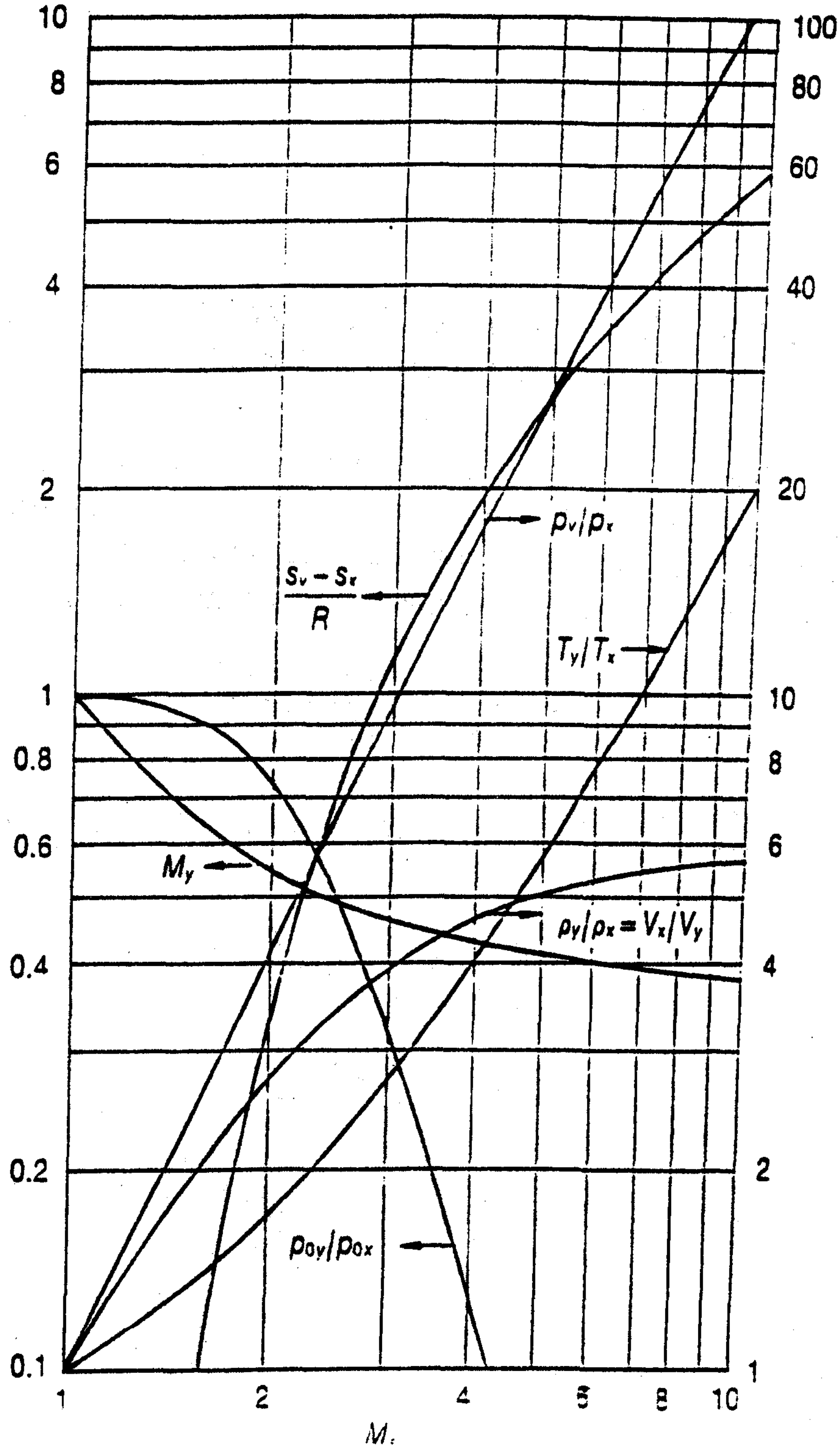


Figure 5.12 Working chart for the flow across a normal shock wave with $k = 1.4$

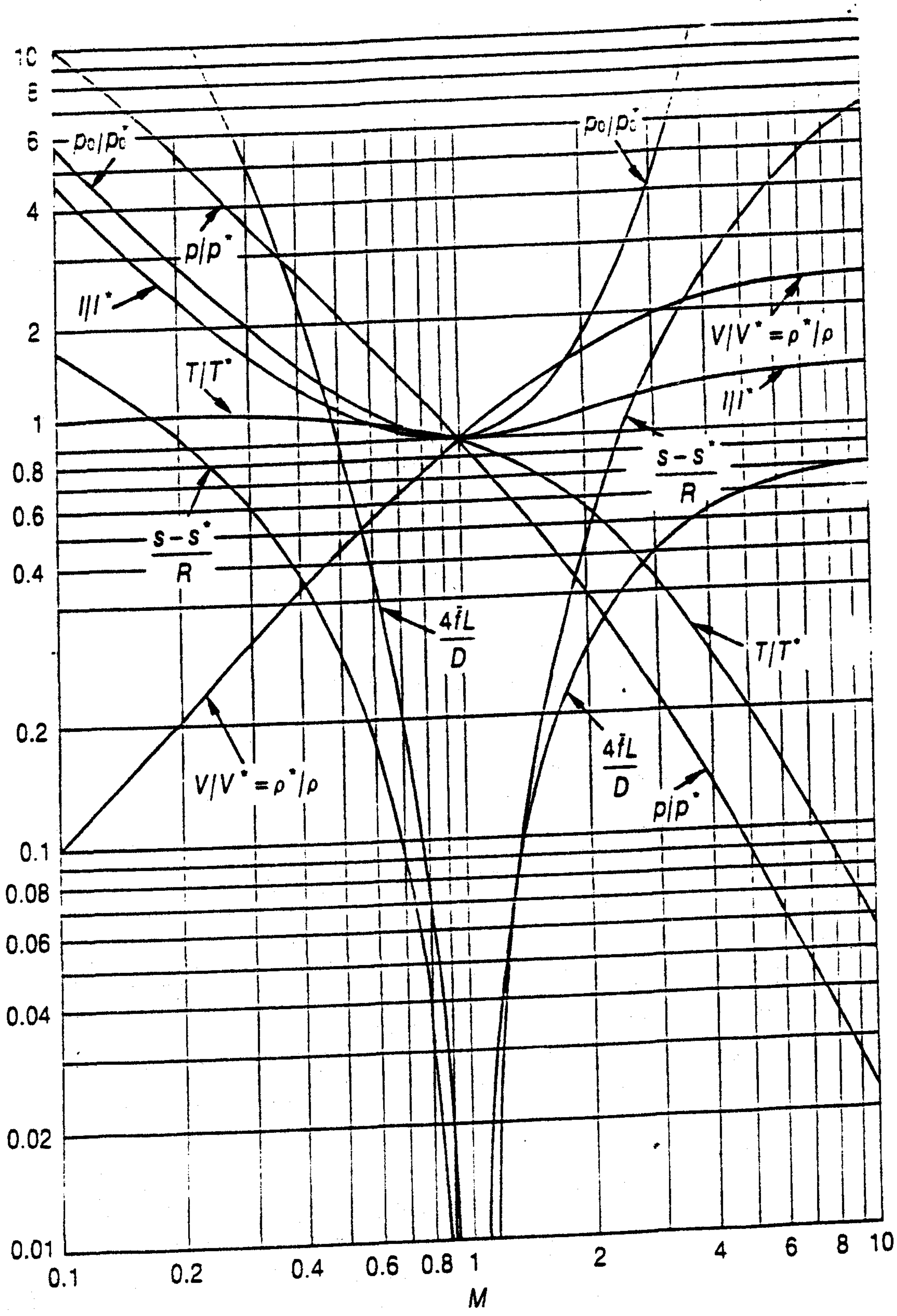


Figure 6.6 Working chart for the Fanno line flow of a perfect gas with $k = 1.4$

equations are the non-dimensional properties for the Fanno line flow of a perfect gas that were derived in the previous section:

$$\frac{p}{p^*} = \frac{1}{M}\sqrt{\left(\frac{k+1}{2[1+\frac{1}{2}(k-1)M^2]}\right)}$$

$$\frac{T}{T^*} = \frac{k+1}{2[1+\frac{1}{2}(k-1)M^2]}$$

$$\frac{\rho}{\rho^*} = \frac{1}{M}\sqrt{\left(\frac{2[1+\frac{1}{2}(k-1)M^2]}{k+1}\right)}$$

$$\frac{V}{V^*} = M\sqrt{\left(\frac{k+1}{2[1+\frac{1}{2}(k-1)M^2]}\right)}$$

$$\frac{p_0}{p_0^*} = \frac{1}{M}\left(\frac{2[1+\frac{1}{2}(k-1)M^2]}{k+1}\right)^{(k+1)/[2(k-1)]}$$

$$\frac{F}{F^*} = \frac{1+kM^2}{M\sqrt{\{2(k+1)[1+\frac{1}{2}(k-1)M^2]\}}}$$

$$\frac{s-s^*}{R} = \ln\left\{M\left[\left(\frac{2}{k+1}\right)\left(1+\frac{k-1}{2}M^2\right)\right]^{(k+1)/[2(1-k)]}\right\}$$

$$\frac{4fL_{max}}{D} = \frac{1-M^2}{kM^2} + \frac{k+1}{2k}\ln\left(\frac{(k+1)M^2}{2[1+\frac{1}{2}(k-1)M^2]}\right)$$

[4/4]

WORKING CHART AND WORKING TABLE FOR THE ISOTHERMAL FLOW OF A PERFECT GAS

Formulas derived thus far introduce quite tedious numerical calculations and their solutions often involve a trial-and-error procedure. The numerical calculations can be facilitated by introducing a working chart and a working table. The following equations are the non-dimensional properties for the isothermal flow of a perfect gas that were derived in the previous section:

$$\frac{p}{p^{*t}} = \frac{1}{\sqrt{(k)}M}$$

$$\frac{\rho}{\rho^{*t}} = \frac{1}{\sqrt{(k)}M}$$

$$\frac{V}{V^{*t}} = \sqrt{(k)}M$$

$$\frac{p_0}{p_0^{*t}} = \frac{1}{\sqrt{(k)}M}\left[\frac{2k}{3k-1}\left(1+\frac{k-1}{2}M^2\right)\right]^{k/(k-1)}$$

$$\frac{T_0}{T_0^{*t}} = \frac{2k}{3k-1}\left(1+\frac{k-1}{2}M^2\right)$$

$$\frac{I}{I^{*t}} = \frac{1+kM^2}{2M\sqrt{k}}$$

$$\frac{s-s^{*t}}{R} = \ln\left(\sqrt{(k)}M\right)$$

$$\frac{4\bar{f}L_{max}}{D} = \frac{1-kM^2}{kM^2} + \ln\left(kM^2\right)$$

$$\frac{4\bar{f}L}{D} = \frac{1-kM_1^2}{kM_1^2} - \frac{1-kM_2^2}{kM_2^2} + \ln\left(\frac{M_1^2}{M_2^2}\right)$$

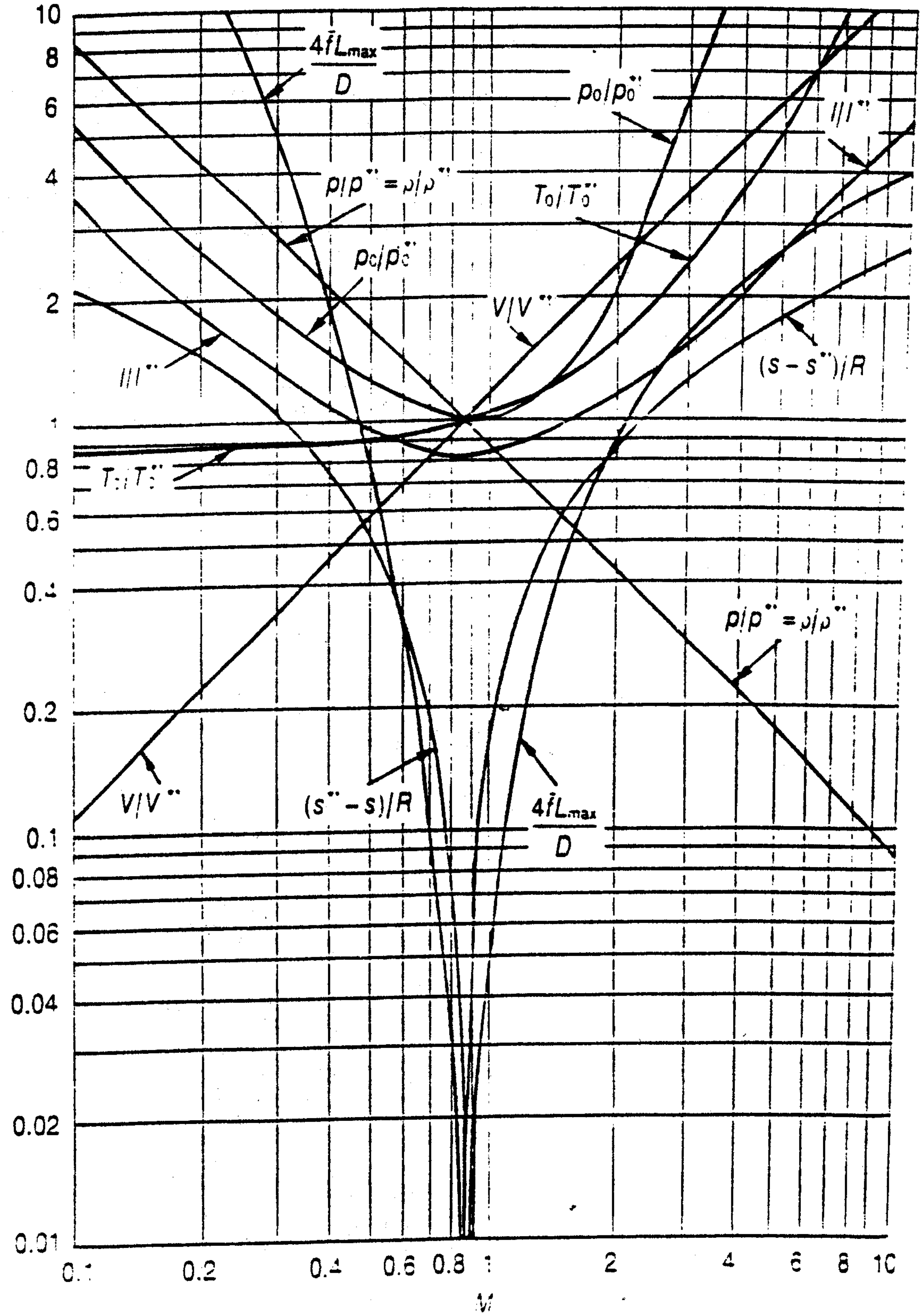


Figure 3.24 Working chart for the isothermal flow of a perfect gas with $k = 1.4$

WORKING CHART AND WORKING TABLE FOR THE FLOW OF A PERFECT GAS ON THE RAYLEIGH LINE

The formulas that were derived in the previous section introduce tedious numerical calculations, and their solution often involves a trial-and-error procedure. The numerical calculations can be facilitated by introducing a working chart and a working table. During the preparation of this working chart and working table, it is convenient to normalize these equations by setting the Mach number equal to unity at one of the sections. For this reason, the Mach number may be chosen to be unity at section 2, and then section 1 may be considered to be any other section of the same duct. If the properties at section 2 are denoted by a superscript asterisk, and those at section 1 are without a subscript, then the following equations are the non-dimensional properties for the Rayleigh line flow of a perfect gas that were derived in the previous section:

$$\frac{p}{p^*} = \frac{1+k}{1+kM^2} \tag{7.33}$$

$$\frac{T}{T^*} = \frac{M^2(1+k)^2}{(1+kM^2)^2} \tag{7.34}$$

$$\frac{\rho}{\rho^*} = \frac{1+kM^2}{(1+k)M^2} \tag{7.35}$$

$$\frac{V}{V^*} = \frac{(1+k)M^2}{1+kM^2} \tag{7.36}$$

$$\frac{p_0}{p_0^*} = \frac{1+k}{1+kM^2}\left(\frac{2+(k-1)M^2}{k+1}\right)^{k/(k-1)} \tag{7.37}$$

$$\frac{T_0}{T_0^*} = \frac{M^2(k+1)\,[2+(k-1)M^2]}{(1+kM^2)^2} \tag{7.38}$$

$$\frac{s^* - s}{R} = \ln\left[\left(\frac{1+kM^2}{1+k}\right)^{(k+1)/(k-1)}\left(\frac{1}{M}\right)^{2k/(k-1)}\right] \tag{7.39}$$

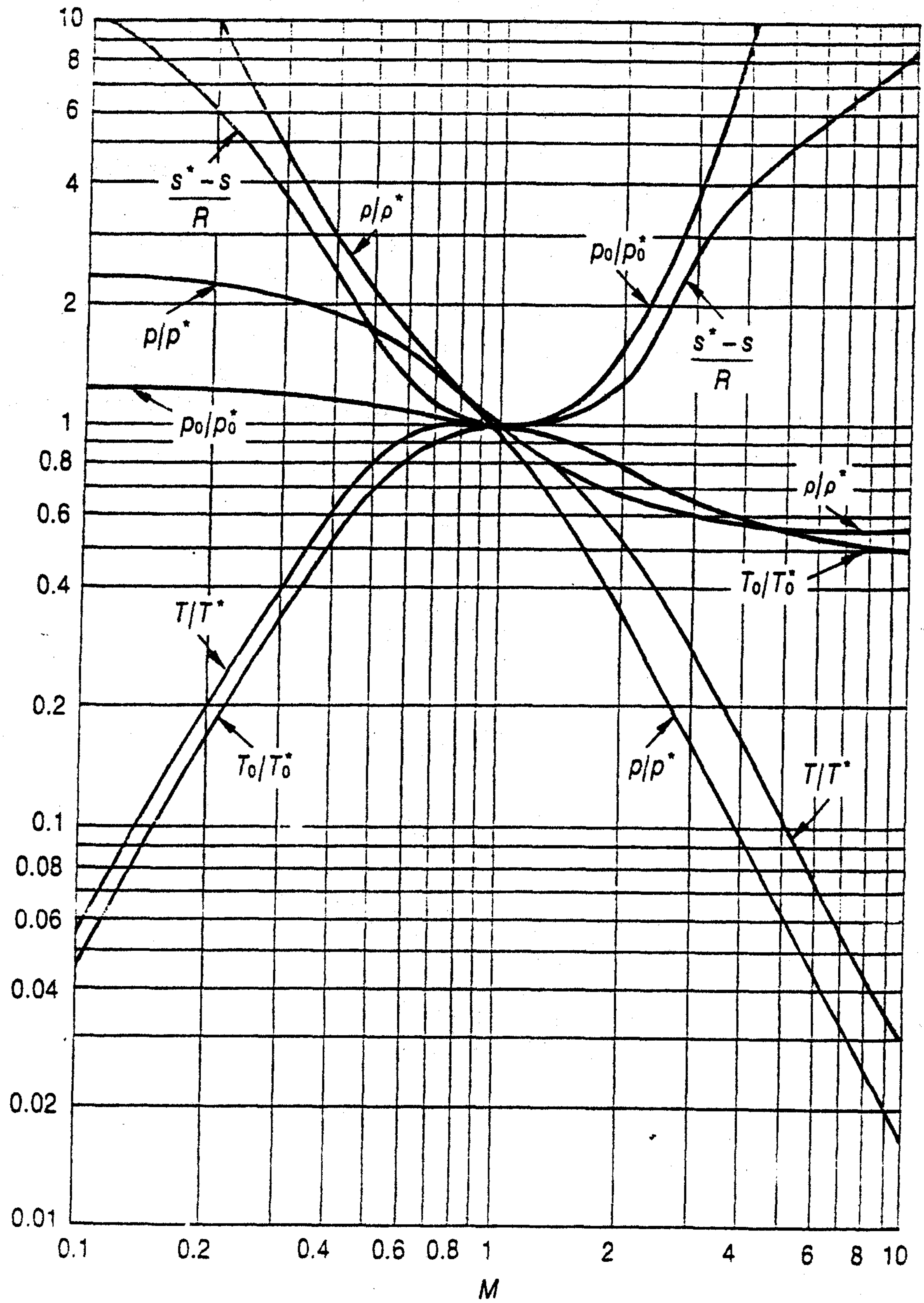


Figure 7.5 Working chart for the flow of a perfect gas with $k = 1.4$ on the Rayleigh Line

Appendix
Properties of the standard atmosphere

Altitude (m)	Temperature (K)	Pressure (N m^{-2})	Density (kg m^{-3})
-1 000	294.7	1.139×10^{5}	1.347
-500	291.5	1.075×10^{5}	1.285
0	288.2	1.013×10^{5}	1.225
500	284.9	9.546×10^{4}	1.167
1 000	281.7	8.988×10^{4}	1.112
1 500	278.4	8.546×10^{4}	1.058
2 000	275.2	7.950×10^{4}	1.007
2 500	271.9	7.469×10^{4}	9.570×10^{-1}
3 000	268.7	7.012×10^{4}	9.023×10^{-1}
3 500	265.4	6.578×10^{4}	8.634×10^{-1}
4 000	262.2	6.166×10^{4}	8.192×10^{-1}
4 500	258.9	5.775×10^{4}	7.770×10^{-1}
5 000	255.7	5.405×10^{4}	7.364×10^{-1}
6 000	249.2	4.722×10^{4}	6.601×10^{-1}
7 000	242.7	4.111×10^{4}	5.900×10^{-1}
8 000	236.2	3.565×10^{4}	5.258×10^{-1}
9 000	229.7	3.080×10^{4}	4.671×10^{-1}
10 000	223.3	2.650×10^{4}	4.135×10^{-1}
11 000	216.8	2.270×10^{4}	3.648×10^{-1}
12 000	216.7	1.940×10^{4}	3.119×10^{-1}
13 000	216.7	1.658×10^{4}	2.666×10^{-1}
14 000	216.7	1.417×10^{4}	2.279×10^{-1}
15 000	216.7	1.211×10^{4}	1.948×10^{-1}
16 000	216.7	1.035×10^{4}	1.665×10^{-1}
17 000	216.7	8.850×10^{3}	1.423×10^{-1}
18 000	216.7	7.565×10^{3}	1.217×10^{-1}
19 000	216.7	6.468×10^{3}	1.040×10^{-1}
20 000	216.7	5.529×10^{3}	8.891×10^{-2}
21 000	217.6	4.729×10^{3}	7.572×10^{-2}
22 000	218.6	4.048×10^{3}	6.451×10^{-2}
23 000	219.6	3.467×10^{3}	5.501×10^{-2}
24 000	220.6	2.972×10^{3}	4.694×10^{-2}
25 000	221.6	2.549×10^{3}	4.008×10^{-2}

Appendix *Continued*

Altitude (m)	Temperature (K)	Pressure (N m^{-2})	Density (kg m^{-3})
26 000	222.5	2.188×10^{3}	3.426×10^{-2}
27 000	223.5	1.880×10^{3}	2.930×10^{-2}
28 000	224.5	1.616×10^{3}	2.508×10^{-2}
29 000	225.5	1.390×10^{3}	2.148×10^{-2}
30 000	226.5	1.197×10^{3}	1.841×10^{-2}
31 000	227.6	1.031×10^{3}	1.579×10^{-2}
32 000	228.5	8.891×10^{2}	1.356×10^{-2}
33 000	231.0	7.673×10^{2}	1.157×10^{-2}
34 000	233.7	6.634×10^{2}	9.887×10^{-3}
35 000	236.5	5.746×10^{2}	8.463×10^{-3}
36 000	239.3	4.985×10^{2}	7.528×10^{-3}
37 000	242.1	4.333×10^{2}	6.236×10^{-3}
38 000	244.8	3.771×10^{2}	5.367×10^{-3}
39 000	247.6	3.288×10^{2}	4.627×10^{-3}
40 000	250.4	2.871×10^{2}	3.996×10^{-3}
42 000	255.9	2.200×10^{2}	2.995×10^{-3}
44 000	261.4	1.695×10^{2}	2.259×10^{-3}
46 000	266.9	1.313×10^{2}	1.714×10^{-3}
48 000	270.7	1.023×10^{2}	1.317×10^{-3}
50 000	270.7	7.978×10^{1}	1.027×10^{-3}
55 000	265.6	4.275×10^{1}	5.608×10^{-4}
60 000	255.8	2.246×10^{1}	3.059×10^{-4}
65 000	239.3	1.145×10^{1}	1.667×10^{-4}
70 000	219.7	5.251	8.754×10^{-5}
75 000	200.2	2.490	4.335×10^{-5}
80 000	180.7	1.037	1.999×10^{-5}
85 000	180.7	4.125×10^{-1}	7.955×10^{-6}
90 000	180.7	1.644×10^{-1}	3.170×10^{-6}
95 000	195.5	6.801×10^{-2}	1.211×10^{-6}
100 000	210.0	3.008×10^{-2}	4.974×10^{-7}

Appendix B
Thermodynamic properties of common gases at standard temperature and pressure (15 °C, 101.325 kPa)

Gas	Chemical formula	Molecular mass, M	R ($J\,kg^{-1}\,K^{-1}$)	c_p ($J\,kg^{-1}\,K^{-1}$)	c_v ($J\,kg^{-1}\,K^{-1}$)	k
Air	–	28.96	287.1	1005	717.7	1.400
Carbon monoxide	CO	28.01	296.8	1043	745.8	1.398
Carbon dioxide	CO_2	44.01	188.9	844.9	655.9	1.288
Helium	He	4.000	2079	5233	3154	1.659
Hydrogen	H_2	2.016	4124	14 307	10 183	1.405
Methane	CH_4	16.04	518.3	2223	1705	1.304
Nitrogen	N_2	28.01	296.8	1039	742.0	1.400
Oxygen	O_2	32.00	259.8	917.6	657.8	1.395
Steam	H_2O	18.02	461.4	1884	1402	1.329

Appendix C
Isentropic flow of a perfect gas ($k = 1.4$)

M	M^*	p/p_0	T/T_0	ρ/ρ_0	A/A^*	I/I^*	$\dot{m}\sqrt{(RT_0)}/Ap_0$
0.00	0.000 00	1.0000	1.000	1.000	∞	∞	0.000 00
0.01	0.010 95	0.9999	1.000	0.9999	57.87	45.65	0.011 83
0.02	0.021 91	0.9997	0.9999	0.9998	28.94	22.83	0.023 66
0.03	0.032 86	0.9994	0.9998	0.9996	19.30	15.23	0.035 48
0.04	0.043 81	0.9989	0.9997	0.9992	14.48	11.43	0.047 28
0.05	0.054 76	0.9983	0.9995	0.9988	11.59	9.158	0.059 07
0.06	0.065 70	0.9975	0.9993	0.9982	9.666	7.643	0.070 84
0.07	0.076 64	0.9966	0.9990	0.9976	8.292	6.562	0.082 58
0.08	0.087 58	0.9955	0.9987	0.9968	7.262	5.753	0.094 29
0.09	0.098 51	0.9944	0.9984	0.9960	6.461	5.125	0.1060
0.10	0.1094	0.9930	0.9980	0.9950	5.822	4.624	0.1176
0.11	0.1204	0.9916	0.9976	0.9940	5.299	4.215	0.1292
0.12	0.1313	0.9900	0.9971	0.9928	4.864	3.875	0.1408
0.13	0.1422	0.9883	0.9966	0.9916	4.497	3.588	0.1523
0.14	0.1531	0.9864	0.9961	0.9903	4.182	3.343	0.1637
0.15	0.1639	0.9844	0.9955	0.9888	3.910	3.132	0.1751
0.16	0.1748	0.9823	0.9949	0.9873	3.673	2.947	0.1864
0.17	0.1857	0.9800	0.9943	0.9857	3.464	2.786	0.1977
0.18	0.1965	0.9776	0.9936	0.9840	3.278	2.642	0.2089
0.19	0.2074	0.9751	0.9928	0.9822	3.112	2.515	0.2200
0.20	0.2182	0.9725	0.9921	0.9803	2.964	2.400	0.2311
0.21	0.2290	0.9697	0.9913	0.9783	2.829	2.298	0.2420
0.22	0.2398	0.9668	0.9904	0.9762	2.708	2.205	0.2529
0.23	0.2506	0.9638	0.9895	0.9740	2.597	2.120	0.2637
0.24	0.2614	0.9607	0.9886	0.9718	2.496	2.043	0.2744
0.25	0.2722	0.9575	0.9877	0.9694	2.403	1.973	0.2850
0.26	0.2829	0.9541	0.9867	0.9670	2.317	1.909	0.2955
0.27	0.2936	0.9506	0.9856	0.9645	2.238	1.850	0.3059
0.28	0.3043	0.9470	0.9846	0.9619	2.166	1.795	0.3162
0.29	0.3150	0.9433	0.9835	0.9592	2.098	1.745	0.3264
0.30	0.3257	0.9395	0.9823	0.9564	2.035	1.698	0.3365
0.31	0.3364	0.9355	0.9811	0.9535	1.977	1.655	0.3464

continued

Appendix C *Continued*

M	M*	p/p₀	T/T₀	ρ/ρ₀	A/A*	I/I*	ṁ√(RT₀)/Ap₀
0.32	0.3470	0.9315	0.9799	0.9506	1.922	1.614	0.3563
0.33	0.3576	0.9274	0.9787	0.9476	1.871	1.577	0.3660
0.34	0.3682	0.9231	0.9774	0.9445	1.823	1.542	0.3756
0.35	0.3788	0.9188	0.9761	0.9413	1.778	1.509	0.3851
0.36	0.3893	0.9143	0.9747	0.9380	1.736	1.479	0.3945
0.37	0.3999	0.9098	0.9733	0.9347	1.696	1.450	0.4037
0.38	0.4104	0.9052	0.9719	0.9313	1.659	1.424	0.4128
0.39	0.4209	0.9004	0.9705	0.9278	1.623	1.398	0.4218
0.40	0.4313	0.8956	0.9690	0.9243	1.590	1.375	0.4306
0.41	0.4418	0.8907	0.9675	0.9207	1.559	1.353	0.4393
0.42	0.4522	0.8857	0.9659	0.9170	1.529	1.332	0.4479
0.43	0.4626	0.8807	0.9643	0.9132	1.501	1.312	0.4563
0.44	0.4729	0.8755	0.9627	0.9094	1.474	1.294	0.4645
0.45	0.4833	0.8703	0.9611	0.9055	1.449	1.276	0.4727
0.46	0.4936	0.8650	0.9594	0.9016	1.425	1.260	0.4806
0.47	0.5038	0.8596	0.9577	0.8976	1.402	1.244	0.4885
0.48	0.5141	0.8541	0.9559	0.8935	1.380	1.230	0.4961
0.49	0.5243	0.8486	0.9542	0.8894	1.359	1.216	0.5037
0.50	0.5345	0.8430	0.9524	0.8852	1.340	1.203	0.5111
0.51	0.5447	0.8374	0.9506	0.8809	1.321	1.190	0.5183
0.52	0.5548	0.8317	0.9487	0.8766	1.303	1.179	0.5253
0.53	0.5649	0.8259	0.9468	0.8723	1.286	1.168	0.5323
0.54	0.5750	0.8201	0.9449	0.8679	1.270	1.157	0.5390
0.55	0.5851	0.8142	0.9430	0.8634	1.255	1.147	0.5456
0.56	0.5951	0.8082	0.9410	0.8589	1.240	1.138	0.5521
0.57	0.6051	0.8022	0.9390	0.8544	1.226	1.129	0.5584
0.58	0.6150	0.7962	0.9370	0.8498	1.213	1.121	0.5645
0.59	0.6249	0.7901	0.9349	0.8451	1.200	1.113	0.5705
0.60	0.6348	0.7840	0.9328	0.8405	1.188	1.105	0.5763
0.61	0.6447	0.7778	0.9307	0.8357	1.177	1.098	0.5819
0.62	0.6545	0.7716	0.9286	0.8310	1.166	1.091	0.5874
0.63	0.6643	0.7654	0.9265	0.8262	1.155	1.085	0.5928
0.64	0.6740	0.7591	0.9243	0.8213	1.145	1.079	0.5979
0.65	0.6837	0.7528	0.9221	0.8164	1.136	1.073	0.6030
0.66	0.6934	0.7465	0.9199	0.8115	1.127	1.068	0.6078
0.67	0.7031	0.7401	0.9176	0.8066	1.118	1.063	0.6125
0.68	0.7127	0.7338	0.9153	0.8016	1.110	1.058	0.6171
0.69	0.7223	0.7274	0.9131	0.7966	1.102	1.053	0.6215
0.70	0.7318	0.7209	0.9107	0.7916	1.094	1.049	0.6257
0.71	0.7413	0.7145	0.9084	0.7865	1.087	1.045	0.6298
0.72	0.7508	0.7080	0.9061	0.7814	1.081	1.041	0.6337
0.73	0.7602	0.7016	0.9037	0.7763	1.074	1.038	0.6374
0.74	0.7696	0.6951	0.9013	0.7712	1.068	1.034	0.6410
0.75	0.7789	0.6886	0.8989	0.7660	1.062	1.031	0.6445

Appendix C *Continued*

M	M*	p/p₀	T/T₀	ρ/ρ₀	A/A*	I/I*	ṁ√(RT₀)/Ap₀
0.76	0.7883	0.6821	0.8964	0.7609	1.057	1.028	0.6478
0.77	0.7975	0.6756	0.8940	0.7557	1.052	1.026	0.6510
0.78	0.8068	0.6691	0.8915	0.7505	1.047	1.023	0.6540
0.79	0.8160	0.6625	0.8890	0.7452	1.043	1.021	0.6568
0.80	0.8251	0.6560	0.8865	0.7400	1.038	1.019	0.6595
0.81	0.8343	0.6495	0.8840	0.7347	1.034	1.016	0.6621
0.82	0.8433	0.6430	0.8815	0.7295	1.030	1.015	0.6645
0.83	0.8524	0.6365	0.8789	0.7242	1.027	1.013	0.6668
0.84	0.8614	0.6300	0.8763	0.7189	1.024	1.011	0.6689
0.85	0.8704	0.6235	0.8737	0.7136	1.021	1.010	0.6709
0.86	0.8793	0.6170	0.8711	0.7083	1.018	1.008	0.6727
0.87	0.8882	0.6106	0.8685	0.7030	1.015	1.007	0.6744
0.88	0.8970	0.6041	0.8659	0.6977	1.013	1.006	0.6760
0.89	0.9058	0.5977	0.8632	0.6924	1.011	1.005	0.6774
0.90	0.9146	0.5913	0.8606	0.6870	1.009	1.004	0.6787
0.91	0.9233	0.5849	0.8579	0.6817	1.007	1.003	0.6799
0.92	0.9320	0.5785	0.8552	0.6764	1.006	1.002	0.6809
0.93	0.9407	0.5721	0.8525	0.6711	1.004	1.002	0.6818
0.94	0.9493	0.5658	0.8498	0.6658	1.003	1.001	0.6826
0.95	0.9578	0.5595	0.8471	0.6604	1.002	1.001	0.6833
0.96	0.9663	0.5532	0.8444	0.6551	1.001	1.001	0.6838
0.97	0.9748	0.5469	0.8416	0.6498	1.001	1.000	0.6842
0.98	0.9832	0.5407	0.8389	0.6445	1.000	1.000	0.6845
0.99	0.9916	0.5345	0.8361	0.6392	1.000	1.000	0.6847
1.00	1.000	0.5283	0.8333	0.6339	1.000	1.000	0.6847
1.01	1.008	0.5221	0.8306	0.6287	1.000	1.000	0.6847
1.02	1.017	0.5160	0.8278	0.6234	1.000	1.000	0.6845
1.03	1.025	0.5099	0.8250	0.6181	1.001	1.000	0.6842
1.04	1.033	0.5039	0.8222	0.6129	1.001	1.001	0.6838
1.05	1.041	0.4979	0.8193	0.6077	1.002	1.001	0.6833
1.06	1.049	0.4919	0.8165	0.6024	1.003	1.001	0.6827
1.07	1.057	0.4860	0.8137	0.5972	1.004	1.002	0.6820
1.08	1.065	0.4800	0.8108	0.5920	1.005	1.002	0.6812
1.09	1.073	0.4742	0.8080	0.5869	1.006	1.003	0.6803
1.10	1.081	0.4684	0.8052	0.5817	1.008	1.003	0.6793
1.11	1.089	0.4626	0.8023	0.5766	1.010	1.004	0.6783
1.12	1.097	0.4568	0.7994	0.5714	1.011	1.004	0.6771
1.13	1.105	0.4511	0.7966	0.5663	1.013	1.005	0.6758
1.14	1.113	0.4455	0.7937	0.5612	1.015	1.006	0.6744
1.15	1.120	0.4398	0.7908	0.5562	1.017	1.006	0.6730
1.16	1.128	0.4343	0.7879	0.5511	1.020	1.007	0.6715
1.17	1.136	0.4287	0.7851	0.5461	1.022	1.008	0.6698

continued

Appendix C Continued

M	M*	p/p₀	T/T₀	ρ/ρ₀	A/A*	I/I*	$\dot{m}\sqrt{RT_0}/Ap_0$
1.18	1.143	0.4232	0.7822	0.5411	[illegible]	1.009	0.6681
1.19	1.151	0.4178	0.7793	0.5361	1.028	1.010	0.6664
1.20	1.158	0.4124	0.7764	0.5311	1.030	1.011	0.6645
1.21	1.166	0.4070	0.7735	0.5262	1.033	1.012	0.6626
1.22	1.173	0.4017	0.7706	0.5213	1.037	1.013	0.6606
1.23	1.181	0.3964	0.7677	0.5164	1.040	1.014	0.6585
1.24	1.188	0.3912	0.7648	0.5115	1.043	1.015	0.6564
1.25	1.195	0.3861	0.7619	0.5067	1.047	1.016	0.6541
1.26	1.202	0.3809	0.7590	0.5019	1.050	1.017	0.6519
1.27	1.210	0.3759	0.7561	0.4971	1.054	1.018	0.6495
1.28	1.217	0.3708	[illegible]	0.4923	1.058	1.019	0.6471
1.29	1.224	0.3658	0.7503	0.4876	1.062	1.021	0.6447
1.30	1.231	0.3609	0.7474	[illegible]	1.066	1.022	0.6422
1.31	1.238	0.3560	0.7445	[illegible]	1.071	1.023	0.6396
1.32	1.245	0.3512	0.7416	0.4736	1.075	1.024	0.6369
1.33	1.252	0.3464	0.7387	0.4690	1.080	1.025	0.6343
1.34	1.259	0.3417	0.7358	0.4644	1.084	1.027	0.6315
1.35	1.266	0.3370	0.7329	0.4598	1.089	1.028	0.6287
1.36	1.273	0.3323	0.7300	0.4553	1.094	1.029	0.6259
1.37	1.280	0.3277	0.7271	0.4508	1.099	1.031	0.6230
1.38	1.286	0.3232	0.7242	0.4463	1.104	1.032	0.6201
1.39	1.293	0.3187	0.7213	0.4418	1.109	1.033	0.6172
1.40	1.300	0.3142	0.7184	0.4374	1.115	1.035	0.6141
1.41	1.307	0.3098	0.7155	0.4330	1.120	1.036	0.6111
1.42	1.314	0.3055	0.7126	0.4287	1.126	1.037	0.6080
1.43	1.320	0.3012	0.7097	0.4244	1.132	1.039	0.6049
1.44	1.326	0.2969	0.7069	0.4201	1.138	1.040	0.6017
1.45	1.333	0.2927	0.7040	0.4158	1.144	1.042	0.5986
1.46	1.339	0.2886	0.7011	0.4116	1.150	1.043	0.5953
1.47	1.346	0.2845	0.6982	0.4074	1.156	1.044	0.5921
1.48	1.352	0.2804	0.6954	0.4032	1.163	1.046	0.5888
1.49	1.358	0.2764	0.6925	0.3991	1.169	1.047	0.5855
1.50	1.365	0.2724	0.6897	0.3950	1.176	1.049	0.5822
1.51	1.371	0.2685	0.6868	0.3909	1.183	1.050	0.5788
1.52	1.377	0.2646	0.6840	0.3869	1.190	1.052	0.5754
1.53	1.383	0.2608	0.6811	0.3829	1.197	1.053	0.5720
1.54	1.389	0.2570	0.6783	0.3789	1.204	1.055	0.5686
1.55	1.395	0.2533	0.6754	0.3750	1.212	1.056	0.5652
1.56	1.402	0.2496	0.6726	0.3710	1.219	1.058	0.5617
1.57	1.408	0.2459	0.6698	0.3672	1.227	1.059	0.5582
1.58	1.414	0.2423	0.6670	0.3633	1.234	1.060	0.5547
1.59	1.419	0.2388	0.6642	0.3595	1.242	1.062	0.5512
1.60	1.425	0.2353	0.6614	0.3557	1.250	1.063	0.5477
1.61	1.431	0.2318	0.6586	0.3520	1.258	1.065	0.5441

Appendix C Continued

M	M*	p/p₀	T/T₀	ρ/ρ₀	A/A*	I/I*	$\dot{m}\sqrt{RT_0}/Ap_0$
1.62	1.437	0.2284	0.6558	0.3483	1.267	1.066	0.5406
1.63	1.443	0.2250	0.6530	0.3446	1.275	1.068	0.5370
1.64	1.449	0.2217	0.6502	0.3409	1.284	1.069	0.5335
1.65	1.454	0.2184	0.6475	0.3373	1.292	1.071	0.5299
1.66	1.460	0.2151	0.6447	0.3337	1.301	1.072	0.5263
1.67	1.466	0.2119	0.6419	0.3302	1.310	1.074	0.5227
1.68	1.471	0.2088	0.6392	0.3266	1.319	1.075	0.5191
1.69	1.477	0.2057	0.6364	0.3232	1.328	1.077	0.5155
1.70	1.482	0.2026	0.6337	0.3197	1.338	1.079	0.5119
1.71	1.488	0.1996	0.6310	0.3163	1.347	1.080	0.5083
1.72	1.493	0.1966	0.6283	0.3129	1.357	1.082	0.5047
1.73	1.499	0.1936	0.6256	0.3095	1.367	1.083	0.5011
1.74	1.504	0.1907	0.6229	0.3062	1.376	1.085	0.4975
1.75	1.510	0.1878	0.6202	0.3029	1.386	1.086	0.4939
1.76	1.515	0.1850	0.6175	0.2996	1.397	1.088	0.4903
1.77	1.520	0.1822	0.6148	0.2964	1.407	1.089	0.4866
1.78	1.526	0.1794	0.6121	0.2931	1.418	1.091	0.4830
1.79	1.531	0.1767	0.6095	0.2900	1.428	1.092	0.4794
1.80	1.536	0.1740	0.6068	0.2868	1.439	1.094	0.4758
1.81	1.541	0.1714	0.6041	0.2837	1.450	1.095	0.4723
1.82	1.546	0.1688	0.6015	0.2806	1.461	1.096	0.4687
1.83	1.551	0.1662	0.5989	0.2776	1.472	1.098	0.4651
1.84	1.556	0.1637	0.5963	0.2745	1.484	1.099	0.4615
1.85	1.561	0.1612	0.5936	0.2715	1.495	1.101	0.4580
1.86	1.566	0.1587	0.5910	0.2686	1.507	1.102	0.4544
1.87	1.571	0.1563	0.5885	0.2656	1.519	1.104	0.4509
1.88	1.576	0.1539	0.5859	0.2627	1.531	1.105	0.4473
1.89	1.581	0.1516	0.5833	0.2598	1.543	1.107	0.4438
1.90	1.586	0.1492	0.5807	0.2570	1.555	1.108	0.4403
1.91	1.591	0.1470	0.5782	0.2542	1.568	1.110	0.4368
1.92	1.596	0.1447	0.5756	0.2514	1.580	1.111	0.4333
1.93	1.600	0.1425	0.5731	0.2486	1.593	1.113	0.4298
1.94	1.605	0.1403	0.5705	0.2459	1.606	1.114	0.4263
1.95	1.610	0.1381	0.5680	0.2432	1.619	1.116	0.4229
1.96	1.615	0.1360	0.5655	0.2405	1.633	1.117	0.4194
1.97	1.619	0.1339	0.5630	0.2378	1.646	1.118	0.4160
1.98	1.624	0.1318	0.5605	0.2352	1.660	1.120	0.4126
1.99	1.628	0.1298	0.5580	0.2326	1.674	1.121	0.4092
2.00	1.633	0.1278	0.5556	0.2300	1.687	1.123	0.4058
2.01	1.638	0.1258	0.5531	0.2275	1.702	1.124	0.4024
2.02	1.642	0.1239	0.5506	0.2250	1.716	1.126	0.3990
2.03	1.646	0.1220	0.5482	0.2225	1.730	1.127	0.3957

continued

Appendix C *Continued*

M	M^*	p/p_0	T/T_0	ρ/ρ_0	A/A^*	I/I^*	$\dot{m}\sqrt{(RT_0)}/Ap_0$
4.62	2.205	0.002 978	0.1898	0.015 69	18.32	1.329	0.037 37
4.63	2.206	0.002 942	0.1891	0.015 56	18.48	1.330	0.037 06
4.64	2.207	0.002 906	0.1885	0.015 42	18.63	1.330	0.036 75
4.65	2.208	0.002 871	0.1878	0.015 29	18.79	1.330	0.036 45
4.66	2.208	0.002 836	0.1872	0.015 15	18.94	1.331	0.036 15
4.67	2.209	0.002 802	0.1865	0.015 02	19.10	1.331	0.035 85
4.68	2.210	0.002 768	0.1859	0.014 89	19.26	1.331	0.035 55
4.69	2.211	0.002 734	0.1852	0.014 76	19.42	1.332	0.035 26
4.70	2.212	0.002 701	0.1846	0.014 64	19.58	1.332	0.034 97
4.71	2.213	0.002 669	0.1839	0.014 51	19.75	1.332	0.034 68
4.72	2.214	0.002 636	0.1833	0.014 38	19.91	1.333	0.034 39
4.73	2.215	0.002 605	0.1827	0.014 26	20.07	1.333	0.034 11
4.74	2.215	0.002 573	0.1820	0.014 14	20.24	1.333	0.033 83
4.75	2.216	0.002 543	0.1814	0.014 02	20.41	1.334	0.033 55
4.76	2.217	0.002 512	0.1808	0.013 90	20.58	1.334	0.033 28
4.77	2.218	0.002 482	0.1802	0.013 78	20.75	1.334	0.033 00
4.78	2.219	0.002 452	0.1795	0.013 66	20.92	1.335	0.032 73
4.79	2.220	0.002 423	0.1789	0.013 54	21.09	1.335	0.032 47
4.80	2.220	0.002 394	0.1783	0.013 43	21.26	1.335	0.032 20
4.81	2.221	0.002 366	0.1777	0.013 31	21.44	1.336	0.031 94
4.82	2.222	0.002 338	0.1771	0.013 20	21.61	1.336	0.031 68
4.83	2.223	0.002 310	0.1765	0.013 09	21.79	1.336	0.031 42
4.84	2.224	0.002 282	0.1759	0.012 98	21.97	1.337	0.031 17
4.85	2.224	0.002 255	0.1753	0.012 87	22.15	1.337	0.030 91
4.86	2.225	0.002 229	0.1747	0.012 76	22.33	1.337	0.030 66
4.87	2.226	0.002 202	0.1741	0.012 65	22.51	1.338	0.030 41
4.88	2.227	0.002 176	0.1735	0.012 54	22.70	1.338	0.030 17
4.89	2.228	0.002 151	0.1729	0.012 44	22.88	1.338	0.029 93
4.90	2.228	0.002 126	0.1724	0.012 33	23.07	1.339	0.029 68
4.91	2.229	0.002 101	0.1718	0.012 23	23.25	1.339	0.029 44
4.92	2.230	0.002 076	0.1712	0.012 13	23.44	1.339	0.029 21
4.93	2.231	0.002 052	0.1706	0.012 02	23.63	1.340	0.028 97
4.94	2.232	0.002 028	0.1700	0.011 92	23.82	1.340	0.028 74
4.95	2.232	0.002 004	0.1695	0.011 82	24.02	1.340	0.028 51
4.96	2.233	0.001 981	0.1689	0.011 73	24.21	1.340	0.028 28
4.97	2.234	0.001 957	0.1683	0.011 63	24.41	1.341	0.028 06
4.98	2.235	0.001 935	0.1678	0.011 53	24.60	1.341	0.027 83
4.99	2.235	0.001 912	0.1672	0.011 44	24.80	1.341	0.027 61
5.00	2.236	0.001 890	0.1667	0.011 34	25.00	1.342	0.027 39
∞	2.450	0.000 000	0.0000	0.000 00	∞	1.429	0.000 00

Appendix D
Flow of a perfect gas across a normal shock wave ($k = 1.4$)

M_x	M_y	$\frac{p_y}{p_x}$	$\frac{T_y}{T_x}$	$\frac{\rho_y}{\rho_x} = \frac{V_x}{V_y}$	$\frac{p_{0y}}{p_{0x}} = \frac{A_x^*}{A_y^*}$	$\frac{s_y - s_x}{R}$
1.00	1.0000	1.000	1.000	1.000	1.0000	0.000 000 000 0
1.01	0.9901	1.023	1.007	1.017	1.0000	0.000 000 852 2
1.02	0.9805	1.047	1.013	1.033	1.0000	0.000 010 05
1.03	0.9712	1.071	1.020	1.050	1.0000	0.000 032 91
1.04	0.9620	1.095	1.026	1.067	0.9999	0.000 076 72
1.05	0.9531	1.120	1.033	1.084	0.9999	0.000 147 1
1.06	0.9444	1.144	1.039	1.101	0.9998	0.000 249 3
1.07	0.9360	1.169	1.046	1.118	0.9996	0.000 388 5
1.08	0.9277	1.194	1.052	1.135	0.9994	0.000 569 3
1.09	0.9196	1.219	1.059	1.152	0.9992	0.000 796 2
1.10	0.9118	1.245	1.065	1.169	0.9989	0.001 072
1.11	0.9041	1.271	1.071	1.186	0.9986	0.001 402
1.12	0.8966	1.297	1.078	1.203	0.9982	0.001 789
1.13	0.8892	1.323	1.084	1.221	0.9978	0.000 235
1.14	0.8820	1.350	1.090	1.238	0.9973	0.002 743
1.15	0.8750	1.376	1.097	1.255	0.9967	0.003 316
1.16	0.8682	1.403	1.103	1.272	0.9961	0.003 956
1.17	0.8615	1.430	1.109	1.290	0.9953	0.004 666
1.18	0.8549	1.458	1.115	1.307	0.9946	0.005 446
1.19	0.8485	1.485	1.122	1.324	0.9937	0.006 300
1.20	0.8422	1.513	1.128	1.342	0.9928	0.007 228
1.21	0.8360	1.541	1.134	1.359	0.9918	0.008 232
1.22	0.8300	1.570	1.141	1.376	0.9907	0.009 313
1.23	0.8241	1.598	1.147	1.394	0.9896	0.010 47
1.24	0.8183	1.627	1.153	1.411	0.9884	0.011 71
1.25	0.8126	1.656	1.159	1.429	0.9871	0.013 03
1.26	0.8071	1.686	1.166	1.446	0.9857	0.014 43
1.27	0.8016	1.715	1.172	1.463	0.9842	0.015 91

continued

Appendix D *Continued*

M_x	M_y	$\frac{p_y}{p_x}$	$\frac{T_y}{T_x}$	$\frac{\rho_y}{\rho_x} = \frac{V_x}{V_y}$	$\frac{p_{0y}}{p_{0x}} = \frac{A_x^*}{A_y^*}$	$\frac{s_y - s_x}{R}$
1.28	0.7963	1.745	1.178	1.481	0.9827	0.017 47
1.29	0.7911	1.775	1.185	1.498	0.9811	0.019 11
1.30	0.7860	1.805	1.191	1.516	0.9794	0.020 84
1.31	0.7809	1.835	1.197	1.533	0.9776	0.022 65
1.32	0.7760	1.866	1.204	1.551	0.9758	0.024 55
1.33	0.7712	1.897	1.210	1.568	0.9738	0.026 52
1.34	0.7664	1.928	1.216	1.585	0.9718	0.028 59
1.35	0.7618	1.960	1.223	1.603	0.9697	0.030 73
1.36	0.7572	1.991	1.229	1.620	0.9676	0.032 96
1.37	0.7527	2.023	1.235	1.638	0.9653	0.035 27
1.38	0.7483	2.055	1.242	1.655	0.9630	0.037 67
1.39	0.7440	2.087	1.248	1.672	0.9607	0.040 14
1.40	0.7397	2.120	1.255	1.690	0.9582	0.042 70
1.41	0.7355	2.153	1.261	1.707	0.9557	0.045 35
1.42	0.7314	2.186	1.268	1.724	0.9531	0.048 07
1.43	0.7274	2.219	1.274	1.742	0.9504	0.050 88
1.44	0.7235	2.253	1.281	1.759	0.9476	0.053 77
1.45	0.7196	2.286	1.287	1.776	0.9448	0.056 74
1.46	0.7157	2.320	1.294	1.793	0.9420	0.059 80
1.47	0.7120	2.354	1.300	1.811	0.9390	0.062 93
1.48	0.7083	2.389	1.307	1.828	0.9360	0.066 14
1.49	0.7047	2.423	1.314	1.845	0.9329	0.069 43
1.50	0.7011	2.458	1.320	1.862	0.9298	0.072 80
1.51	0.6976	2.493	1.327	1.879	0.9266	0.076 25
1.52	0.6941	2.529	1.334	1.896	0.9233	0.079 77
1.53	0.6907	2.564	1.340	1.913	0.9200	0.083 38
1.54	0.6874	2.600	1.347	1.930	0.9166	0.087 06
1.55	0.6841	2.636	1.354	1.947	0.9132	0.090 81
1.56	0.6809	2.673	1.361	1.964	0.9097	0.094 64
1.57	0.6777	2.709	1.367	1.981	0.9062	0.098 55
1.58	0.6746	2.746	1.374	1.998	0.9026	0.1025
1.59	0.6715	2.783	1.381	2.015	0.8989	0.1066
1.60	0.6684	2.820	1.388	2.032	0.8952	0.1107
1.61	0.6655	2.857	1.395	2.049	0.8915	0.1149
1.62	0.6625	2.895	1.402	2.065	0.8877	0.1192
1.63	0.6596	2.933	1.409	2.082	0.8838	0.1235
1.64	0.6568	2.971	1.416	2.099	0.8799	0.1279
1.65	0.6540	3.010	1.423	2.115	0.8760	0.1324
1.66	0.6512	3.048	1.430	2.132	0.8720	0.1369
1.67	0.6485	3.087	1.437	2.148	0.8680	0.1416
1.68	0.6458	3.126	1.444	2.165	0.8639	0.1462
1.69	0.6431	3.165	1.451	2.181	0.8599	0.1510

Appendix D *Continued*

M_x	M_y	$\frac{p_y}{p_x}$	$\frac{T_y}{T_x}$	$\frac{\rho_y}{\rho_x} = \frac{V_x}{V_y}$	$\frac{p_{0y}}{p_{0x}} = \frac{A_x^*}{A_y^*}$	$\frac{s_y - s_x}{R}$
1.70	0.6405	3.205	1.458	2.198	0.8557	0.1558
1.71	0.6380	3.245	1.466	2.214	0.8516	0.1607
1.72	0.6355	3.285	1.473	2.230	0.8474	0.1656
1.73	0.6330	3.325	1.480	2.247	0.8431	0.1706
1.74	0.6305	3.366	1.487	2.263	0.8389	0.1757
1.75	0.6281	3.406	1.495	2.279	0.8346	0.1808
1.76	0.6257	3.447	1.502	2.295	0.8302	0.1860
1.77	0.6234	3.488	1.509	2.311	0.8259	0.1913
1.78	0.6210	3.530	1.517	2.327	0.8215	0.1966
1.79	0.6188	3.571	1.524	2.343	0.8171	0.2020
1.80	0.6165	3.613	1.532	2.359	0.8127	0.2074
1.81	0.6143	3.655	1.539	2.375	0.8082	0.2129
1.82	0.6121	3.698	1.547	2.391	0.8038	0.2185
1.83	0.6099	3.740	1.554	2.407	0.7993	0.2241
1.84	0.6078	3.783	1.562	2.422	0.7948	0.2297
1.85	0.6057	3.826	1.569	2.438	0.7902	0.2354
1.86	0.6036	3.870	1.577	2.454	0.7857	0.2412
1.87	0.6016	3.913	1.585	2.469	0.7811	0.2470
1.88	0.5996	3.957	1.592	2.485	0.7765	0.2529
1.89	0.5976	4.001	1.600	2.500	0.7720	0.2588
1.90	0.5956	4.045	1.608	2.516	0.7674	0.2648
1.91	0.5937	4.089	1.616	2.531	0.7627	0.2708
1.92	0.5918	4.134	1.624	2.546	0.7581	0.2769
1.93	0.5899	4.179	1.631	2.562	0.7535	0.2830
1.94	0.5880	4.224	1.639	2.577	0.7488	0.2892
1.95	0.5862	4.270	1.647	2.592	0.7442	0.2955
1.96	0.5844	4.315	1.655	2.607	0.7395	0.3017
1.97	0.5826	4.361	1.663	2.622	0.7349	0.3080
1.98	0.5808	4.407	1.671	2.637	0.7302	0.3144
1.99	0.5791	4.453	1.679	2.652	0.7255	0.3208
2.00	0.5774	4.500	1.687	2.667	0.7209	0.3273
2.01	0.5757	4.547	1.696	2.681	0.7162	0.3338
2.02	0.5740	4.594	1.704	2.696	0.7115	0.3403
2.03	0.5723	4.641	1.712	2.711	0.7069	0.3469
2.04	0.5707	4.689	1.720	2.725	0.7022	0.3536
2.05	0.5691	4.736	1.729	2.740	0.6975	0.3602
2.06	0.5675	4.784	1.737	2.755	0.6928	0.3670
2.07	0.5659	4.832	1.745	2.769	0.6882	0.3737
2.08	0.5643	4.881	1.754	2.783	0.6835	0.3805
2.09	0.5628	4.929	1.762	2.798	0.6789	0.3873

continued

262

Appendix E
Flow of a perfect gas on the Fanno line ($k = 1.4$)

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho}{\rho^*} = \frac{V^*}{V}$	$\frac{p_0}{p_0^*}$	$\frac{I}{I^*}$	$\frac{s^* - s}{R}$	$\frac{4fL_{max}}{D}$
0.00	∞	1.200	∞	∞	∞	∞	∞
0.01	109.5	1.200	91.29	57.87	45.65	4.058	7134.0
0.02	54.77	1.200	45.65	28.94	22.83	3.365	1779.0
0.03	36.51	1.200	30.43	19.30	15.23	2.960	787.1
0.04	27.38	1.200	22.83	14.48	11.44	2.673	440.4
0.05	21.90	1.199	18.26	11.59	9.158	2.450	280.0
0.06	18.25	1.199	15.22	9.666	7.643	2.269	193.0
0.07	15.64	1.199	13.05	8.292	6.562	2.115	140.7
0.08	13.68	1.198	11.42	7.262	5.753	1.983	106.7
0.09	12.16	1.198	10.15	6.461	5.125	1.866	83.50
0.10	10.94	1.198	9.138	5.822	4.624	1.762	66.92
0.11	9.947	1.197	8.309	5.299	4.215	1.668	54.69
0.12	9.116	1.197	7.618	4.864	3.875	1.582	45.41
0.13	8.412	1.196	7.034	4.497	3.588	1.503	38.21
0.14	7.809	1.195	6.534	4.182	3.343	1.431	32.51
0.15	7.287	1.195	6.099	3.910	3.132	1.364	27.93
0.16	6.829	1.194	5.720	3.673	2.947	1.301	24.20
0.17	6.425	1.193	5.385	3.464	2.786	1.242	21.12
0.18	6.066	1.192	5.088	3.278	2.642	1.187	18.54
0.19	5.745	1.191	4.822	3.112	2.515	1.135	16.38
0.20	5.455	1.190	4.583	2.964	2.400	1.086	14.53
0.21	5.194	1.190	4.366	2.829	2.298	1.040	12.96
0.22	4.955	1.188	4.169	2.708	2.205	0.9961	11.60
0.23	4.738	1.187	3.990	2.597	2.120	0.9543	10.42
0.24	4.538	1.186	3.825	2.496	2.043	0.9145	9.386
0.25	4.355	1.185	3.674	2.403	1.973	0.8766	8.483
0.26	4.185	1.184	3.535	2.317	1.909	0.8404	7.688
0.27	4.028	1.183	3.406	2.238	1.850	0.8058	6.983
0.28	3.882	1.181	3.286	2.166	1.795	0.7727	6.357
0.29	3.746	1.180	3.174	2.098	1.745	0.7409	5.799
0.30	3.619	1.179	3.070	2.035	1.698	0.7105	5.299

Appendix E *Continued*

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho}{\rho^*} = \frac{V^*}{V}$	$\frac{p_0}{p_0^*}$	$\frac{I}{I^*}$	$\frac{s^* - s}{R}$	$\frac{4fL_{max}}{D}$
0.31	3.500	1.177	2.973	1.977	1.655	0.6813	4.851
0.32	3.389	1.176	2.882	1.922	1.614	0.6533	4.447
0.33	3.284	1.174	2.796	1.871	1.577	0.6263	4.082
0.34	3.185	1.173	2.716	1.823	1.542	0.6004	3.752
0.35	3.092	1.171	2.640	1.778	1.509	0.5755	3.452
0.36	3.004	1.170	2.568	1.736	1.479	0.5515	3.180
0.37	2.921	1.168	2.501	1.696	1.450	0.5283	2.932
0.38	2.842	1.166	2.437	1.659	1.424	0.5060	2.705
0.39	2.767	1.165	2.376	1.623	1.398	0.4845	2.498
0.40	2.696	1.163	2.318	1.590	1.375	0.4638	2.308
0.41	2.628	1.161	2.264	1.559	1.353	0.4438	2.134
0.42	2.563	1.159	2.212	1.529	1.332	0.4246	1.974
0.43	2.502	1.157	2.162	1.501	1.312	0.4059	1.827
0.44	2.443	1.155	2.114	1.474	1.294	0.3880	1.692
0.45	2.386	1.153	2.069	1.449	1.276	0.3706	1.566
0.46	2.333	1.151	2.026	1.425	1.260	0.3539	1.451
0.47	2.281	1.149	1.985	1.402	1.244	0.3378	1.344
0.48	2.231	1.147	1.945	1.380	1.230	0.3222	1.245
0.49	2.184	1.145	1.907	1.359	1.216	0.3071	1.154
0.50	2.138	1.143	1.871	1.340	1.203	0.2926	1.069
0.51	2.094	1.141	1.836	1.321	1.190	0.2785	0.9904
0.52	2.052	1.138	1.802	1.303	1.179	0.2650	0.9174
0.53	2.011	1.136	1.770	1.286	1.168	0.2519	0.8496
0.54	1.972	1.134	1.739	1.270	1.157	0.2393	0.7866
0.55	1.934	1.132	1.709	1.255	1.147	0.2271	0.7281
0.56	1.898	1.129	1.680	1.240	1.138	0.2154	0.6736
0.57	1.862	1.127	1.653	1.226	1.129	0.2040	0.6229
0.58	1.828	1.124	1.626	1.213	1.121	0.1931	0.5757
0.59	1.795	1.122	1.600	1.200	1.113	0.1826	0.5317
0.60	1.763	1.119	1.575	1.188	1.105	0.1724	0.4908
0.61	1.733	1.117	1.551	1.177	1.098	0.1627	0.4527
0.62	1.703	1.114	1.528	1.166	1.091	0.1533	0.4172
0.63	1.674	1.112	1.505	1.155	1.085	0.1442	0.3841
0.64	1.646	1.109	1.484	1.145	1.079	0.1355	0.3533
0.65	1.618	1.107	1.463	1.136	1.073	0.1272	0.3246
0.66	1.592	1.104	1.442	1.127	1.068	0.1192	0.2979
0.67	1.566	1.101	1.422	1.118	1.063	0.1114	0.2730
0.68	1.541	1.098	1.403	1.110	1.058	0.1041	0.2498
0.69	1.517	1.096	1.385	1.102	1.053	0.096 97	0.2262
0.70	1.493	1.093	1.367	1.094	1.049	0.090 18	0.2081

continued

263

Appendix E *Continued*

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho}{\rho^*} = \frac{V^*}{V}$	$\frac{p_0}{p_0^*}$	$\frac{I}{I^*}$	$\frac{s^* - s}{R}$	$\frac{4fL_{max}}{D}$
0.71	1.471	1.090	1.349	1.087	1.045	0.083 69	0.1895
0.72	1.448	1.087	1.332	1.081	1.041	0.077 49	0.1722
0.73	1.427	1.084	1.315	1.074	1.038	0.071 57	0.1561
0.74	1.405	1.082	1.299	1.068	1.034	0.065 92	0.1411
0.75	1.385	1.079	1.284	1.062	1.031	0.060 55	0.1273
0.76	1.365	1.076	1.269	1.057	1.028	0.055 43	0.1145
0.77	1.345	1.073	1.254	1.052	1.026	0.050 58	0.1026
0.78	1.326	1.070	1.240	1.047	1.023	0.045 98	0.091 67
0.79	1.307	1.067	1.226	1.043	1.021	0.041 63	0.081 58
0.80	1.289	1.064	1.212	1.038	1.019	0.037 52	0.072 29
0.81	1.272	1.061	1.199	1.034	1.016	0.033 65	0.063 76
0.82	1.254	1.058	1.186	1.030	1.015	0.030 01	0.055 93
0.83	1.237	1.055	1.173	1.027	1.013	0.026 60	0.048 78
0.84	1.221	1.052	1.161	1.024	1.011	0.023 42	0.042 26
0.85	1.205	1.048	1.149	1.021	1.010	0.020 46	0.036 33
0.86	1.189	1.045	1.137	1.018	1.008	0.017 71	0.030 97
0.87	1.173	1.042	1.126	1.015	1.007	0.015 18	0.026 13
0.88	1.158	1.039	1.115	1.013	1.006	0.012 86	0.021 80
0.89	1.144	1.036	1.104	1.011	1.005	0.010 74	0.017 93
0.90	1.129	1.033	1.093	1.009	1.004	0.008 823	0.014 51
0.91	1.115	1.029	1.083	1.007	1.003	0.007 105	0.011 51
0.92	1.101	1.026	1.073	1.006	1.002	0.005 581	0.008 914
0.93	1.088	1.023	1.063	1.004	1.002	0.004 249	0.006 687
0.94	1.074	1.020	1.053	1.003	1.001	0.003 103	0.004 816
0.95	1.061	1.017	1.044	1.002	1.001	0.002 143	0.003 278
0.96	1.049	1.013	1.035	1.001	1.001	0.001 364	0.002 057
0.97	1.036	1.010	1.026	1.001	1.000	0.000 762 5	0.001 135
0.98	1.024	1.007	1.017	1.000	1.000	0.000 337 0	0.000 494 8
0.99	1.012	1.003	1.008	1.000	1.000	0.000 083 75	0.000 121 3
1.00	1.000	1.000	1.000	1.000	1.000	0.000 000 00	0.000 000 0
1.01	0.9884	0.9967	0.9918	1.000	1.000	0.000 082 97	0.000 116 8
1.02	0.9771	0.9933	0.9837	1.000	1.000	0.000 329 3	0.000 458 8
1.03	0.9660	0.9900	0.9758	1.001	1.000	0.000 737 6	0.001 013
1.04	0.9551	0.9866	0.9681	1.001	1.001	0.001 304	0.001 769
1.05	0.9443	0.9832	0.9605	1.002	1.001	0.002 027	0.002 714
1.06	0.9338	0.9798	0.9531	1.003	1.001	0.002 903	0.003 838
1.07	0.9235	0.9764	0.9458	1.004	1.002	0.003 930	0.005 131
1.08	0.9133	0.9730	0.9387	1.005	1.002	0.005 106	0.006 585
1.09	0.9034	0.9696	0.9317	1.006	1.003	0.006 428	0.008 189
1.10	0.8936	0.9662	0.9249	1.008	1.003	0.007 894	0.009 935
1.11	0.8840	0.9628	0.9182	1.010	1.004	0.009 502	0.011 82
1.12	0.8745	0.9593	0.9116	1.011	1.004	0.011 25	0.013 82

Appendix E *Continued*

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho}{\rho^*} = \frac{V^*}{V}$	$\frac{p_0}{p_0^*}$	$\frac{I}{I^*}$	$\frac{s^* - s}{R}$	$\frac{4fL_{max}}{D}$
1.13	0.8652	0.9559	0.9051	1.013	1.005	0.013 13	0.015 95
1.14	0.8561	0.9524	0.8988	1.015	1.006	0.015 15	0.018 19
1.15	0.8471	0.9490	0.8926	1.017	1.006	0.017 30	0.020 53
1.16	0.8383	0.9455	0.8865	1.020	1.007	0.019 59	0.022 98
1.17	0.8296	0.9421	0.8806	1.022	1.008	0.022 00	0.025 52
1.18	0.8210	0.9386	0.8747	1.025	1.009	0.024 54	0.028 14
1.19	0.8126	0.9351	0.8690	1.028	1.010	0.027 20	0.030 85
1.20	0.8044	0.9317	0.8633	1.030	1.011	0.029 99	0.033 64
1.21	0.7962	0.9282	0.8578	1.033	1.012	0.032 89	0.036 50
1.22	0.7882	0.9247	0.8524	1.037	1.013	0.035 92	0.039 43
1.23	0.7803	0.9212	0.8470	1.040	1.014	0.039 06	0.042 42
1.24	0.7726	0.9178	0.8418	1.043	1.015	0.042 32	0.045 47
1.25	0.7649	0.9143	0.8367	1.047	1.016	0.045 69	0.048 58
1.26	0.7574	0.9108	0.8316	1.050	1.017	0.049 18	0.051 74
1.27	0.7500	0.9073	0.8266	1.054	1.018	0.052 77	0.054 95
1.28	0.7427	0.9038	0.8218	1.058	1.019	0.056 47	0.058 20
1.29	0.7356	0.9003	0.8170	1.062	1.021	0.060 28	0.061 50
1.30	0.7285	0.8969	0.8123	1.066	1.022	0.064 20	0.064 83
1.31	0.7215	0.8934	0.8076	1.071	1.023	0.068 22	0.068 20
1.32	0.7147	0.8899	0.8031	1.075	1.024	0.072 34	0.071 61
1.33	0.7079	0.8864	0.7986	1.080	1.025	0.076 56	0.075 04
1.34	0.7012	0.8829	0.7942	1.084	1.027	0.080 88	0.078 50
1.35	0.6947	0.8794	0.7899	1.089	1.028	0.085 30	0.081 99
1.36	0.6882	0.8760	0.7856	1.094	1.029	0.089 81	0.085 50
1.37	0.6818	0.8725	0.7814	1.099	1.031	0.094 42	0.089 04
1.38	0.6755	0.8690	0.7773	1.104	1.032	0.099 12	0.092 59
1.39	0.6693	0.8655	0.7733	1.109	1.033	0.1039	0.096 16
1.40	0.6632	0.8621	0.7693	1.115	1.035	0.1088	0.099 74
1.41	0.6572	0.8586	0.7654	1.120	1.036	0.1138	0.1033
1.42	0.6512	0.8551	0.7615	1.126	1.037	0.1188	0.1070
1.43	0.6454	0.8517	0.7577	1.132	1.039	0.1240	0.1106
1.44	0.6396	0.8482	0.7540	1.138	1.040	0.1292	0.1142
1.45	0.6339	0.8448	0.7503	1.144	1.042	0.1345	0.1178
1.46	0.6282	0.8413	0.7467	1.150	1.043	0.1399	0.1215
1.47	0.6227	0.8379	0.7432	1.156	1.044	0.1454	0.1251
1.48	0.6172	0.8344	0.7397	1.163	1.046	0.1509	0.1287
1.49	0.6118	0.8310	0.7362	1.169	1.047	0.1566	0.1324
1.50	0.6065	0.8276	0.7328	1.176	1.049	0.1623	0.1361
1.51	0.6012	0.8242	0.7295	1.183	1.050	0.1680	0.1397
1.52	0.5960	0.8207	0.7262	1.190	1.052	0.1739	0.1433

continued

Appendix E *Continued*

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho}{\rho^*}=\frac{V^*}{V}$	$\frac{p_0}{p_0^*}$	$\frac{I}{I^*}$	$\frac{s^*-s}{R}$	$\frac{4\bar{f}L_{max}}{D}$
1.53	0.5909	0.8173	0.7229	1.197	1.053	0.1798	0.1470
1.54	0.5858	0.8139	0.7198	1.204	1.055	0.1858	0.1506
1.55	0.5808	0.8105	0.7166	1.212	1.056	0.1919	0.1543
1.56	0.5759	0.8071	0.7135	1.219	1.058	0.1981	0.1579
1.57	0.5710	0.8038	0.7105	1.227	1.059	0.2043	0.1615
1.58	0.5662	0.8004	0.7074	1.234	1.060	0.2106	0.1651
1.59	0.5615	0.7970	0.7045	1.242	1.062	0.2169	0.1688
1.60	0.5568	0.7937	0.7016	1.250	1.063	0.2233	0.1724
1.61	0.5522	0.7903	0.6987	1.258	1.065	0.2298	0.1760
1.62	0.5476	0.7869	0.6958	1.267	1.066	0.2364	0.1795
1.63	0.5431	0.7836	0.6930	1.275	1.068	0.2430	0.1831
1.64	0.5386	0.7803	0.6903	1.284	1.069	0.2496	0.1867
1.65	0.5342	0.7770	0.6876	1.292	1.071	0.2564	0.1902
1.66	0.5299	0.7736	0.6849	1.301	1.072	0.2631	0.1938
1.67	0.5256	0.7703	0.6823	1.310	1.074	0.2700	0.1973
1.68	0.5213	0.7670	0.6796	1.319	1.075	0.2769	0.2008
1.69	0.5171	0.7637	0.6771	1.328	1.077	0.2839	0.2043
1.70	0.5130	0.7605	0.6745	1.338	1.079	0.2909	0.2078
1.71	0.5089	0.7572	0.6721	1.347	1.080	0.2980	0.2113
1.72	0.5048	0.7539	0.6696	1.357	1.082	0.3051	0.2147
1.73	0.5008	0.7507	0.6672	1.367	1.083	0.3123	0.2182
1.74	0.4969	0.7474	0.6648	1.376	1.085	0.3195	0.2216
1.75	0.4929	0.7442	0.6624	1.386	1.086	0.3268	0.2250
1.76	0.4891	0.7410	0.6601	1.397	1.088	0.3341	0.2284
1.77	0.4853	0.7377	0.6578	1.407	1.089	0.3415	0.2318
1.78	0.4815	0.7345	0.6555	1.418	1.091	0.3489	0.2352
1.79	0.4778	0.7313	0.6533	1.428	1.092	0.3564	0.2385
1.80	0.4741	0.7282	0.6511	1.439	1.094	0.3639	0.2419
1.81	0.4704	0.7250	0.6489	1.450	1.095	0.3715	0.2452
1.82	0.4668	0.7218	0.6467	1.461	1.096	0.3791	0.2485
1.83	0.4632	0.7187	0.6446	1.472	1.098	0.3868	0.2518
1.84	0.4597	0.7155	0.6425	1.484	1.099	0.3945	0.2551
1.85	0.4562	0.7124	0.6404	1.495	1.101	0.4023	0.2583
1.86	0.4528	0.7093	0.6384	1.507	1.102	0.4101	0.2616
1.87	0.4494	0.7061	0.6364	1.519	1.104	0.4179	0.2648
1.88	0.4460	0.7030	0.6344	1.531	1.105	0.4258	0.2680
1.89	0.4427	0.6999	0.6324	1.543	1.107	0.4337	0.2712
1.90	0.4394	0.6969	0.6305	1.555	1.108	0.4416	0.2743
1.91	0.4361	0.6938	0.6286	1.568	1.110	0.4496	0.2775
1.92	0.4329	0.6907	0.6267	1.580	1.111	0.4577	0.2806
1.93	0.4297	0.6877	0.6248	1.593	1.113	0.4657	0.2837
1.94	0.4265	0.6847	0.6230	1.606	1.114	0.4739	0.2868

Appendix E *Continued*

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho}{\rho^*}=\frac{V^*}{V}$	$\frac{p_0}{p_0^*}$	$\frac{I}{I^*}$	$\frac{s^*-s}{R}$	$\frac{4\bar{f}L_{max}}{D}$
1.95	0.4234	0.6816	0.6211	1.619	1.116	0.4820	0.2899
1.96	0.4203	0.6786	0.6193	1.633	1.117	0.4902	0.2929
1.97	0.4172	0.6756	0.6176	1.646	1.118	0.4984	0.2960
1.98	0.4142	0.6726	0.6158	1.660	1.120	0.5066	0.2990
1.99	0.4112	0.6696	0.6141	1.674	1.121	0.5149	0.3020
2.00	0.4082	0.6667	0.6124	1.687	1.123	0.5232	0.3050
2.01	0.4053	0.6637	0.6107	1.702	1.124	0.5316	0.3080
2.02	0.4024	0.6608	0.6090	1.716	1.126	0.5400	0.3109
2.03	0.3995	0.6578	0.6074	1.730	1.127	0.5484	0.3138
2.04	0.3967	0.6549	0.6057	1.745	1.128	0.5568	0.3168
2.05	0.3939	0.6520	0.6041	1.760	1.130	0.5653	0.3197
2.06	0.3911	0.6491	0.6025	1.775	1.131	0.5738	0.3225
2.07	0.3883	0.6462	0.6010	1.790	1.132	0.5823	0.3254
2.08	0.3856	0.6433	0.5994	1.806	1.134	0.5909	0.3282
2.09	0.3829	0.6405	0.5979	1.821	1.135	0.5995	0.3310
2.10	0.3802	0.6376	0.5963	1.837	1.137	0.6081	0.3339
2.11	0.3776	0.6348	0.5948	1.853	1.138	0.6167	0.3366
2.12	0.3750	0.6320	0.5934	1.869	1.139	0.6254	0.3394
2.13	0.3724	0.6291	0.5919	1.885	1.141	0.6341	0.3422
2.14	0.3698	0.6263	0.5905	1.902	1.142	0.6428	0.3449
2.15	0.3673	0.6235	0.5890	1.919	1.143	0.6516	0.3476
2.16	0.3648	0.6208	0.5876	1.935	1.145	0.6603	0.3503
2.17	0.3623	0.6180	0.5862	1.953	1.146	0.6691	0.3530
2.18	0.3598	0.6152	0.5848	1.970	1.147	0.6779	0.3556
2.19	0.3574	0.6125	0.5835	1.987	1.149	0.6868	0.3583
2.20	0.3549	0.6098	0.5821	2.005	1.150	0.6956	0.3609
2.21	0.3525	0.6070	0.5808	2.023	1.151	0.7045	0.3635
2.22	0.3502	0.6043	0.5794	2.041	1.153	0.7134	0.3661
2.23	0.3478	0.6016	0.5781	2.059	1.154	0.7223	0.3687
2.24	0.3455	0.5989	0.5768	2.078	1.155	0.7313	0.3712
2.25	0.3432	0.5963	0.5756	2.096	1.156	0.7402	0.3738
2.26	0.3409	0.5936	0.5743	2.115	1.158	0.7492	0.3763
2.27	0.3387	0.5910	0.5731	2.134	1.159	0.7582	0.3788
2.28	0.3364	0.5883	0.5718	2.154	1.160	0.7672	0.3813
2.29	0.3342	0.5857	0.5706	2.173	1.162	0.7763	0.3838
2.30	0.3320	0.5831	0.5694	2.193	1.163	0.7853	0.3862
2.31	0.3298	0.5805	0.5682	2.213	1.164	0.7944	0.3887
2.32	0.3277	0.5779	0.5670	2.233	1.165	0.8035	0.3911
2.33	0.3255	0.5753	0.5658	2.254	1.167	0.8126	0.3935
2.34	0.3234	0.5728	0.5647	2.274	1.168	0.8217	0.3959

continued

Appendix E *Continued*

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho}{\rho^*} = \frac{V^*}{V}$	$\frac{p_0}{p_0^*}$	$\frac{I}{I^*}$	$\frac{s^* - s}{R}$	$\frac{4fL_{max}}{D}$
4.81	0.096 01	0.2132	0.4502	21.44	1.336	3.065	0.6847
4.82	0.095 64	0.2125	0.4500	21.61	1.336	3.073	0.6852
4.83	0.095 28	0.2118	0.4499	21.79	1.336	3.082	0.6857
4.84	0.094 92	0.2111	0.4497	21.97	1.337	3.090	0.6862
4.85	0.094 57	0.2104	0.4495	22.15	1.337	3.098	0.6867
4.86	0.094 21	0.2096	0.4494	22.33	1.337	3.106	0.6872
4.87	0.093 86	0.2089	0.4492	22.51	1.338	3.114	0.6877
4.88	0.093 51	0.2082	0.4491	22.70	1.338	3.122	0.6881
4.89	0.093 16	0.2075	0.4489	22.88	1.338	3.130	0.6886
4.90	0.092 81	0.2068	0.4487	23.07	1.339	3.138	0.6891
4.91	0.092 47	0.2061	0.4486	23.25	1.339	3.146	0.6896
4.92	0.092 12	0.2054	0.4484	23.44	1.339	3.155	0.6901
4.93	0.091 78	0.2047	0.4483	23.63	1.340	3.163	0.6905
4.94	0.091 44	0.2041	0.4481	23.82	1.340	3.171	0.6910
4.95	0.091 10	0.2034	0.4480	24.02	1.340	3.179	0.6915
4.96	0.090 77	0.2027	0.4478	24.21	1.340	3.187	0.6920
4.97	0.090 43	0.2020	0.4477	24.41	1.341	3.195	0.6924
4.98	0.090 10	0.2013	0.4475	24.60	1.341	3.203	0.6929
4.99	0.089 77	0.2007	0.4474	24.80	1.341	3.211	0.6933
5.00	0.089 44	0.2000	0.4472	25.00	1.342	3.219	0.6938
∞	0.000 00	0.0000	0.4083	∞	1.429	∞	0.8215

Appendix F
Isothermal flow of a perfect gas ($k = 1.4$)

M	$\frac{p}{p^{*t}} = \frac{\rho}{\rho^{*t}} = \frac{V^{*t}}{V}$	$\frac{p_0}{p_0^{*t}}$	$\frac{T_0}{T_0^{*t}}$	$\frac{I}{I^{*t}}$	$\frac{s^{*t} - s}{R}$	$\frac{4\bar{f}L_{max}}{D}$
0.00	∞	∞	0.8750	∞	∞	∞
0.01	84.52	52.97	0.8750	42.26	4.4369	7133.0
0.02	42.26	26.49	0.8751	21.14	3.7438	1777.0
0.03	28.17	17.67	0.8752	14.10	3.3383	786.0
0.04	21.13	13.26	0.8753	10.59	3.0506	439.3
0.05	16.90	10.61	0.8754	8.481	2.8275	279.1
0.06	14.09	8.849	0.8756	7.078	2.6452	192.1
0.07	12.07	7.592	0.8759	6.078	2.4910	139.8
0.08	10.56	6.650	0.8761	5.330	2.3575	105.9
0.09	9.391	5.918	0.8764	4.749	2.2397	82.70
0.10	8.452	5.333	0.8768	4.285	2.1343	66.16
0.11	7.683	4.856	0.8771	3.907	2.0390	53.95
0.12	7.043	4.458	0.8775	3.592	1.9520	44.70
0.13	6.501	4.122	0.8780	3.328	1.8720	37.52
0.14	6.037	3.835	0.8784	3.101	1.7979	31.85
0.15	5.634	3.587	0.8789	2.906	1.7289	27.29
0.16	5.282	3.370	0.8795	2.736	1.6643	23.57
0.17	4.971	3.179	0.8801	2.586	1.6037	20.51
0.18	4.695	3.010	0.8807	2.454	1.5466	17.95
0.19	4.448	2.859	0.8813	2.336	1.4925	15.80
0.20	4.226	2.723	0.8820	2.231	1.4412	13.98
0.21	4.025	2.601	0.8827	2.137	1.3924	12.41
0.22	3.842	2.490	0.8835	2.051	1.3459	11.07
0.23	3.675	2.389	0.8843	1.973	1.3014	9.900
0.24	3.521	2.297	0.8851	1.903	1.2589	8.883
0.25	3.381	2.213	0.8859	1.838	1.2181	7.993
0.26	3.251	2.135	0.8868	1.779	1.1788	7.209
0.27	3.130	2.063	0.8878	1.725	1.1411	6.516
0.28	3.018	1.997	0.8887	1.675	1.1047	5.901
0.29	2.914	1.936	0.8897	1.629	1.0696	5.354

continued

Appendix F *Continued*

M	$\frac{p}{p^{*}{}_{1}} = \frac{\rho}{\rho^{*}{}_{1}} = \frac{V^{*}{}_{1}}{V}$	$\frac{p_0}{p_0^{*}{}_{1}}$	$\frac{T_0}{T_0^{*}{}_{1}}$	$\frac{I}{I^{*}{}_{1}}$	$\frac{s^{*}{}_{1} - s}{R}$	$\frac{4f l}{D}$
1.30	2.817	1.879	0.8908	1.586	1.0357	4.865
1.31	2.726	1.826	0.8918	1.547	1.0029	4.427
1.32	2.641	1.777	0.8929	1.510	0.9712	4.033
1.33	2.561	1.731	0.8941	1.476	0.9404	3.678
1.34	2.486	1.687	0.8952	1.444	0.9106	3.358
1.35	2.415	1.647	0.8964	1.414	0.8816	3.068
1.36	2.348	1.609	0.8977	1.387	0.8534	2.805
1.37	2.284	1.573	0.8990	1.361	0.8260	2.566
1.38	2.224	1.540	0.9003	1.337	0.7993	2.348
1.39	2.167	1.508	0.9016	1.314	0.7734	2.149
1.40	2.113	1.478	0.9030	1.293	0.7481	1.968
1.41	2.061	1.450	0.9044	1.273	0.7234	1.802
1.42	2.012	1.424	0.9059	1.255	0.6993	1.651
1.43	1.965	1.399	0.9074	1.237	0.6757	1.512
1.44	1.921	1.375	0.9089	1.221	0.6527	1.384
1.45	1.878	1.352	0.9104	1.205	0.6303	1.267
1.46	1.847	1.331	0.9120	1.191	0.6083	1.159
1.47	1.798	1.311	0.9137	1.177	0.5868	1.060
1.48	1.761	1.292	0.9153	1.164	0.5657	0.9687
1.49	1.725	1.274	0.9170	1.152	0.5451	0.8847
1.50	1.690	1.256	0.9187	1.141	0.5249	0.8073
1.51	1.657	1.240	0.9205	1.130	0.5051	0.7360
1.52	1.625	1.225	0.9223	1.120	0.4857	0.6702
1.53	1.595	1.210	0.9242	1.111	0.4666	0.6096
1.54	1.565	1.196	0.9260	1.102	0.4480	0.5536
1.55	1.537	1.183	0.9279	1.094	0.4296	0.5021
1.56	1.509	1.170	0.9299	1.086	0.4116	0.4545
1.57	1.483	1.158	0.9319	1.079	0.3939	0.4107
1.58	1.457	1.147	0.9339	1.072	0.3765	0.3703
1.59	1.433	1.136	0.9359	1.065	0.3594	0.3332
1.60	1.409	1.126	0.9380	1.059	0.3426	0.2990
1.61	1.386	1.116	0.9401	1.054	0.3261	0.2675
1.62	1.363	1.107	0.9423	1.048	0.3098	0.2386
1.63	1.342	1.098	0.9445	1.044	0.2938	0.2121
1.64	1.321	1.090	0.9467	1.039	0.2781	0.1878
1.65	1.300	1.082	0.9489	1.035	0.2626	0.1655
1.66	1.281	1.075	0.9512	1.031	0.2473	0.1452
67	1.261	1.068	0.9536	1.027	0.2322	0.1267
68	1.243	1.062	0.9559	1.024	0.2174	0.1099
69	1.225	1.055	0.9583	1.021	0.2028	0.094 63
70	1.207	1.050	0.9608	1.018	0.1885	0.080 85
71	1.190	1.044	0.9632	1.015	0.1743	0.068 44

Appendix F *Continued*

M	$\frac{p}{p^{*}{}_{1}} = \frac{\rho}{\rho^{*}{}_{1}} = \frac{V^{*}{}_{1}}{V}$	$\frac{p_0}{p_0^{*}{}_{1}}$	$\frac{T_0}{T_0^{*}{}_{1}}$	$\frac{I}{I^{*}{}_{1}}$	$\frac{s^{*}{}_{1} - s}{R}$	$\frac{4f L_{max}}{D}$
0.72	1.174	1.039	0.9657	1.013	0.1603	0.057 33
0.73	1.158	1.034	0.9683	1.011	0.1465	0.047 43
0.74	1.142	1.030	0.9708	1.009	0.1329	0.038 66
0.75	1.127	1.026	0.9734	1.007	0.1195	0.030 95
0.76	1.112	1.022	0.9761	1.006	0.1062	0.024 24
0.77	1.098	1.018	0.9788	1.004	0.093 13	0.018 48
0.78	1.084	1.015	0.9815	1.003	0.080 23	0.013 59
0.79	1.067	1.012	0.9842	1.002	0.067 49	0.009 532
0.80	1.056	1.009	0.9870	1.002	0.054 91	0.006 257
0.81	1.043	1.007	0.9898	1.001	0.042 49	0.003 715
0.82	1.031	1.005	0.9927	1.001	0.030 22	0.001 863
0.83	1.018	1.003	0.9956	1.000	0.018 09	0.000 662 8
0.84	1.006	1.001	0.9985	1.000	0.006 117	0.000 075 15
0.85	0.9943	0.9993	1.001	1.000	−0.005 717	0.000 065 12
0.86	0.9827	0.9981	1.004	1.000	−0.017 41	0.000 599 5
0.87	0.9714	0.9970	1.008	1.000	−0.028 97	0.001 647
0.88	0.9604	0.9962	1.011	1.001	−0.040 40	0.003 179
0.89	0.9496	0.9956	1.014	1.001	−0.051 70	0.005 167
0.90	0.9391	0.9953	1.017	1.002	−0.062 88	0.007 585
0.91	0.9287	0.9951	1.020	1.003	−0.073 93	0.010 41
0.92	0.9186	0.9952	1.023	1.004	−0.084 86	0.013 62
0.93	0.9088	0.9954	1.026	1.005	−0.095 67	0.017 19
0.94	0.8991	0.9958	1.030	1.006	−0.1064	0.021 10
0.95	0.8896	0.9965	1.033	1.007	−0.1169	0.025 34
0.96	0.8804	0.9973	1.036	1.008	−0.1274	0.029 88
0.97	0.8713	0.9983	1.040	1.010	−0.1378	0.034 71
0.98	0.8624	0.9996	1.043	1.011	−0.1480	0.039 81
0.99	0.8537	1.0010	1.047	1.013	−0.1582	0.045 16
1.00	0.8452	1.0025	1.050	1.014	−0.1682	0.050 76
1.01	0.8368	1.004	1.054	1.016	−0.1782	0.056 58
1.02	0.8286	1.006	1.057	1.018	−0.1880	0.062 63
1.03	0.8205	1.008	1.061	1.020	−0.1978	0.068 87
1.04	0.8126	1.011	1.064	1.022	−0.2075	0.075 31
1.05	0.8049	1.013	1.068	1.024	−0.2170	0.081 93
1.06	0.7973	1.016	1.072	1.026	−0.2265	0.088 72
1.07	0.7899	1.019	1.075	1.028	−0.2359	0.095 67
1.08	0.7826	1.022	1.079	1.030	−0.2452	0.1028
1.09	0.7754	1.025	1.083	1.033	−0.2544	0.1100
1.10	0.7683	1.028	1.087	1.035	−0.2635	0.1174
1.11	0.7614	1.031	1.091	1.037	−0.2726	0.1249

continued

208

Appendix F *Continued*

M	$\frac{p}{p^{*}}$, $\frac{\rho}{\rho^{*}} = \frac{V^{*}}{V}$	$\frac{p_0}{p_0^{*}}$	$\frac{T_0}{T_0^{*}}$	$\frac{f}{f^{*}}$	$\frac{s^{*} - s}{R}$	$\frac{4fL_{max}}{D}$
1.12	0.7546	1.035	1.095	1.040	−0.2816	0.1326
1.13	0.7479	1.039	1.098	1.042	−0.2905	0.1403
1.14	0.7414	1.043	1.102	1.045	−0.2993	0.1482
1.15	0.7349	1.047	1.106	1.048	−0.3080	0.1561
1.16	0.7286	1.051	1.110	1.051	−0.3167	0.1641
1.17	0.7224	1.056	1.115	1.053	−0.3252	0.1723
1.18	0.7162	1.061	1.119	1.056	−0.3338	0.1805
1.19	0.7102	1.065	1.123	1.059	−0.3422	0.1888
1.20	0.7043	1.070	1.127	1.062	−0.3506	0.1972
1.21	0.6985	1.075	1.131	1.065	−0.3589	0.2056
1.22	0.6927	1.081	1.135	1.068	−0.3671	0.2141
1.23	0.6871	1.086	1.140	1.071	−0.3753	0.2226
1.24	0.6816	1.092	1.144	1.074	−0.3833	0.2312
1.25	0.6761	1.097	1.148	1.078	−0.3914	0.2399
1.26	0.6708	1.104	1.153	1.081	−0.3993	0.2486
1.27	0.6655	1.110	1.157	1.084	−0.4073	0.2574
1.28	0.6603	1.116	1.162	1.087	−0.4151	0.2662
1.29	0.6552	1.122	1.166	1.091	−0.4229	0.2750
1.30	0.6501	1.129	1.171	1.094	−0.4306	0.2839
1.31	0.6452	1.136	1.175	1.098	−0.4383	0.2928
1.32	0.6403	1.142	1.180	1.101	−0.4459	0.3017
1.33	0.6355	1.150	1.185	1.105	−0.4534	0.3106
1.34	0.6307	1.157	1.189	1.108	−0.4609	0.3196
1.35	0.6260	1.164	1.194	1.112	−0.4683	0.3286
1.36	0.6214	1.172	1.199	1.115	−0.4757	0.3376
1.37	0.6169	1.180	1.203	1.119	−0.4830	0.3467
1.38	0.6124	1.187	1.208	1.123	−0.4903	0.3557
1.39	0.6080	1.196	1.213	1.126	−0.4975	0.3648
1.40	0.6037	1.204	1.218	1.130	−0.5047	0.3739
1.41	0.5994	1.212	1.223	1.134	−0.5118	0.3829
1.42	0.5952	1.221	1.228	1.138	−0.5189	0.3920
1.43	0.5910	1.230	1.233	1.142	−0.5259	0.4011
1.44	0.5869	1.239	1.238	1.145	−0.5329	0.4102
1.45	0.5829	1.248	1.243	1.149	−0.5398	0.4193
1.46	0.5789	1.257	1.248	1.153	−0.5467	0.4284
1.47	0.5749	1.267	1.253	1.157	−0.5535	0.4376
1.48	0.5711	1.276	1.258	1.161	−0.5603	0.4467
1.49	0.5672	1.286	1.264	1.165	−0.5670	0.4558
1.50	0.5634	1.296	1.269	1.169	−0.5737	0.4649
1.51	0.5597	1.306	1.274	1.173	−0.5803	0.4740
1.52	0.5560	1.317	1.279	1.177	−0.5869	0.4831
1.53	0.5524	1.327	1.285	1.181	−0.5935	0.4921

Appendix F Continued

M	$\frac{p}{p^{*}} = \frac{\rho}{\rho^{*}} = \frac{V^{*}}{V}$	$\frac{p_0}{p_0^{*}}$	$\frac{T_0}{T_0^{*}}$	$\frac{f}{f^{*}}$	$\frac{s^{*} - s}{R}$	$\frac{4fL_{max}}{D}$
1.54	0.5488	1.338	1.290	1.185	−0.6000	0.5012
1.55	0.5453	1.349	1.295	1.190	−0.6065	0.5103
1.56	0.5418	1.360	1.301	1.194	−0.6129	0.5194
1.57	0.5383	1.372	1.306	1.198	−0.6193	0.5284
1.58	0.5349	1.383	1.312	1.202	−0.6257	0.5374
1.59	0.5315	1.395	1.317	1.206	−0.6320	0.5465
1.60	0.5282	1.407	1.323	1.211	−0.6382	0.5555
1.61	0.5249	1.419	1.329	1.215	−0.6445	0.5645
1.62	0.5217	1.431	1.334	1.219	−0.6507	0.5735
1.63	0.5185	1.444	1.340	1.224	−0.6568	0.5825
1.64	0.5153	1.457	1.346	1.228	−0.6629	0.5914
1.65	0.5122	1.470	1.351	1.232	−0.6690	0.6004
1.66	0.5091	1.483	1.357	1.237	−0.6751	0.6093
1.67	0.5061	1.496	1.363	1.241	−0.6811	0.6182
1.68	0.5031	1.510	1.369	1.245	−0.6870	0.6271
1.69	0.5001	1.524	1.375	1.250	−0.6930	0.6360
1.70	0.4971	1.538	1.381	1.254	−0.6989	0.6449
1.71	0.4942	1.552	1.387	1.259	−0.7047	0.6537
1.72	0.4914	1.567	1.393	1.263	−0.7106	0.6626
1.73	0.4885	1.581	1.399	1.268	−0.7164	0.6714
1.74	0.4857	1.596	1.405	1.272	−0.7221	0.6802
1.75	0.4829	1.611	1.411	1.277	−0.7279	0.6889
1.76	0.4802	1.627	1.417	1.281	−0.7335	0.6977
1.77	0.4775	1.642	1.423	1.286	−0.7392	0.7064
1.78	0.4748	1.658	1.429	1.290	−0.7448	0.7151
1.79	0.4722	1.674	1.436	1.295	−0.7505	0.7238
1.80	0.4695	1.691	1.442	1.300	−0.7560	0.7325
1.81	0.4669	1.707	1.448	1.304	−0.7616	0.7412
1.82	0.4644	1.724	1.455	1.309	−0.7671	0.7498
1.83	0.4618	1.741	1.461	1.314	−0.7726	0.7584
1.84	0.4593	1.758	1.467	1.318	−0.7780	0.7670
1.85	0.4568	1.776	1.474	1.323	−0.7834	0.7755
1.86	0.4544	1.794	1.480	1.328	−0.7888	0.7841
1.87	0.4520	1.812	1.487	1.332	−0.7942	0.7926
1.88	0.4496	1.830	1.494	1.337	−0.7995	0.8011
1.89	0.4472	1.849	1.500	1.342	−0.8048	0.8096
1.90	0.4448	1.868	1.507	1.346	−0.8101	0.8180
1.91	0.4425	1.887	1.513	1.351	−0.8153	0.8265
1.92	0.4402	1.906	1.520	1.356	−0.8206	0.8349
1.93	0.4379	1.926	1.527	1.361	−0.8258	0.8433

continued

Appendix G
Flow of a perfect gas on the Rayleigh line ($k = 1.4$)

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho}{\rho^*} = \frac{V^*}{V}$	$\frac{p_0}{p_0^*}$	$\frac{T_0}{T_0^*}$	$\frac{s^* - s}{R}$
0.00	2.400	0.000 000 0	∞	1.268	0.000 000 0	∞
0.01	2.400	0.000 578 8	4167.0	1.268	0.000 479 9	26.98
0.02	2.399	0.002 301	1042.0	1.268	0.001 918	22.14
0.03	2.397	0.005 171	463.6	1.267	0.004 310	19.30
0.04	2.395	0.009 175	261.0	1.266	0.007 648	17.29
0.05	2.392	0.014 30	167.3	1.266	0.011 92	15.74
0.06	2.388	0.020 53	116.32	1.265	0.017 12	14.47
0.07	2.384	0.027 84	85.62	1.264	0.023 22	13.40
0.08	2.379	0.036 21	65.69	1.262	0.030 22	12.48
0.09	2.373	0.045 62	52.02	1.261	0.038 08	11.67
0.10	2.367	0.056 02	42.25	1.259	0.046 78	10.95
0.11	2.360	0.067 39	35.02	1.257	0.056 30	10.30
0.12	2.353	0.079 70	29.52	1.255	0.066 61	9.709
0.13	2.345	0.092 90	25.24	1.253	0.077 68	9.169
0.14	2.336	0.1070	21.84	1.251	0.089 47	8.672
0.15	2.327	0.1218	19.10	1.249	0.1020	8.213
0.16	2.317	0.1374	16.86	1.246	0.1151	7.787
0.17	2.307	0.1538	15.00	1.243	0.1289	7.389
0.18	2.296	0.1708	13.44	1.241	0.1432	7.017
0.19	2.285	0.1884	12.13	1.238	0.1581	6.668
0.20	2.273	0.2066	11.00	1.235	0.1736	6.340
0.21	2.260	0.2253	10.03	1.231	0.1894	6.031
0.22	2.248	0.2445	9.192	1.228	0.2057	5.739
0.23	2.235	0.2641	8.460	1.225	0.2224	5.464
0.24	2.221	0.2841	7.817	1.221	0.2395	5.202
0.25	2.207	0.3044	7.250	1.218	0.2568	4.955
0.26	2.193	0.3250	6.747	1.214	0.2745	4.719
0.27	2.178	0.3457	6.299	1.210	0.2923	4.496
0.28	2.163	0.3667	5.898	1.206	0.3104	4.283
0.29	2.147	0.3877	5.538	1.203	0.3286	4.080
0.30	2.131	0.4089	5.213	1.199	0.3469	3.887

Appendix G *Continued*

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho}{\rho^*} = \frac{V^*}{V}$	$\frac{p_0}{p_0^*}$	$\frac{T_0}{T_0^*}$	$\frac{s^* - s}{R}$
0.31	2.115	0.4300	4.919	1.195	0.3653	3.703
0.32	2.099	0.4512	4.652	1.190	0.3837	3.527
0.33	2.083	0.4723	4.409	1.186	0.4021	3.359
0.34	2.066	0.4933	4.188	1.182	0.4206	3.199
0.35	2.049	0.5141	3.985	1.178	0.4389	3.046
0.36	2.031	0.5348	3.798	1.174	0.4572	2.899
0.37	2.014	0.5553	3.627	1.169	0.4754	2.759
0.38	1.996	0.5755	3.469	1.165	0.4935	2.625
0.39	1.979	0.5955	3.323	1.161	0.5113	2.497
0.40	1.961	0.6152	3.187	1.157	0.5290	2.374
0.41	1.943	0.6345	3.062	1.152	0.5465	2.256
0.42	1.925	0.6535	2.945	1.148	0.5638	2.144
0.43	1.906	0.6721	2.837	1.144	0.5808	2.036
0.44	1.888	0.6903	2.736	1.139	0.5975	1.933
0.45	1.870	0.7080	2.641	1.135	0.6139	1.834
0.46	1.852	0.7254	2.552	1.131	0.6301	1.740
0.47	1.833	0.7423	2.470	1.127	0.6459	1.649
0.48	1.815	0.7587	2.392	1.122	0.6613	1.562
0.49	1.796	0.7747	2.319	1.118	0.6766	1.479
0.50	1.778	0.7901	2.250	1.114	0.6914	1.400
0.51	1.759	0.8051	2.185	1.110	0.7058	1.324
0.52	1.741	0.8196	2.124	1.106	0.7199	1.251
0.53	1.723	0.8335	2.067	1.102	0.7336	1.181
0.54	1.704	0.8469	2.012	1.098	0.7470	1.115
0.55	1.686	0.8599	1.961	1.094	0.7599	1.051
0.56	1.668	0.8723	1.912	1.090	0.7725	0.9898
0.57	1.650	0.8842	1.866	1.086	0.7847	0.9315
0.58	1.632	0.8955	1.822	1.083	0.7965	0.8758
0.59	1.614	0.9064	1.780	1.079	0.8079	0.8226
0.60	1.596	0.9167	1.741	1.075	0.8189	0.7717
0.61	1.578	0.9265	1.703	1.072	0.8296	0.7232
0.62	1.560	0.9358	1.667	1.068	0.8398	0.6770
0.63	1.543	0.9447	1.633	1.065	0.8497	0.6328
0.64	1.525	0.9530	1.601	1.061	0.8592	0.5908
0.65	1.508	0.9608	1.570	1.058	0.8683	0.5507
0.66	1.491	0.9682	1.540	1.055	0.8771	0.5126
0.67	1.474	0.9750	1.512	1.052	0.8855	0.4763
0.68	1.457	0.9814	1.484	1.049	0.8935	0.4419
0.69	1.440	0.9874	1.458	1.046	0.9012	0.4092
0.70	1.423	0.9929	1.434	1.043	0.9085	0.3781

270

continu

Appendix G *Continued*

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho^*}{\rho}=\frac{V}{V^*}$	$\frac{p_0}{p_0^*}$	$\frac{T_0}{T_0^*}$	$\frac{s^*-s}{R}$
0.71	1.407	0.9980	1.410	1.040	0.9155	0.3486
0.72	1.391	1.003	1.387	1.038	0.9221	0.3207
0.73	1.375	1.007	1.365	1.035	0.9284	0.2943
0.74	1.359	1.011	1.344	1.033	0.9344	0.2694
0.75	1.343	1.014	1.324	1.030	0.9401	0.2459
0.76	1.327	1.017	1.305	1.028	0.9455	0.2237
0.77	1.311	1.020	1.286	1.026	0.9505	0.2028
0.78	1.296	1.022	1.268	1.023	0.9553	0.1832
0.79	1.281	1.024	1.251	1.021	0.9598	0.1649
0.80	1.266	1.026	1.234	1.019	0.9639	0.1477
0.81	1.251	1.027	1.218	1.017	0.9679	0.1316
0.82	1.236	1.028	1.203	1.016	0.9715	0.1167
0.83	1.222	1.028	1.188	1.014	0.9749	0.1028
0.84	1.207	1.029	1.174	1.012	0.9781	0.089 95
0.85	1.193	1.029	1.160	1.011	0.9810	0.078 10
0.86	1.179	1.028	1.147	1.010	0.9836	0.067 22
0.87	1.165	1.028	1.134	1.008	0.9861	0.057 27
0.88	1.152	1.027	1.121	1.007	0.9883	0.048 22
0.89	1.138	1.026	1.109	1.006	0.9903	0.040 04
0.90	1.125	1.025	1.098	1.005	0.9921	0.032 70
0.91	1.111	1.023	1.086	1.004	0.9937	0.026 18
0.92	1.098	1.021	1.076	1.003	0.9951	0.020 44
0.93	1.086	1.019	1.065	1.002	0.9963	0.015 47
0.94	1.073	1.017	1.055	1.002	0.9973	0.011 24
0.95	1.060	1.015	1.045	1.001	0.9981	0.007 714
0.96	1.048	1.012	1.035	1.001	0.9988	0.004 881
0.97	1.036	1.009	1.026	1.000	0.9993	0.002 715
0.98	1.024	1.006	1.017	1.000	0.9997	0.001 193
0.99	1.012	1.003	1.008	1.000	0.9999	0.000 294 8
1.00	1.000	1.000	1.000	1.000	1.0000	0.000 000 0
1.01	0.9884	0.9966	0.9918	1.000	0.9999	0.000 288 2
1.02	0.9770	0.9930	0.9838	1.000	0.9997	0.001 141
1.03	0.9657	0.9894	0.9761	1.000	0.9994	0.002 539
1.04	0.9546	0.9855	0.9686	1.001	0.9989	0.004 466
1.05	0.9436	0.9816	0.9613	1.001	0.9984	0.006 902
1.06	0.9327	0.9776	0.9542	1.002	0.9977	0.009 833
1.07	0.9221	0.9734	0.9473	1.002	0.9969	0.013 24
1.08	0.9115	0.9691	0.9406	1.003	0.9960	0.017 11
1.09	0.9011	0.9648	0.9340	1.004	0.9950	0.021 43
1.10	0.8909	0.9603	0.9277	1.005	0.9939	0.026 18
1.11	0.8808	0.9558	0.9215	1.006	0.9927	0.031 35
1.12	0.8708	0.9512	0.9155	1.007	0.9915	0.036 92

Appendix G *Continued*

M	$\frac{p}{p^*}$	$\frac{T}{T^*}$	$\frac{\rho^*}{\rho}=\frac{V}{V^*}$	$\frac{p_0}{p_0^*}$	$\frac{T_0}{T_0^*}$	$\frac{s^*-s}{R}$
1.13	0.9609	0.9465	0.9096	1.008	0.9901	0.042 88
1.14	0.9512	0.9417	0.9039	1.010	0.9887	0.049 22
1.15	0.8417	0.9369	0.8984	1.011	0.9872	0.055 93
1.16	0.8322	0.9320	0.8930	1.012	0.9856	0.062 98
1.17	0.8229	0.9270	0.8877	1.014	0.9840	0.070 39
1.18	0.8137	0.9220	0.8826	1.016	0.9823	0.078 12
1.19	0.8047	0.9169	0.8776	1.018	0.9805	0.086 17
1.20	0.7958	0.9118	0.8727	1.019	0.9787	0.094 53
1.21	0.7870	0.9067	0.8679	1.021	0.9768	0.1032
1.22	0.7783	0.9015	0.8633	1.023	0.9749	0.1121
1.23	0.7697	0.8963	0.8587	1.026	0.9729	0.1214
1.24	0.7613	0.8911	0.8543	1.028	0.9709	0.1309
1.25	0.7529	0.8858	0.8500	1.030	0.9689	0.1408
1.26	0.7447	0.8805	0.8458	1.033	0.9668	0.1508
1.27	0.7366	0.8752	0.8417	1.035	0.9646	0.1609
1.28	0.7287	0.8699	0.8376	1.038	0.9624	0.1714
1.29	0.7208	0.8645	0.8337	1.041	0.9602	0.1821
1.30	0.7130	0.8592	0.8299	1.044	0.9580	0.1930
1.31	0.7054	0.8538	0.8261	1.047	0.9557	0.2044
1.32	0.6978	0.8484	0.8225	1.050	0.9531	0.2155
1.33	0.6904	0.8430	0.8189	1.053	0.9511	0.2270
1.34	0.6830	0.8377	0.8154	1.056	0.9487	0.2388
1.35	0.6758	0.8323	0.8120	1.059	0.9464	0.2507
1.36	0.6686	0.8269	0.8086	1.063	0.9440	0.2628
1.37	0.6616	0.8215	0.8053	1.066	0.9416	0.2750
1.38	0.6546	0.8161	0.8021	1.070	0.9391	0.2875
1.39	0.6478	0.8108	0.7990	1.074	0.9367	0.3001
1.40	0.6410	0.8054	0.7959	1.078	0.9343	0.3128
1.41	0.6344	0.8000	0.7929	1.082	0.9318	0.3257
1.42	0.6278	0.7947	0.7900	1.086	0.9293	0.3387
1.43	0.6213	0.7894	0.7871	1.090	0.9268	0.3519
1.44	0.6149	0.7840	0.7843	1.094	0.9243	0.3652
1.45	0.6086	0.7787	0.7815	1.098	0.9218	0.3787
1.46	0.6024	0.7735	0.7788	1.103	0.9193	0.3922
1.47	0.5962	0.7682	0.7762	1.107	0.9168	0.4059
1.48	0.5902	0.7629	0.7736	1.112	0.9143	0.4197
1.49	0.5842	0.7577	0.7710	1.117	0.9118	0.4336
1.50	0.5783	0.7525	0.7685	1.122	0.9093	0.4476
1.51	0.5725	0.7473	0.7661	1.126	0.9068	0.4617
1.52	0.5668	0.7422	0.7637	1.132	0.9042	0.4759

continued