Compressible Flow - TME085

Formulas, tables, and graphs

Contents

Chapter 1

Introduction

Note: numbering of equations and tables follows the numbering in Andersson J. D., 2021,"*Modern Compressible Flow With Historical Perspective*", McGraw Hill 4^{th} edition.

1.1 Conversion Factors

It is recommended to only use SI units when doing the calculations. To convert from non-SI to SI units the following may help:

1 foot = 0.3048 m

1 inch = 0.0254 m

1 slug = 14.593902937 kg

1 pound (force) = 4.448221615 N

1 atm = 101325 Pa

1 psi = 6894.757293178 Pa

1 degree R = 0.555556 degree K

1 lb/ft^2 = 47.88025898 Pa

1.4 A Brief Review of Thermodynamics

1.4.1 Perfect gas

The gas relation for a perfect gas is given by

$$p = \rho RT \tag{1.9}$$

or $p\nu = RT$ where $\nu = 1/\rho$. R is the gas constant given by

$$R = \frac{R_{univ}}{M}$$

where $R_{univ} = 8314 \ \left[\frac{J}{kmol \ K}\right]$ and M is the molecular weight [kg/kmol].

For air at normal conditions $R = 287.0 \ [J/(kg \ K)]$

1.4.2 Internal Energy and Enthalpy

General relations (all gases):

$$h = e + p/\rho$$

Chemically reacting mixture of thermally perfect gases (in chemical equilibrium):

$$p = p(\rho, T)$$

$$\begin{aligned} e &= e(\nu, T) \\ h &= h(p, T) \end{aligned} \tag{1.17}$$

$$C_v = \left(\frac{\partial e}{\partial T}\right)_v$$

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

Thermally perfect gas:

$$p = \rho R T \tag{1.9}$$

$$\begin{aligned} e &= e(T) \\ h &= h(T) \\ de &= C_v dT \\ dh &= C_p dT \end{aligned} \tag{1.18}$$

Calorically perfect gas:

$$p = \rho R T \tag{1.9}$$

$$\begin{aligned} e &= C_v T \\ h &= C_p T \end{aligned} \tag{1.19}$$

For thermally perfect gas and calorically perfect gas:

$$C_p - C_v = R \tag{1.20}$$

$$\gamma \equiv C_p/C_v$$

$$C_p = \frac{\gamma R}{\gamma - 1} \tag{1.22}$$

$$C_v = \frac{R}{\gamma - 1} \tag{1.23}$$

1.4.5 Calculation of Entropy

General relations (all gases):

$$Tds = de + pd\nu \tag{1.30}$$

or

$$Tds = dh - \nu dp \tag{1.32}$$

where $\nu = 1/\rho$

Thermally perfect gas:

$$s_2 - s_1 = \int_{T_1}^{T_2} C_p \frac{dT}{T} - R \ln \frac{p_2}{p_1} \tag{1.35}$$

Calorically perfect gas:

$$s_2 - s_1 = C_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1} \tag{1.36}$$

or

$$s_2 - s_1 = C_v \ln \frac{T_2}{T_1} + R \ln \frac{\nu_2}{\nu_1} \tag{1.37}$$

1.4.6 Isentropic Relations

Isentropic process, calorically perfect gas:

$$\frac{p_2}{p_1} = \left(\frac{\rho_2}{\rho_1}\right)^{\gamma} = \left(\frac{T_2}{T_1}\right)^{\gamma/(\gamma-1)} \tag{1.43}$$

Chapter 2

Integral Forms of the Conservation Equations for Inviscid Flows

Assumptions: Fixed volume Ω, boundary $\partial\Omega$, outward facing unit normal vector $\mathbf{n}$

2.3 Continuity Equation

$$\frac{d}{dt}\iiint_{\Omega}\rho d\mathscr{V}+\oiint_{\partial\Omega}\rho\mathbf{v}\cdot\mathbf{n}dS=0 \tag{2.2}$$

2.4 Momentum Equation

$$\frac{d}{dt}\iiint_{\Omega}\rho\mathbf{v}d\mathscr{V}+\oiint_{\partial\Omega}\left[\rho(\mathbf{v}\cdot\mathbf{n})\mathbf{v}+p\mathbf{n}\right]dS=\iiint_{\Omega}\rho\mathbf{f}d\mathscr{V} \tag{2.11}$$

2.6 Energy Equation

$$\frac{d}{dt}\iiint_{\Omega}\rho\left(e+\frac{1}{2}\mathbf{v}\cdot\mathbf{v}\right)d\mathscr{V}+\oiint_{\partial\Omega}\rho\left(h+\frac{1}{2}\mathbf{v}\cdot\mathbf{v}\right)\mathbf{v}\cdot\mathbf{n}dS=\iiint_{\Omega}\rho\dot{q}d\mathscr{V}+\iiint_{\Omega}\rho\mathbf{f}\cdot\mathbf{v}d\mathscr{V} \tag{2.20}$$

or

$$\frac{d}{dt}\iiint_{\Omega}\rho e_o d\mathscr{V}+\oiint_{\partial\Omega}\rho h_o\mathbf{v}\cdot\mathbf{n}dS=\iiint_{\Omega}\rho\dot{q}d\mathscr{V}+\iiint_{\Omega}\rho\mathbf{f}\cdot\mathbf{v}d\mathscr{V}$$

Chapter 3

One-Dimensional Flow

3.3 Speed of Sound and Mach Number

General relations (all gases):

$$a^2 = \left(\frac{\partial p}{\partial \rho}\right)_s \tag{3.17}$$

$$M = \frac{V}{a} = \frac{|\mathbf{v}|}{a}$$

Thermally perfect gas or calorically perfect gas:

$$a = \sqrt{\frac{\gamma p}{\rho}} \tag{3.19}$$

$$a = \sqrt{\gamma RT} \tag{3.20}$$

Chemically reacting mixture of thermally perfect gases (in chemical equilibrium):

$$a_e^2 = \gamma RT \left[1 + \frac{1}{p}\left(\frac{\partial e}{\partial \nu}\right)_T\right] \Big/ \left[1 - \rho\left(\frac{\partial h}{\partial p}\right)_T\right] \tag{17.35}$$

where

$$\gamma \equiv \frac{C_p}{C_v} = \left(\frac{\partial h}{\partial T}\right)_p \Big/ \left(\frac{\partial e}{\partial T}\right)_v$$

and

$$RT = \frac{p}{\rho} \tag{1.9}$$

3.5 Alternative Forms of the Energy Equation

3.5.1 Total Flow Conditions

General relations (all gases):

$$h_o = h + \frac{1}{2}V^2$$

Calorically perfect gas:

$$\frac{T_o}{T} = 1 + \frac{\gamma - 1}{2}M^2 \tag{3.28}$$

$$\frac{p_o}{p} = \left(1 + \frac{\gamma - 1}{2}M^2\right)^{\gamma/(\gamma-1)} \tag{3.30}$$

$$\frac{\rho_o}{\rho} = \left(1 + \frac{\gamma - 1}{2}M^2\right)^{1/(\gamma-1)} \tag{3.31}$$

(see also Table A.1 for $\gamma = 1.4$)

3.5.2 Sonic flow conditions (isentropic flow)

Calorically perfect gas:

$$\left(\frac{a^*}{a_o}\right)^2 = \frac{T^*}{T_o} = \frac{2}{\gamma + 1} \tag{3.34}$$

$$\frac{p^*}{p_o} = \left(\frac{2}{\gamma + 1}\right)^{\gamma/(\gamma-1)} \tag{3.35}$$

$$\frac{\rho^*}{\rho_o} = \left(\frac{2}{\gamma + 1}\right)^{1/(\gamma-1)} \tag{3.36}$$

$$M^2 = \frac{2}{[(\gamma + 1)/M^{*2}] - (\gamma - 1)} \tag{3.37}$$

or

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

where

$$M^* = \frac{|\mathbf{v}|}{a^*}$$

3.6 Normal Shock Relations

General shock relations (all gases):

continuity:

$$\rho_1 u_1 = \rho_2 u_2 \tag{3.38}$$

momentum:

$$\rho_1 u_1^2 + p_1 = \rho_2 u_2^2 + p_2 \tag{3.39}$$

energy:

$$h_1 + \frac{1}{2}u_1^2 = h_2 + \frac{1}{2}u_2^2 \tag{3.40}$$

Calorically perfect gas:

$$a^{*2} = u_1 u_2 \tag{3.47}$$

or

$$M_2^* = \frac{1}{M_1^*} \tag{3.48}$$

$$M_2^2 = \frac{1 + [(\gamma-1)/2]M_1^2}{\gamma M_1^2 - (\gamma-1)/2} \tag{3.51}$$

$$\frac{\rho_2}{\rho_1} = \frac{u_1}{u_2} = \frac{(\gamma+1)M_1^2}{2 + (\gamma-1)M_1^2} \tag{3.53}$$

$$\frac{p_2}{p_1} = 1 + \frac{2\gamma}{\gamma+1}\left(M_1^2 - 1\right) \tag{3.57}$$

$$\frac{T_2}{T_1} = \frac{h_2}{h_1} = \left[1 + \frac{2\gamma}{\gamma+1}\left(M_1^2 - 1\right)\right]\left[\frac{2 + (\gamma-1)M_1^2}{(\gamma+1)M_1^2}\right] \tag{3.59}$$

$$T_{o_1} = T_{o_2} \tag{3.61}$$

$$s_2 - s_1 = -R \ln \frac{p_{o_2}}{p_{o_1}} \tag{3.63}$$

(see also Table A.2 for $\gamma = 1.4$)

3.7 Hugoniot Equation

General relations (all gases):

$$e_2 - e_1 = \frac{1}{2}(p_1 + p_2)\left(\frac{1}{\rho_1} - \frac{1}{\rho_2}\right) \tag{3.71}$$

or

$$e_2 - e_1 = \frac{1}{2}(p_1 + p_2)\,(\nu_1 - \nu_2) \tag{3.72}$$

3.8 One-Dimensional Flow with Heat Addition

General relations (all gases):

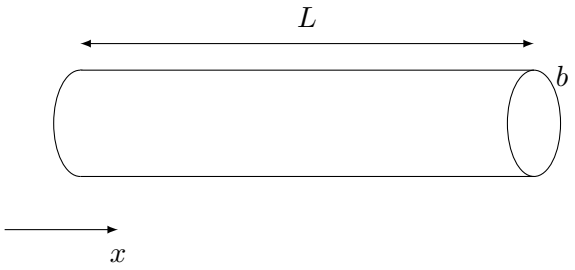
$$\rho_1 u_1 = \rho_2 u_2 \tag{3.2}$$

$$\rho_1 u_1^2 + p_1 = \rho_2 u_2^2 + p_2 \tag{3.5}$$

$$h_1 + \frac{1}{2}u_1^2 + q = h_2 + \frac{1}{2}u_2^2 \tag{3.9}$$

Relation between added heat per unit mass (q) and heat per unit surface area and unit time ($\dot{q}_{wall}$) for pipe with arbitrary cross section (constant in x), where

- L length of pipe
- b cross-section circumference
- $\dot{m}$ max flow through pipe



$$q = \frac{Lb\dot{q}_{wall}}{\dot{m}}$$

Calorically perfect gas:

$$q = C_p T_{o_2} - C_p T_{o_1} = C_p(T_{o_2} - T_{o_1}) \tag{3.77}$$

$$\frac{p_2}{p_1} = \frac{1 + \gamma M_1^2}{1 + \gamma M_2^2} \tag{3.78}$$

$$\frac{T_2}{T_1} = \left(\frac{1+\gamma M_1^2}{1+\gamma M_2^2}\right)^2 \left(\frac{M_2}{M_1}\right)^2 \tag{3.81}$$

$$\frac{\rho_2}{\rho_1} = \left(\frac{1+\gamma M_2^2}{1+\gamma M_1^2}\right) \left(\frac{M_1}{M_2}\right)^2 \tag{3.82}$$

$$\frac{p_{o_2}}{p_{o_1}} = \left(\frac{1+\gamma M_1^2}{1+\gamma M_2^2}\right) \left(\frac{1+\frac{\gamma-1}{2}M_2^2}{1+\frac{\gamma-1}{2}M_1^2}\right)^{\gamma/(\gamma-1)} \tag{3.83}$$

$$\frac{T_{o_2}}{T_{o_1}} = \left(\frac{1+\gamma M_1^2}{1+\gamma M_2^2}\right)^2 \left(\frac{M_2}{M_1}\right)^2 \left(\frac{1+\frac{\gamma-1}{2}M_2^2}{1+\frac{\gamma-1}{2}M_1^2}\right) \tag{3.84}$$

Calorically perfect gas, relative to sonic conditions:

$$\frac{p}{p^*} = \frac{1+\gamma}{1+\gamma M^2} \tag{3.85}$$

$$\frac{T}{T^*} = M^2 \left(\frac{1+\gamma}{1+\gamma M^2}\right)^2 \tag{3.86}$$

$$\frac{\rho}{\rho^*} = \frac{1}{M^2} \left(\frac{1+\gamma M^2}{1+\gamma}\right) \tag{3.87}$$

$$\frac{p_o}{p_o^*} = \left(\frac{1+\gamma}{1+\gamma M^2}\right) \left(\frac{2+(\gamma-1)M^2}{(\gamma+1)}\right)^{\gamma/(\gamma-1)} \tag{3.88}$$

$$\frac{T_o}{T_o^*} = \frac{(\gamma+1)M^2}{(1+\gamma M^2)^2} \left(2+(\gamma-1)M^2\right) \tag{3.89}$$

Amount of added heat per unit mass needed to choke the flow:

$$q^* = C_p(T_o^* - T_o) = C_p T_o \left(\frac{T_o^*}{T_o} - 1\right)$$

(See also Table A.3 for $\gamma = 1.4$)

3.9 One-Dimensional Flow with Friction

General relations (all gases):

$$\rho_1 u_1 = \rho_2 u_2 \tag{3.2}$$

$$\rho_1 u_1^2 + p_1 - \bar{\tau}_w \frac{Lb}{A} = \rho_2 u_2^2 + p_2 \tag{3.92}$$

$$h_1 + \frac{1}{2}u_1^2 = h_2 + \frac{1}{2}u_2^2 \tag{3.40}$$

where L is the length of the pipe, b is the cross-section circumference, A is the cross-section area and $\bar{\tau}_w$ is the average wall friction. Note that the momentum equation in Andersson (Eqn. 3.92) is not expressed in terms of averaged wall friction, $\bar{\tau}_w$, as it is here. For a round pipe with diameter D we get

$$\rho_1 u_1 = \rho_2 u_2 \tag{3.2}$$

$$\rho_1 u_1^2 + p_1 - \bar{\tau}_w \frac{4L}{D} = \rho_2 u_2^2 + p_2 \tag{3.92}$$

$$h_1 + \frac{1}{2}u_1^2 = h_2 + \frac{1}{2}u_2^2 \tag{3.40}$$

Calorically perfect gas:

Assumptions:

Frictionmodel: $\tau_w = \frac{1}{2}\rho u^2 f$, where f is a friction coefficient

Pipe cross-section: round pipe

$$\int_{x_1}^{x_2} \frac{4f}{D} dx = \left[\frac{-1}{\gamma M^2} - \frac{\gamma+1}{2\gamma} \ln \left(\frac{M^2}{1 + \frac{\gamma-1}{2} M^2} \right) \right]_{M_1}^{M_2} \tag{3.97}$$

$$\frac{T_2}{T_1} = \frac{2 + (\gamma-1)M_1^2}{2 + (\gamma-1)M_2^2} \tag{3.98}$$

$$\frac{p_2}{p_1} = \frac{M_1}{M_2} \left(\frac{2 + (\gamma-1)M_1^2}{2 + (\gamma-1)M_2^2} \right)^{1/2} \tag{3.100}$$

$$\frac{\rho_2}{\rho_1} = \frac{M_1}{M_2} \left(\frac{2 + (\gamma-1)M_1^2}{2 + (\gamma-1)M_2^2} \right)^{-1/2} \tag{3.101}$$

$$\frac{p_{o_2}}{p_{o_1}} = \frac{M_1}{M_2}\left(\frac{2+(\gamma-1)M_2^2}{2+(\gamma-1)M_1^2}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \tag{3.102}$$

Calorically prefect gas, relative to sonic conditions:

$$\frac{T}{T^*} = \frac{\gamma+1}{2+(\gamma-1)M^2} \tag{3.103}$$

$$\frac{p}{p^*} = \frac{1}{M}\left(\frac{\gamma+1}{2+(\gamma-1)M^2}\right)^{1/2} \tag{3.104}$$

$$\frac{\rho}{\rho^*} = \frac{1}{M}\left(\frac{2+(\gamma-1)M^2}{\gamma+1}\right)^{1/2} \tag{3.105}$$

$$\frac{p_o}{p_o^*} = \frac{1}{M}\left(\frac{2+(\gamma-1)M^2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \tag{3.106}$$

$$\frac{4\bar{f}L^*}{D} = \frac{1-M^2}{\gamma M^2} + \frac{\gamma+1}{2\gamma}\ln\left(\frac{(\gamma+1)M^2}{2+(\gamma-1)M^2}\right) \tag{3.107}$$

where $\bar{f}$ is an average friction coefficient defined as

$$\bar{f} = \frac{1}{L^*}\int_0^{L^*} f dx$$

and where L^* is the length of tube for which sonic conditions are reached.

(See also Table A.4 for $\gamma = 1.4$)

Chapter 4

Oblique Shock and Expansion Waves

Relations for oblique shocks and expansion waves in two-dimensional steady-state flows.

4.2 Source of Oblique Waves

Angle μ of Mach wave in two-dimensional steady-state supersonic flow:

$$\mu = \sin^{-1}\left(\frac{1}{M}\right) \tag{4.1}$$

4.3 Oblique Shock Relations

General relations (all gases):

$$\rho_1 u_1 = \rho_2 u_2 \tag{4.2}$$

$$\begin{gathered}\rho_1 u_1^2 + p_1 = \rho_2 u_2^2 + p_2 \\ w_1 = w_2\end{gathered} \tag{4.3}$$

$$h_1 + \frac{1}{2}u_1^2 = h_2 + \frac{1}{2}u_2^2 \tag{4.6}$$

where u is the velocity component normal to shock and w is the velocity component tangential to shock

Calorically perfect gas:

$$M_{n_1} = M_1 \sin\beta \tag{4.7}$$

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma+1)M_{n_1}^2}{(\gamma-1)M_{n_1}^2 + 2} \tag{4.8}$$

$$\frac{p_2}{p_1} = 1 + \frac{2\gamma}{\gamma+1}\left(M_{n_1}^2 - 1\right) \tag{4.9}$$

$$M_{n_2}^2 = \frac{M_{n_1}^2 + [2/(\gamma-1)]}{[2\gamma/(\gamma-1)]M_{n_1}^2 - 1} \tag{4.10}$$

$$\frac{T_2}{T_1} = \frac{p_2}{p_1}\frac{\rho_1}{\rho_2} \tag{4.11}$$

$$M_2 = \frac{M_{n_2}}{\sin(\beta-\theta)} \tag{4.12}$$

The θ-β-M relation:

$$\tan\theta = 2\cot\beta\left(\frac{M_1^2\sin^2\beta - 1}{M_1^2(\gamma+\cos 2\beta)+2}\right) \tag{4.17}$$

where θ is the flow deflection, β is the shock angle, and M_1 is the upstream Mach number

(See also graphical representation of this relation in Appendix B, for $\gamma = 1.4$)

4.14 Prandtl-Meyer Expansion Waves

General relation (all gases):

$$d\theta = \sqrt{M^2-1}\frac{dV}{V} \tag{4.35}$$

Calorically perfect gas:

$$\nu(M) = \sqrt{\frac{\gamma+1}{\gamma-1}}\tan^{-1}\sqrt{\frac{\gamma-1}{\gamma+1}(M^2-1)} - \tan^{-1}\sqrt{M^2-1} \tag{4.44}$$

$$\theta_2 = \nu(M_2) - \nu(M_1) \tag{4.45}$$

(See also Table A.5 for $\gamma = 1.4$)

Isentropic process throughout expansion wave:

$$\frac{T_1}{T_2} = \frac{1+\frac{(\gamma-1)}{2}M_2^2}{1+\frac{(\gamma-1)}{2}M_1^2}$$

$$\frac{p_1}{p_2} = \left(\frac{1+\frac{(\gamma-1)}{2}M_2^2}{1+\frac{(\gamma-1)}{2}M_1^2}\right)^{\frac{\gamma}{\gamma-1}}$$

Chapter 5

Quasi-One-Dimensional Flow

5.2 Governing Equations

General relations (all gases):

$$\rho_1 u_1 A_1 = \rho_2 u_2 A_2 \tag{5.1}$$

$$\rho_1 u_1^2 A_1 + p_1 A_1 + \int_{A_1}^{A_2} p dA = \rho_2 u_2^2 A_2 + p_2 A_2 \tag{5.2}$$

$$h_1 + \frac{1}{2} u_1^2 = h_2 + \frac{1}{2} u_2^2 \tag{5.5}$$

5.3 Area-Velocity Relation

General relations (all gases):

$$\frac{dA}{A} = (M^2 - 1)\frac{du}{u} \tag{5.15}$$

5.4 Nozzles

Calorically perfect gas:

Isentropic flow (no shocks) implies

$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2}\left(\frac{2}{\gamma+1}\left(1 + \frac{\gamma-1}{2}M^2\right)\right)^{\frac{\gamma+1}{\gamma-1}} \tag{5.20}$$

which is the area-Mach number relation

(See also Table A.1 for $\gamma = 1.4$)

Mass flow through choked nozzle (calorically perfect gas):

$$\dot{m} = \frac{p_o A^*}{\sqrt{T_o}}\sqrt{\frac{\gamma}{R}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} \tag{5.21}$$

Exit Mach number for a choked nozzle with shock before exit:

$$M_e^2 = \frac{-1}{\gamma - 1} + \sqrt{\frac{1}{(\gamma-1)^2} + \left(\frac{2}{\gamma - 1}\right)\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}\left(\frac{p_{o_1} A_t}{p_e A_e}\right)^2} \tag{5.28}$$

where subscript e denotes nozzle exit and A_t is the throat area. p_{o_1}/p_e is the nozzle pressure ratio. Note that Eqn. 5.28 as given here is slightly different than the one in Andersson. Using the following relation

$$p_{o_1} A_t = p_{o_e} A_e^* \tag{5.23}$$

we get

$$\frac{p_e A_e}{p_{o_e} A_e^*} = \frac{p_e A_e}{p_{o_1} A_t} \tag{5.24}$$

which can be used to rewrite Eqn. 5.28 and end up with the, less useful, version given in Andersson.

Chapter 6

Differential Conservation Equations for Inviscid Flows

6.2 Differential Equations in Conservation Form

6.2.1 Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \tag{6.5}$$

6.2.2 Momentum Equation

$$\frac{\partial}{\partial t}(\rho u) + \nabla \cdot (\rho u \mathbf{v}) + \frac{\partial p}{\partial x} = \rho f_x \tag{6.11}$$

$$\frac{\partial}{\partial t}(\rho v) + \nabla \cdot (\rho v \mathbf{v}) + \frac{\partial p}{\partial y} = \rho f_y \tag{6.12}$$

$$\frac{\partial}{\partial t}(\rho w) + \nabla \cdot (\rho w \mathbf{v}) + \frac{\partial p}{\partial z} = \rho f_z \tag{6.13}$$

vector notation

$$\frac{\partial}{\partial t}(\rho \mathbf{v}) + \nabla \cdot (\rho \mathbf{v}\mathbf{v} + p\mathbf{I}) = \rho \mathbf{f}$$

6.2.3 Energy Equation

$$\frac{\partial}{\partial t}\left[\rho\left(e+\frac{1}{2}\mathbf{v}\cdot\mathbf{v}\right)\right]+\nabla\cdot\left[\rho\left(h+\frac{1}{2}\mathbf{v}\cdot\mathbf{v}\right)\mathbf{v}\right]=\rho\dot{q}+\rho\mathbf{f}\cdot\mathbf{v} \tag{6.17}$$

or

$$\frac{\partial}{\partial t}\left(\rho e_o\right)+\nabla\cdot\left(\rho h_o\mathbf{v}\right)=\rho\dot{q}+\rho\mathbf{f}\cdot\mathbf{v}$$

6.4 Differential Equations in Nonconservation Form

6.4.1 Continuity Equation

$$\frac{D\rho}{Dt}+\rho\nabla\cdot\mathbf{v}=0 \tag{6.22}$$

6.4.2 Momentum Equation

$$\rho\frac{Du}{Dt}=-\frac{\partial p}{\partial x}+\rho f_x \tag{6.26}$$

$$\rho\frac{Dv}{Dt}=-\frac{\partial p}{\partial y}+\rho f_y \tag{6.27}$$

$$\rho\frac{Dw}{Dt}=-\frac{\partial p}{\partial z}+\rho f_z \tag{6.28}$$

vector notation

$$\rho\frac{D\mathbf{v}}{Dt}=-\nabla p+\rho\mathbf{f} \tag{6.29}$$

6.4.3 Energy Equation

$$\rho\frac{D}{Dt}\left(e+\frac{1}{2}\mathbf{v}\cdot\mathbf{v}\right)=-\nabla\cdot\left(p\mathbf{v}\right)+\rho\dot{q}+\rho(\mathbf{f}\cdot\mathbf{v}) \tag{6.31}$$

or

$$\rho\frac{De_o}{Dt}=-\nabla\cdot\left(p\mathbf{v}\right)+\rho\dot{q}+\rho(\mathbf{f}\cdot\mathbf{v})$$

Alternative forms of the energy equation in non-conservation form:

$$\frac{De}{Dt} = \dot{q} - \frac{p}{\rho}\nabla \cdot \mathbf{v} \tag{6.36}$$

$$\frac{Dh}{Dt} = \dot{q} + \frac{1}{\rho}\frac{Dp}{Dt} \tag{6.40}$$

$$\frac{Dh_o}{Dt} = \frac{1}{\rho}\frac{\partial p}{\partial t} + \dot{q} + \mathbf{f} \cdot \mathbf{v} \tag{6.43}$$

$$\frac{De}{Dt} = \dot{q} - p\frac{D}{Dt}\left(\frac{1}{\rho}\right) \tag{6.48}$$

6.5 The Entropy Equation

$$T\frac{Ds}{Dt} = \frac{De}{Dt} + p\frac{D}{Dt}\left(\frac{1}{\rho}\right) \tag{6.49}$$

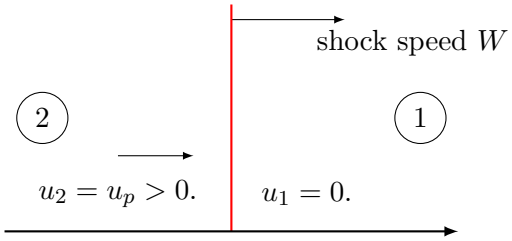
6.6 Crocco's Theorem

$$T\nabla s = \nabla h_o - \mathbf{v} \times (\nabla \times \mathbf{v}) + \frac{\partial \mathbf{v}}{\partial t} \tag{6.59}$$

Chapter 7

Unsteady Wave Motion

7.2 Moving Normal Shock Waves



General relations (all gases):

$$\rho_1 W = \rho_2 (W - u_p) \tag{7.1}$$

$$\rho_1 W^2 + p_1 = \rho_2 (W - u_p)^2 + p_2 \tag{7.2}$$

$$h_1 + \frac{1}{2} W^2 = h_2 + \frac{1}{2} (W - u_p)^2 \tag{7.3}$$

Calorically perfect gas:

$$\frac{T_2}{T_1} = \frac{p_2}{p_1} \left[\frac{\dfrac{\gamma+1}{\gamma-1} + \dfrac{p_2}{p_1}}{1 + \dfrac{\gamma+1}{\gamma-1} \left(\dfrac{p_2}{p_1} \right)} \right] \tag{7.10}$$

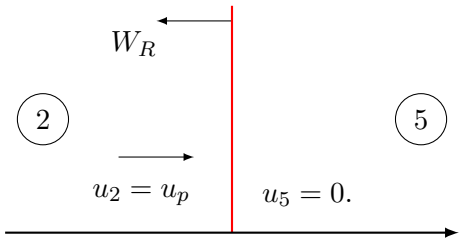
$$\frac{\rho_2}{\rho_1} = \frac{1 + \dfrac{\gamma+1}{\gamma-1} \left(\dfrac{p_2}{p_1} \right)}{\dfrac{\gamma+1}{\gamma-1} + \dfrac{p_2}{p_1}} \tag{7.11}$$

$$M_s = \frac{W}{a_1}$$

$$M_s = \sqrt{\frac{\gamma+1}{2\gamma}\left(\frac{p_2}{p_1}-1\right)+1} \tag{7.13}$$

$$u_p = \frac{a_1}{\gamma}\left(\frac{p_2}{p_1}-1\right)\left[\frac{\frac{2\gamma}{\gamma+1}}{\frac{p_2}{p_1}+\frac{\gamma-1}{\gamma+1}}\right]^{1/2} \tag{7.16}$$

7.3 Reflected Shock Wave



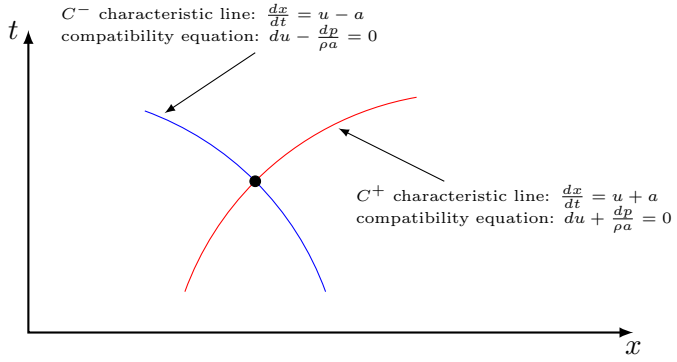
$$\frac{M_R}{M_R^2-1} = \frac{M_s}{M_s^2-1}\sqrt{1+\frac{2(\gamma-1)}{(\gamma+1)^2}(M_s^2-1)\left(\gamma+\frac{1}{M_s^2}\right)} \tag{7.23}$$

where

$$M_R = \frac{W_R + u_p}{a_2}$$

7.6 Finite (Nonlinear) Waves

7.6.1 Characteristics and Compatibility Relations



Calorically perfect gas:

$$J_+ = u + \frac{2a}{\gamma - 1} \tag{7.73}$$

$$J_- = u - \frac{2a}{\gamma - 1} \tag{7.74}$$

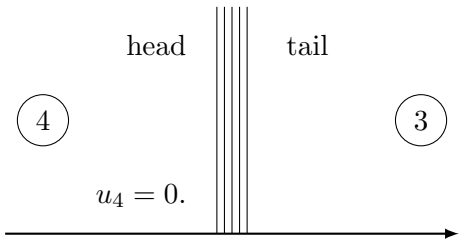
J_+ is constant along a C^+ characteristic and J_- is constant along a C^- characteristic.

$$a = \frac{\gamma - 1}{4}(J_+ - J_-) \tag{7.75}$$

$$u = \frac{1}{2}(J_+ + J_-) \tag{7.76}$$

7.7 Incident and Reflected Expansion Waves

7.7.1 Left-going expansion wave



Calorically perfect gas:

$$\frac{a}{a_4} = 1 - \frac{\gamma - 1}{2}\left(\frac{u}{a_4}\right) \tag{7.84}$$

$$\frac{T}{T_4} = \left(1 - \frac{\gamma - 1}{2}\left(\frac{u}{a_4}\right)\right)^2 \tag{7.85}$$

$$\frac{p}{p_4} = \left(1 - \frac{\gamma - 1}{2}\left(\frac{u}{a_4}\right)\right)^{\frac{2\gamma}{\gamma-1}} \tag{7.86}$$

$$\frac{\rho}{\rho_4} = \left(1 - \frac{\gamma - 1}{2}\left(\frac{u}{a_4}\right)\right)^{\frac{2}{\gamma-1}} \tag{7.87}$$

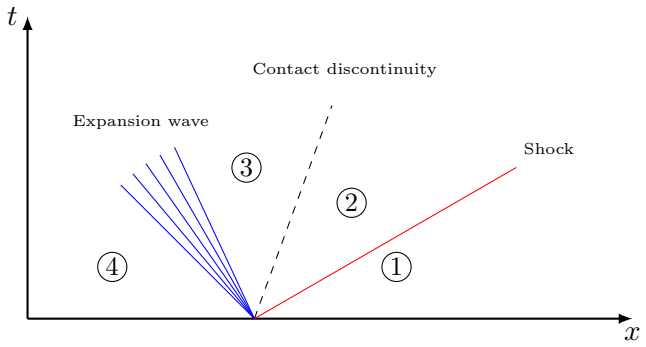
$$u = \frac{2}{\gamma + 1}\left(a_4 + \frac{x}{t}\right) \tag{7.89}$$

7.8 Shock Tube Relations

Calorically perfect gas:

Formula to find intermediate pressure $p_2 = p_3$ between left-going expansion wave and right-going shock:

$$\frac{p_4}{p_1} = \frac{p_2}{p_1}\left\{1 - \frac{(\gamma_4 - 1)(a_1/a_4)(p_2/p_1 - 1)}{\sqrt{2\gamma_1\left[2\gamma_1 + (\gamma_1 + 1)(p_2/p_1 - 1)\right]}}\right\}^{\frac{-2\gamma_4}{\gamma_4 - 1}} \tag{7.94}$$



Appendix A

Tables

Table	Column	Relation
A.1	2	Eqn. 3.30
A.1	3	Eqn. 3.31
A.1	4	Eqn. 3.28
A.1	5	Eqn. 5.20
A.2	2	Eqn. 3.57
A.2	3	Eqn. 3.53
A.2	4	Eqn. 3.59
A.2	5	Eqn. 1.36, 3.57, 3.59, and 3.63
A.2	6	Eqn. 1.36, 3.57, 3.59, and 3.63 + 3.30
A.2	7	Eqn. 3.51
A.3	2	Eqn. 3.85
A.3	3	Eqn. 3.86
A.3	4	Eqn. 3.87
A.3	5	Eqn. 3.88
A.3	6	Eqn. 3.89
A.4	2	Eqn. 3.103
A.4	3	Eqn. 3.104
A.4	4	Eqn. 3.105
A.4	5	Eqn. 3.106
A.4	6	Eqn. 3.107
A.5	2	Eqn. 4.44
A.5	3	Eqn. 4.1

Table A.1: Isentropic flow properties ($\gamma = 1.4$)

M	p_o/p	ρ_o/ρ	T_o/T	A/A^*
2.00000e-02	1.00028e+00	1.00020e+00	1.00008e+00	2.89421e+01
4.00000e-02	1.00112e+00	1.00080e+00	1.00032e+00	1.44815e+01
6.00000e-02	1.00252e+00	1.00180e+00	1.00072e+00	9.66591e+00
8.00000e-02	1.00449e+00	1.00320e+00	1.00128e+00	7.26161e+00
1.00000e-01	1.00702e+00	1.00501e+00	1.00200e+00	5.82183e+00
1.20000e-01	1.01012e+00	1.00722e+00	1.00288e+00	4.86432e+00
1.40000e-01	1.01379e+00	1.00983e+00	1.00392e+00	4.18240e+00
1.60000e-01	1.01803e+00	1.01285e+00	1.00512e+00	3.67274e+00
1.80000e-01	1.02286e+00	1.01628e+00	1.00648e+00	3.27793e+00
2.00000e-01	1.02828e+00	1.02012e+00	1.00800e+00	2.96352e+00
2.20000e-01	1.03429e+00	1.02438e+00	1.00968e+00	2.70760e+00
2.40000e-01	1.04090e+00	1.02905e+00	1.01152e+00	2.49556e+00
2.60000e-01	1.04813e+00	1.03414e+00	1.01352e+00	2.31729e+00
2.80000e-01	1.05596e+00	1.03966e+00	1.01568e+00	2.16555e+00
3.00000e-01	1.06443e+00	1.04561e+00	1.01800e+00	2.03507e+00
3.20000e-01	1.07353e+00	1.05199e+00	1.02048e+00	1.92185e+00
3.40000e-01	1.08329e+00	1.05881e+00	1.02312e+00	1.82288e+00
3.60000e-01	1.09370e+00	1.06607e+00	1.02592e+00	1.73578e+00
3.80000e-01	1.10478e+00	1.07377e+00	1.02888e+00	1.65870e+00
4.00000e-01	1.11655e+00	1.08193e+00	1.03200e+00	1.59014e+00
4.20000e-01	1.12902e+00	1.09055e+00	1.03528e+00	1.52890e+00
4.40000e-01	1.14221e+00	1.09963e+00	1.03872e+00	1.47401e+00
4.60000e-01	1.15612e+00	1.10918e+00	1.04232e+00	1.42463e+00
4.80000e-01	1.17078e+00	1.11921e+00	1.04608e+00	1.38010e+00
5.00000e-01	1.18621e+00	1.12973e+00	1.05000e+00	1.33984e+00
5.20000e-01	1.20242e+00	1.14073e+00	1.05408e+00	1.30339e+00
5.40000e-01	1.21944e+00	1.15224e+00	1.05832e+00	1.27032e+00
5.60000e-01	1.23727e+00	1.16425e+00	1.06272e+00	1.24029e+00
5.80000e-01	1.25596e+00	1.17678e+00	1.06728e+00	1.21301e+00
6.00000e-01	1.27550e+00	1.18984e+00	1.07200e+00	1.18820e+00
6.20000e-01	1.29594e+00	1.20342e+00	1.07688e+00	1.16565e+00
6.40000e-01	1.31729e+00	1.21755e+00	1.08192e+00	1.14515e+00
6.60000e-01	1.33959e+00	1.23224e+00	1.08712e+00	1.12654e+00
6.80000e-01	1.36285e+00	1.24748e+00	1.09248e+00	1.10965e+00
7.00000e-01	1.38710e+00	1.26330e+00	1.09800e+00	1.09437e+00
7.20000e-01	1.41238e+00	1.27970e+00	1.10368e+00	1.08057e+00
7.40000e-01	1.43871e+00	1.29670e+00	1.10952e+00	1.06814e+00
7.60000e-01	1.46612e+00	1.31430e+00	1.11552e+00	1.05700e+00
7.80000e-01	1.49466e+00	1.33252e+00	1.12168e+00	1.04705e+00
8.00000e-01	1.52434e+00	1.35137e+00	1.12800e+00	1.03823e+00
8.20000e-01	1.55521e+00	1.37086e+00	1.13448e+00	1.03046e+00
8.40000e-01	1.58730e+00	1.39100e+00	1.14112e+00	1.02370e+00
8.60000e-01	1.62066e+00	1.41182e+00	1.14792e+00	1.01787e+00
8.80000e-01	1.65531e+00	1.43332e+00	1.15488e+00	1.01294e+00
9.00000e-01	1.69130e+00	1.45551e+00	1.16200e+00	1.00886e+00
9.20000e-01	1.72868e+00	1.47841e+00	1.16928e+00	1.00560e+00
9.40000e-01	1.76749e+00	1.50204e+00	1.17672e+00	1.00311e+00
9.60000e-01	1.80776e+00	1.52642e+00	1.18432e+00	1.00136e+00
9.80000e-01	1.84956e+00	1.55154e+00	1.19208e+00	1.00034e+00
1.00000e+00	1.89293e+00	1.57744e+00	1.20000e+00	1.00000e+00
1.02000e+00	1.93792e+00	1.60413e+00	1.20808e+00	1.00033e+00
1.04000e+00	1.98457e+00	1.63162e+00	1.21632e+00	1.00131e+00
1.06000e+00	2.03296e+00	1.65994e+00	1.22472e+00	1.00291e+00
1.08000e+00	2.08313e+00	1.68910e+00	1.23328e+00	1.00512e+00
1.10000e+00	2.13514e+00	1.71911e+00	1.24200e+00	1.00793e+00
1.12000e+00	2.18905e+00	1.75000e+00	1.25088e+00	1.01131e+00
1.14000e+00	2.24492e+00	1.78179e+00	1.25992e+00	1.01527e+00
1.16000e+00	2.30282e+00	1.81450e+00	1.26912e+00	1.01978e+00
1.18000e+00	2.36281e+00	1.84814e+00	1.27848e+00	1.02484e+00
1.20000e+00	2.42497e+00	1.88274e+00	1.28800e+00	1.03044e+00
1.22000e+00	2.48935e+00	1.91831e+00	1.29768e+00	1.03657e+00
1.24000e+00	2.55605e+00	1.95488e+00	1.30752e+00	1.04323e+00
1.26000e+00	2.62513e+00	1.99248e+00	1.31752e+00	1.05041e+00
1.28000e+00	2.69666e+00	2.03111e+00	1.32768e+00	1.05810e+00
1.30000e+00	2.77074e+00	2.07081e+00	1.33800e+00	1.06630e+00

Table A.1: Isentropic flow properties ($\gamma = 1.4$) *continued*

M	p_o/p	ρ_o/ρ	T_o/T	A/A^*
1.32000e+00	2.84745e+00	2.11160e+00	1.34848e+00	1.07502e+00
1.34000e+00	2.92686e+00	2.15350e+00	1.35912e+00	1.08424e+00
1.36000e+00	3.00908e+00	2.19653e+00	1.36992e+00	1.09396e+00
1.38000e+00	3.09418e+00	2.24073e+00	1.38088e+00	1.10419e+00
1.40000e+00	3.18227e+00	2.28612e+00	1.39200e+00	1.11493e+00
1.42000e+00	3.27345e+00	2.33271e+00	1.40328e+00	1.12616e+00
1.44000e+00	3.36780e+00	2.38054e+00	1.41472e+00	1.13790e+00
1.46000e+00	3.46545e+00	2.42964e+00	1.42632e+00	1.15015e+00
1.48000e+00	3.56649e+00	2.48003e+00	1.43808e+00	1.16290e+00
1.50000e+00	3.67103e+00	2.53175e+00	1.45000e+00	1.17617e+00
1.52000e+00	3.77919e+00	2.58481e+00	1.46208e+00	1.18994e+00
1.54000e+00	3.89109e+00	2.63924e+00	1.47432e+00	1.20423e+00
1.56000e+00	4.00684e+00	2.69509e+00	1.48672e+00	1.21904e+00
1.58000e+00	4.12657e+00	2.75237e+00	1.49928e+00	1.23438e+00
1.60000e+00	4.25041e+00	2.81112e+00	1.51200e+00	1.25024e+00
1.62000e+00	4.37849e+00	2.87137e+00	1.52488e+00	1.26663e+00
1.64000e+00	4.51095e+00	2.93315e+00	1.53792e+00	1.28355e+00
1.66000e+00	4.64792e+00	2.99649e+00	1.55112e+00	1.30102e+00
1.68000e+00	4.78955e+00	3.06143e+00	1.56448e+00	1.31904e+00
1.70000e+00	4.93599e+00	3.12801e+00	1.57800e+00	1.33761e+00
1.72000e+00	5.08739e+00	3.19624e+00	1.59168e+00	1.35674e+00
1.74000e+00	5.24391e+00	3.26617e+00	1.60552e+00	1.37643e+00
1.76000e+00	5.40570e+00	3.33784e+00	1.61952e+00	1.39670e+00
1.78000e+00	5.57294e+00	3.41128e+00	1.63368e+00	1.41755e+00
1.80000e+00	5.74580e+00	3.48653e+00	1.64800e+00	1.43898e+00
1.82000e+00	5.92444e+00	3.56362e+00	1.66248e+00	1.46101e+00
1.84000e+00	6.10906e+00	3.64259e+00	1.67712e+00	1.48365e+00
1.86000e+00	6.29984e+00	3.72348e+00	1.69192e+00	1.50689e+00
1.88000e+00	6.49696e+00	3.80634e+00	1.70688e+00	1.53076e+00
1.90000e+00	6.70064e+00	3.89119e+00	1.72200e+00	1.55526e+00
1.92000e+00	6.91106e+00	3.97809e+00	1.73728e+00	1.58039e+00
1.94000e+00	7.12843e+00	4.06707e+00	1.75272e+00	1.60617e+00
1.96000e+00	7.35297e+00	4.15817e+00	1.76832e+00	1.63261e+00
1.98000e+00	7.58490e+00	4.25144e+00	1.78408e+00	1.65972e+00
2.00000e+00	7.82445e+00	4.34692e+00	1.80000e+00	1.68750e+00
2.05000e+00	8.45815e+00	4.59557e+00	1.84050e+00	1.75999e+00
2.10000e+00	9.14468e+00	4.85902e+00	1.88200e+00	1.83694e+00
2.15000e+00	9.88810e+00	5.13801e+00	1.92450e+00	1.91854e+00
2.20000e+00	1.06927e+01	5.43329e+00	1.96800e+00	2.00497e+00
2.25000e+00	1.15631e+01	5.74566e+00	2.01250e+00	2.09644e+00
2.30000e+00	1.25043e+01	6.07594e+00	2.05800e+00	2.19313e+00
2.35000e+00	1.35214e+01	6.42499e+00	2.10450e+00	2.29528e+00
2.40000e+00	1.46200e+01	6.79369e+00	2.15200e+00	2.40310e+00
2.45000e+00	1.58061e+01	7.18296e+00	2.20050e+00	2.51683e+00
2.50000e+00	1.70859e+01	7.59375e+00	2.25000e+00	2.63672e+00
2.55000e+00	1.84662e+01	8.02704e+00	2.30050e+00	2.76301e+00
2.60000e+00	1.99540e+01	8.48386e+00	2.35200e+00	2.89598e+00
2.65000e+00	2.15569e+01	8.96524e+00	2.40450e+00	3.03588e+00
2.70000e+00	2.32829e+01	9.47228e+00	2.45800e+00	3.18301e+00
2.75000e+00	2.51403e+01	1.00061e+01	2.51250e+00	3.33766e+00
2.80000e+00	2.71383e+01	1.05679e+01	2.56800e+00	3.50012e+00
2.85000e+00	2.92862e+01	1.11588e+01	2.62450e+00	3.67072e+00
2.90000e+00	3.15941e+01	1.17800e+01	2.68200e+00	3.84977e+00
2.95000e+00	3.40725e+01	1.24330e+01	2.74050e+00	4.03760e+00
3.00000e+00	3.67327e+01	1.31188e+01	2.80000e+00	4.23457e+00
3.05000e+00	3.95865e+01	1.38390e+01	2.86050e+00	4.44102e+00
3.10000e+00	4.26462e+01	1.45949e+01	2.92200e+00	4.65731e+00
3.15000e+00	4.59251e+01	1.53879e+01	2.98450e+00	4.88383e+00
3.20000e+00	4.94370e+01	1.62195e+01	3.04800e+00	5.12096e+00
3.25000e+00	5.31965e+01	1.70912e+01	3.11250e+00	5.36909e+00
3.30000e+00	5.72188e+01	1.80047e+01	3.17800e+00	5.62865e+00
3.35000e+00	6.15201e+01	1.89614e+01	3.24450e+00	5.90004e+00
3.40000e+00	6.61175e+01	1.99630e+01	3.31200e+00	6.18370e+00
3.45000e+00	7.10286e+01	2.10113e+01	3.38050e+00	6.48007e+00
3.50000e+00	7.62723e+01	2.21079e+01	3.45000e+00	6.78962e+00

Table A.1: Isentropic flow properties ($\gamma = 1.4$) *continued*

M	p_o/p	ρ_o/ρ	T_o/T	A/A^*
3.55000e+00	8.18682e+01	2.32547e+01	3.52050e+00	7.11281e+00
3.60000e+00	8.78369e+01	2.44535e+01	3.59200e+00	7.45011e+00
3.65000e+00	9.42001e+01	2.57061e+01	3.66450e+00	7.80203e+00
3.70000e+00	1.00981e+02	2.70146e+01	3.73800e+00	8.16907e+00
3.75000e+00	1.08202e+02	2.83808e+01	3.81250e+00	8.55174e+00
3.80000e+00	1.15889e+02	2.98068e+01	3.88800e+00	8.95059e+00
3.85000e+00	1.24068e+02	3.12947e+01	3.96450e+00	9.36614e+00
3.90000e+00	1.32766e+02	3.28466e+01	4.04200e+00	9.79897e+00
3.95000e+00	1.42012e+02	3.44647e+01	4.12050e+00	1.02496e+01
4.00000e+00	1.51835e+02	3.61512e+01	4.20000e+00	1.07188e+01
4.05000e+00	1.62267e+02	3.79085e+01	4.28050e+00	1.12069e+01
4.10000e+00	1.73340e+02	3.97387e+01	4.36200e+00	1.17147e+01
4.15000e+00	1.85089e+02	4.16445e+01	4.44450e+00	1.22427e+01
4.20000e+00	1.97548e+02	4.36281e+01	4.52800e+00	1.27916e+01
4.25000e+00	2.10755e+02	4.56921e+01	4.61250e+00	1.33622e+01
4.30000e+00	2.24748e+02	4.78390e+01	4.69800e+00	1.39549e+01
4.35000e+00	2.39568e+02	5.00716e+01	4.78450e+00	1.45706e+01
4.40000e+00	2.55256e+02	5.23924e+01	4.87200e+00	1.52099e+01
4.45000e+00	2.71856e+02	5.48042e+01	4.96050e+00	1.58735e+01
4.50000e+00	2.89414e+02	5.73097e+01	5.05000e+00	1.65622e+01
4.55000e+00	3.07977e+02	5.99119e+01	5.14050e+00	1.72767e+01
4.60000e+00	3.27595e+02	6.26137e+01	5.23200e+00	1.80178e+01
4.65000e+00	3.48318e+02	6.54180e+01	5.32450e+00	1.87862e+01
4.70000e+00	3.70200e+02	6.83278e+01	5.41800e+00	1.95828e+01
4.75000e+00	3.93297e+02	7.13463e+01	5.51250e+00	2.04084e+01
4.80000e+00	4.17665e+02	7.44766e+01	5.60800e+00	2.12637e+01
4.85000e+00	4.43365e+02	7.77220e+01	5.70450e+00	2.21497e+01
4.90000e+00	4.70459e+02	8.10857e+01	5.80200e+00	2.30671e+01
4.95000e+00	4.99012e+02	8.45711e+01	5.90050e+00	2.40169e+01
5.00000e+00	5.29090e+02	8.81816e+01	6.00000e+00	2.50000e+01
5.10000e+00	5.94102e+02	9.57920e+01	6.20200e+00	2.70696e+01
5.20000e+00	6.66084e+02	1.03946e+02	6.40800e+00	2.92833e+01
5.30000e+00	7.45665e+02	1.12672e+02	6.61800e+00	3.16491e+01
5.40000e+00	8.33523e+02	1.22003e+02	6.83200e+00	3.41748e+01
5.50000e+00	9.30383e+02	1.31969e+02	7.05000e+00	3.68690e+01
5.60000e+00	1.03702e+03	1.42605e+02	7.27200e+00	3.97402e+01
5.70000e+00	1.15427e+03	1.53944e+02	7.49800e+00	4.27974e+01
5.80000e+00	1.28302e+03	1.66023e+02	7.72800e+00	4.60500e+01
5.90000e+00	1.42422e+03	1.78877e+02	7.96200e+00	4.95075e+01
6.00000e+00	1.57888e+03	1.92546e+02	8.20000e+00	5.31798e+01
6.10000e+00	1.74807e+03	2.07068e+02	8.44200e+00	5.70772e+01
6.20000e+00	1.93294e+03	2.22484e+02	8.68800e+00	6.12102e+01
6.30000e+00	2.13472e+03	2.38837e+02	8.93800e+00	6.55899e+01
6.40000e+00	2.35470e+03	2.56168e+02	9.19200e+00	7.02274e+01
6.50000e+00	2.59425e+03	2.74523e+02	9.45000e+00	7.51343e+01
6.60000e+00	2.85483e+03	2.93949e+02	9.71200e+00	8.03227e+01
6.70000e+00	3.13800e+03	3.14491e+02	9.97800e+00	8.58049e+01
6.80000e+00	3.44538e+03	3.36200e+02	1.02480e+01	9.15935e+01
6.90000e+00	3.77871e+03	3.59125e+02	1.05220e+01	9.77017e+01
7.00000e+00	4.13984e+03	3.83318e+02	1.08000e+01	1.04143e+02
7.10000e+00	4.53068e+03	4.08832e+02	1.10820e+01	1.10931e+02
7.20000e+00	4.95330e+03	4.35723e+02	1.13680e+01	1.18080e+02
7.30000e+00	5.40984e+03	4.64045e+02	1.16580e+01	1.25605e+02
7.40000e+00	5.90258e+03	4.93857e+02	1.19520e+01	1.33520e+02
7.50000e+00	6.43393e+03	5.25219e+02	1.22500e+01	1.41841e+02
7.60000e+00	7.00641e+03	5.58190e+02	1.25520e+01	1.50585e+02
7.70000e+00	7.62267e+03	5.92835e+02	1.28580e+01	1.59767e+02
7.80000e+00	8.28551e+03	6.29216e+02	1.31680e+01	1.69403e+02
7.90000e+00	8.99788e+03	6.67399e+02	1.34820e+01	1.79511e+02
8.00000e+00	9.76285e+03	7.07453e+02	1.38000e+01	1.90109e+02
9.00000e+00	2.11033e+04	1.22693e+03	1.72000e+01	3.27189e+02
1.00000e+01	4.24392e+04	2.02092e+03	2.10000e+01	5.35938e+02
1.10000e+01	8.03345e+04	3.18788e+03	2.52000e+01	8.41909e+02
1.20000e+01	1.44463e+05	4.84775e+03	2.98000e+01	1.27621e+03
1.30000e+01	2.48615e+05	7.14411e+03	3.48000e+01	1.87608e+03

Table A.1: Isentropic flow properties ($\gamma = 1.4$) *continued*

M	p_o/p	ρ_o/ρ	T_o/T	A/A^*
1.40000e+01	4.11899e+05	1.02463e+04	4.02000e+01	2.68538e+03
1.50000e+01	6.60165e+05	1.43514e+04	4.60000e+01	3.75525e+03
1.60000e+01	1.02765e+06	1.96869e+04	5.22000e+01	5.14455e+03
1.70000e+01	1.55891e+06	2.65121e+04	5.88000e+01	6.92053e+03
1.80000e+01	2.31095e+06	3.51208e+04	6.58000e+01	9.15928e+03
1.90000e+01	3.35574e+06	4.58435e+04	7.32000e+01	1.19464e+04
2.00000e+01	4.78297e+06	5.90490e+04	8.10000e+01	1.53773e+04
2.20000e+01	9.25094e+06	9.45904e+04	9.78000e+01	2.46065e+04
2.40000e+01	1.69130e+07	1.45551e+05	1.16200e+02	3.78324e+04
2.60000e+01	2.94863e+07	2.16492e+05	1.36200e+02	5.62360e+04
2.80000e+01	4.93599e+07	3.12801e+05	1.57800e+02	8.12118e+04
3.00000e+01	7.97765e+07	4.40754e+05	1.81000e+02	1.14385e+05
3.20000e+01	1.25043e+08	6.07594e+05	2.05800e+02	1.57631e+05
3.40000e+01	1.90773e+08	8.21591e+05	2.32200e+02	2.13090e+05
3.60000e+01	2.84168e+08	1.09211e+06	2.60200e+02	2.83189e+05
3.80000e+01	4.14328e+08	1.42970e+06	2.89800e+02	3.70653e+05
4.00000e+01	5.92608e+08	1.84613e+06	3.21000e+02	4.78532e+05
4.20000e+01	8.33014e+08	2.35448e+06	3.53800e+02	6.10212e+05
4.40000e+01	1.15264e+09	2.96920e+06	3.88200e+02	7.69432e+05
4.60000e+01	1.57216e+09	3.70618e+06	4.24200e+02	9.60308e+05
4.80000e+01	2.11636e+09	4.58284e+06	4.61800e+02	1.18734e+06
5.00000e+01	2.81470e+09	5.61816e+06	5.01000e+02	1.45546e+06

Table A.2: Normal shock properties ($\gamma = 1.4$)

M	p_2/p_1	ρ_2/ρ_1	T_2/T_1	p_{o_2}/p_{o_1}	p_{o_2}/p_1	M_2
1.00000e+00	1.00000e+00	1.00000e+00	1.00000e+00	1.00000e+00	1.89293e+00	1.00000e+00
1.02000e+00	1.04713e+00	1.03344e+00	1.01325e+00	9.99990e-01	1.93790e+00	9.80519e-01
1.04000e+00	1.09520e+00	1.06709e+00	1.02634e+00	9.99923e-01	1.98442e+00	9.62025e-01
1.06000e+00	1.14420e+00	1.10092e+00	1.03931e+00	9.99751e-01	2.03245e+00	9.44445e-01
1.08000e+00	1.19413e+00	1.13492e+00	1.05217e+00	9.99431e-01	2.08194e+00	9.27713e-01
1.10000e+00	1.24500e+00	1.16908e+00	1.06494e+00	9.98928e-01	2.13285e+00	9.11770e-01
1.12000e+00	1.29680e+00	1.20338e+00	1.07763e+00	9.98213e-01	2.18513e+00	8.96563e-01
1.14000e+00	1.34953e+00	1.23779e+00	1.09027e+00	9.97261e-01	2.23877e+00	8.82042e-01
1.16000e+00	1.40320e+00	1.27231e+00	1.10287e+00	9.96052e-01	2.29372e+00	8.68162e-01
1.18000e+00	1.45780e+00	1.30693e+00	1.11544e+00	9.94569e-01	2.34998e+00	8.54884e-01
1.20000e+00	1.51333e+00	1.34161e+00	1.12799e+00	9.92798e-01	2.40750e+00	8.42170e-01
1.22000e+00	1.56980e+00	1.37636e+00	1.14054e+00	9.90731e-01	2.46628e+00	8.29986e-01
1.24000e+00	1.62720e+00	1.41116e+00	1.15309e+00	9.88359e-01	2.52629e+00	8.18301e-01
1.26000e+00	1.68553e+00	1.44599e+00	1.16566e+00	9.85677e-01	2.58753e+00	8.07085e-01
1.28000e+00	1.74480e+00	1.48084e+00	1.17825e+00	9.82682e-01	2.64996e+00	7.96312e-01
1.30000e+00	1.80500e+00	1.51570e+00	1.19087e+00	9.79374e-01	2.71359e+00	7.85957e-01
1.32000e+00	1.86613e+00	1.55055e+00	1.20353e+00	9.75752e-01	2.77840e+00	7.75997e-01
1.34000e+00	1.92820e+00	1.58538e+00	1.21624e+00	9.71819e-01	2.84438e+00	7.66412e-01
1.36000e+00	1.99120e+00	1.62018e+00	1.22900e+00	9.67579e-01	2.91152e+00	7.57181e-01
1.38000e+00	2.05513e+00	1.65494e+00	1.24181e+00	9.63035e-01	2.97981e+00	7.48286e-01
1.40000e+00	2.12000e+00	1.68966e+00	1.25469e+00	9.58194e-01	3.04924e+00	7.39709e-01
1.42000e+00	2.18580e+00	1.72430e+00	1.26764e+00	9.53063e-01	3.11980e+00	7.31436e-01
1.44000e+00	2.25253e+00	1.75888e+00	1.28066e+00	9.47648e-01	3.19149e+00	7.23451e-01
1.46000e+00	2.32020e+00	1.79337e+00	1.29377e+00	9.41958e-01	3.26431e+00	7.15740e-01
1.48000e+00	2.38880e+00	1.82777e+00	1.30695e+00	9.36001e-01	3.33823e+00	7.08290e-01
1.50000e+00	2.45833e+00	1.86207e+00	1.32022e+00	9.29787e-01	3.41327e+00	7.01089e-01
1.52000e+00	2.52880e+00	1.89626e+00	1.33357e+00	9.23324e-01	3.48942e+00	6.94125e-01
1.54000e+00	2.60020e+00	1.93033e+00	1.34703e+00	9.16624e-01	3.56667e+00	6.87388e-01
1.56000e+00	2.67253e+00	1.96427e+00	1.36057e+00	9.09697e-01	3.64501e+00	6.80867e-01
1.58000e+00	2.74580e+00	1.99808e+00	1.37422e+00	9.02552e-01	3.72445e+00	6.74553e-01
1.60000e+00	2.82000e+00	2.03175e+00	1.38797e+00	8.95200e-01	3.80497e+00	6.68437e-01
1.62000e+00	2.89513e+00	2.06526e+00	1.40182e+00	8.87653e-01	3.88658e+00	6.62511e-01
1.64000e+00	2.97120e+00	2.09863e+00	1.41578e+00	8.79921e-01	3.96928e+00	6.56765e-01
1.66000e+00	3.04820e+00	2.13183e+00	1.42985e+00	8.72014e-01	4.05305e+00	6.51194e-01
1.68000e+00	3.12613e+00	2.16486e+00	1.44403e+00	8.63944e-01	4.13791e+00	6.45789e-01
1.70000e+00	3.20500e+00	2.19772e+00	1.45833e+00	8.55721e-01	4.22383e+00	6.40544e-01
1.72000e+00	3.28480e+00	2.23040e+00	1.47274e+00	8.47356e-01	4.31083e+00	6.35452e-01
1.74000e+00	3.36553e+00	2.26289e+00	1.48727e+00	8.38860e-01	4.39890e+00	6.30508e-01
1.76000e+00	3.44720e+00	2.29520e+00	1.50192e+00	8.30242e-01	4.48804e+00	6.25705e-01
1.78000e+00	3.52980e+00	2.32731e+00	1.51669e+00	8.21513e-01	4.57825e+00	6.21037e-01
1.80000e+00	3.61333e+00	2.35922e+00	1.53158e+00	8.12684e-01	4.66952e+00	6.16501e-01
1.82000e+00	3.69780e+00	2.39093e+00	1.54659e+00	8.03763e-01	4.76185e+00	6.12091e-01
1.84000e+00	3.78320e+00	2.42244e+00	1.56173e+00	7.94761e-01	4.85524e+00	6.07802e-01
1.86000e+00	3.86953e+00	2.45373e+00	1.57700e+00	7.85686e-01	4.94970e+00	6.03629e-01
1.88000e+00	3.95680e+00	2.48481e+00	1.59239e+00	7.76549e-01	5.04521e+00	5.99569e-01
1.90000e+00	4.04500e+00	2.51568e+00	1.60792e+00	7.67357e-01	5.14178e+00	5.95616e-01
1.92000e+00	4.13413e+00	2.54633e+00	1.62357e+00	7.58119e-01	5.23940e+00	5.91769e-01
1.94000e+00	4.22420e+00	2.57675e+00	1.63935e+00	7.48844e-01	5.33808e+00	5.88022e-01
1.96000e+00	4.31520e+00	2.60695e+00	1.65527e+00	7.39540e-01	5.43782e+00	5.84372e-01
1.98000e+00	4.40713e+00	2.63692e+00	1.67132e+00	7.30214e-01	5.53860e+00	5.80816e-01
2.00000e+00	4.50000e+00	2.66667e+00	1.68750e+00	7.20874e-01	5.64044e+00	5.77350e-01
2.05000e+00	4.73625e+00	2.74002e+00	1.72855e+00	6.97508e-01	5.89963e+00	5.69063e-01
2.10000e+00	4.97833e+00	2.81190e+00	1.77045e+00	6.74203e-01	6.16537e+00	5.61277e-01
2.15000e+00	5.22625e+00	2.88231e+00	1.81322e+00	6.51052e-01	6.43766e+00	5.53953e-01
2.20000e+00	5.48000e+00	2.95122e+00	1.85686e+00	6.28136e-01	6.71648e+00	5.47056e-01
2.25000e+00	5.73958e+00	3.01863e+00	1.90138e+00	6.05530e-01	7.00182e+00	5.40552e-01
2.30000e+00	6.00500e+00	3.08455e+00	1.94680e+00	5.83295e-01	7.29368e+00	5.34411e-01
2.35000e+00	6.27625e+00	3.14897e+00	1.99311e+00	5.61484e-01	7.59205e+00	5.28608e-01
2.40000e+00	6.55333e+00	3.21190e+00	2.04033e+00	5.40144e-01	7.89691e+00	5.23118e-01
2.45000e+00	6.83625e+00	3.27335e+00	2.08846e+00	5.19311e-01	8.20828e+00	5.17918e-01
2.50000e+00	7.12500e+00	3.33333e+00	2.13750e+00	4.99015e-01	8.52614e+00	5.12989e-01
2.55000e+00	7.41958e+00	3.39187e+00	2.18746e+00	4.79280e-01	8.85048e+00	5.08312e-01
2.60000e+00	7.72000e+00	3.44898e+00	2.23834e+00	4.60123e-01	9.18131e+00	5.03871e-01
2.65000e+00	8.02625e+00	3.50468e+00	2.29015e+00	4.41557e-01	9.51862e+00	4.99649e-01
2.70000e+00	8.33833e+00	3.55899e+00	2.34289e+00	4.23590e-01	9.86240e+00	4.95634e-01

Table A.2: Normal shock properties ($\gamma = 1.4$) *continued*

M	p_2/p_1	ρ_2/ρ_1	T_2/T_1	p_{o_2}/p_{o_1}	p_{o_2}/p_1	M_2
2.75000e+00	8.65625e+00	3.61194e+00	2.39657e+00	4.06226e-01	1.02127e+01	4.91810e-01
2.80000e+00	8.98000e+00	3.66355e+00	2.45117e+00	3.89464e-01	1.05694e+01	4.88167e-01
2.85000e+00	9.30958e+00	3.71385e+00	2.50672e+00	3.73302e-01	1.09326e+01	4.84694e-01
2.90000e+00	9.64500e+00	3.76286e+00	2.56321e+00	3.57733e-01	1.13022e+01	4.81380e-01
2.95000e+00	9.98625e+00	3.81062e+00	2.62064e+00	3.42750e-01	1.16784e+01	4.78215e-01
3.00000e+00	1.03333e+01	3.85714e+00	2.67901e+00	3.28344e-01	1.20610e+01	4.75191e-01
3.05000e+00	1.06862e+01	3.90246e+00	2.73833e+00	3.14502e-01	1.24500e+01	4.72300e-01
3.10000e+00	1.10450e+01	3.94661e+00	2.79860e+00	3.01211e-01	1.28455e+01	4.69534e-01
3.15000e+00	1.14096e+01	3.98961e+00	2.85982e+00	2.88458e-01	1.32475e+01	4.66885e-01
3.20000e+00	1.17800e+01	4.03150e+00	2.92199e+00	2.76229e-01	1.36559e+01	4.64349e-01
3.25000e+00	1.21562e+01	4.07229e+00	2.98511e+00	2.64506e-01	1.40708e+01	4.61917e-01
3.30000e+00	1.25383e+01	4.11202e+00	3.04919e+00	2.53276e-01	1.44921e+01	4.59586e-01
3.35000e+00	1.29262e+01	4.15072e+00	3.11422e+00	2.42521e-01	1.49199e+01	4.57348e-01
3.40000e+00	1.33200e+01	4.18841e+00	3.18021e+00	2.32226e-01	1.53542e+01	4.55200e-01
3.45000e+00	1.37196e+01	4.22511e+00	3.24715e+00	2.22373e-01	1.57949e+01	4.53137e-01
3.50000e+00	1.41250e+01	4.26087e+00	3.31505e+00	2.12948e-01	1.62420e+01	4.51154e-01
3.55000e+00	1.45362e+01	4.29570e+00	3.38391e+00	2.03933e-01	1.66956e+01	4.49247e-01
3.60000e+00	1.49533e+01	4.32962e+00	3.45373e+00	1.95312e-01	1.71556e+01	4.47413e-01
3.65000e+00	1.53763e+01	4.36267e+00	3.52451e+00	1.87071e-01	1.76221e+01	4.45648e-01
3.70000e+00	1.58050e+01	4.39486e+00	3.59624e+00	1.79194e-01	1.80951e+01	4.43948e-01
3.75000e+00	1.62396e+01	4.42623e+00	3.66894e+00	1.71665e-01	1.85745e+01	4.42310e-01
3.80000e+00	1.66800e+01	4.45679e+00	3.74260e+00	1.64470e-01	1.90603e+01	4.40732e-01
3.85000e+00	1.71262e+01	4.48657e+00	3.81723e+00	1.57596e-01	1.95526e+01	4.39210e-01
3.90000e+00	1.75783e+01	4.51559e+00	3.89281e+00	1.51027e-01	2.00513e+01	4.37742e-01
3.95000e+00	1.80363e+01	4.54387e+00	3.96936e+00	1.44752e-01	2.05565e+01	4.36326e-01
4.00000e+00	1.85000e+01	4.57143e+00	4.04687e+00	1.38756e-01	2.10681e+01	4.34959e-01
4.05000e+00	1.89696e+01	4.59829e+00	4.12535e+00	1.33028e-01	2.15861e+01	4.33638e-01
4.10000e+00	1.94450e+01	4.62448e+00	4.20479e+00	1.27556e-01	2.21106e+01	4.32363e-01
4.15000e+00	1.99263e+01	4.65002e+00	4.28520e+00	1.22328e-01	2.26416e+01	4.31130e-01
4.20000e+00	2.04133e+01	4.67491e+00	4.36657e+00	1.17334e-01	2.31790e+01	4.29938e-01
4.25000e+00	2.09062e+01	4.69919e+00	4.44891e+00	1.12561e-01	2.37228e+01	4.28785e-01
4.30000e+00	2.14050e+01	4.72286e+00	4.53221e+00	1.08002e-01	2.42731e+01	4.27669e-01
4.35000e+00	2.19096e+01	4.74595e+00	4.61648e+00	1.03644e-01	2.48298e+01	4.26590e-01
4.40000e+00	2.24200e+01	4.76847e+00	4.70171e+00	9.94806e-02	2.53930e+01	4.25545e-01
4.45000e+00	2.29363e+01	4.79044e+00	4.78792e+00	9.55013e-02	2.59626e+01	4.24532e-01
4.50000e+00	2.34583e+01	4.81188e+00	4.87509e+00	9.16979e-02	2.65387e+01	4.23552e-01
4.55000e+00	2.39862e+01	4.83280e+00	4.96322e+00	8.80622e-02	2.71212e+01	4.22601e-01
4.60000e+00	2.45200e+01	4.85321e+00	5.05233e+00	8.45865e-02	2.77101e+01	4.21680e-01
4.65000e+00	2.50596e+01	4.87313e+00	5.14240e+00	8.12633e-02	2.83055e+01	4.20787e-01
4.70000e+00	2.56050e+01	4.89258e+00	5.23343e+00	7.80856e-02	2.89073e+01	4.19920e-01
4.75000e+00	2.61562e+01	4.91156e+00	5.32544e+00	7.50466e-02	2.95156e+01	4.19079e-01
4.80000e+00	2.67133e+01	4.93010e+00	5.41842e+00	7.21398e-02	3.01303e+01	4.18263e-01
4.85000e+00	2.72762e+01	4.94820e+00	5.51236e+00	6.93591e-02	3.07514e+01	4.17471e-01
4.90000e+00	2.78450e+01	4.96587e+00	5.60727e+00	6.66986e-02	3.13790e+01	4.16701e-01
4.95000e+00	2.84196e+01	4.98314e+00	5.70315e+00	6.41528e-02	3.20130e+01	4.15954e-01
5.00000e+00	2.90000e+01	5.00000e+00	5.80000e+00	6.17163e-02	3.26535e+01	4.15227e-01
5.10000e+00	3.01783e+01	5.03257e+00	5.99660e+00	5.71513e-02	3.39537e+01	4.13835e-01
5.20000e+00	3.13800e+01	5.06367e+00	6.19709e+00	5.29659e-02	3.52797e+01	4.12519e-01
5.30000e+00	3.26050e+01	5.09338e+00	6.40144e+00	4.91260e-02	3.66315e+01	4.11273e-01
5.40000e+00	3.38533e+01	5.12178e+00	6.60968e+00	4.56005e-02	3.80091e+01	4.10093e-01
5.50000e+00	3.51250e+01	5.14894e+00	6.82180e+00	4.23614e-02	3.94124e+01	4.08974e-01
5.60000e+00	3.64200e+01	5.17492e+00	7.03779e+00	3.93833e-02	4.08414e+01	4.07912e-01
5.70000e+00	3.77383e+01	5.19979e+00	7.25767e+00	3.66431e-02	4.22962e+01	4.06903e-01
5.80000e+00	3.90800e+01	5.22360e+00	7.48143e+00	3.41200e-02	4.37768e+01	4.05944e-01
5.90000e+00	4.04450e+01	5.24642e+00	7.70907e+00	3.17950e-02	4.52831e+01	4.05031e-01
6.00000e+00	4.18333e+01	5.26829e+00	7.94059e+00	2.96509e-02	4.68152e+01	4.04162e-01
6.10000e+00	4.32450e+01	5.28927e+00	8.17599e+00	2.76723e-02	4.83730e+01	4.03333e-01
6.20000e+00	4.46800e+01	5.30939e+00	8.41528e+00	2.58448e-02	4.99566e+01	4.02543e-01
6.30000e+00	4.61383e+01	5.32871e+00	8.65845e+00	2.41558e-02	5.15660e+01	4.01790e-01
6.40000e+00	4.76200e+01	5.34726e+00	8.90550e+00	2.25936e-02	5.32011e+01	4.01070e-01
6.50000e+00	4.91250e+01	5.36508e+00	9.15643e+00	2.11476e-02	5.48620e+01	4.00381e-01
6.60000e+00	5.06533e+01	5.38221e+00	9.41126e+00	1.98080e-02	5.65486e+01	3.99724e-01
6.70000e+00	5.22050e+01	5.39868e+00	9.66996e+00	1.85663e-02	5.82610e+01	3.99094e-01
6.80000e+00	5.37800e+01	5.41452e+00	9.93255e+00	1.74144e-02	5.99991e+01	3.98491e-01
6.90000e+00	5.53783e+01	5.42977e+00	1.01990e+01	1.63450e-02	6.17630e+01	3.97913e-01

Table A.2: Normal shock properties ($\gamma = 1.4$) *continued*

M	p_2/p_1	ρ_2/ρ_1	T_2/T_1	p_{o_2}/p_{o_1}	p_{o_2}/p_1	M_2
7.00000e+00	5.70000e+01	5.44444e+00	1.04694e+01	1.53515e-02	6.35526e+01	3.97360e-01
7.10000e+00	5.86450e+01	5.45858e+00	1.07436e+01	1.44279e-02	6.53680e+01	3.96829e-01
7.20000e+00	6.03133e+01	5.47220e+00	1.10218e+01	1.35686e-02	6.72092e+01	3.96319e-01
7.30000e+00	6.20050e+01	5.48533e+00	1.13038e+01	1.27686e-02	6.90761e+01	3.95829e-01
7.40000e+00	6.37200e+01	5.49799e+00	1.15897e+01	1.20233e-02	7.09687e+01	3.95359e-01
7.50000e+00	6.54583e+01	5.51020e+00	1.18795e+01	1.13286e-02	7.28871e+01	3.94907e-01
7.60000e+00	6.72200e+01	5.52199e+00	1.21732e+01	1.06804e-02	7.48313e+01	3.94472e-01
7.70000e+00	6.90050e+01	5.53336e+00	1.24707e+01	1.00754e-02	7.68012e+01	3.94054e-01
7.80000e+00	7.08133e+01	5.54435e+00	1.27722e+01	9.51020e-03	7.87969e+01	3.93651e-01
7.90000e+00	7.26450e+01	5.55496e+00	1.30775e+01	8.98193e-03	8.08183e+01	3.93264e-01
8.00000e+00	7.45000e+01	5.56522e+00	1.33867e+01	8.48783e-03	8.28655e+01	3.92890e-01
9.00000e+00	9.43333e+01	5.65116e+00	1.66927e+01	4.96386e-03	1.04754e+02	3.89799e-01
1.00000e+01	1.16500e+02	5.71429e+00	2.03875e+01	3.04475e-03	1.29217e+02	3.87575e-01
1.10000e+01	1.41000e+02	5.76190e+00	2.44711e+01	1.94506e-03	1.56256e+02	3.85922e-01
1.20000e+01	1.67833e+02	5.79866e+00	2.89435e+01	1.28662e-03	1.85869e+02	3.84661e-01
1.30000e+01	1.97000e+02	5.82759e+00	3.38047e+01	8.77092e-04	2.18058e+02	3.83677e-01
1.40000e+01	2.28500e+02	5.85075e+00	3.90548e+01	6.13796e-04	2.52822e+02	3.82895e-01
1.50000e+01	2.62333e+02	5.86957e+00	4.46938e+01	4.39529e-04	2.90161e+02	3.82262e-01
1.60000e+01	2.98500e+02	5.88506e+00	5.07217e+01	3.21193e-04	3.30076e+02	3.81744e-01
1.70000e+01	3.37000e+02	5.89796e+00	5.71384e+01	2.38991e-04	3.72565e+02	3.81314e-01
1.80000e+01	3.77833e+02	5.90881e+00	6.39440e+01	1.80718e-04	4.17630e+02	3.80954e-01
1.90000e+01	4.21000e+02	5.91803e+00	7.11385e+01	1.38649e-04	4.65269e+02	3.80648e-01
2.00000e+01	4.66500e+02	5.92593e+00	7.87219e+01	1.07775e-04	5.15484e+02	3.80387e-01
2.20000e+01	5.64500e+02	5.93865e+00	9.50553e+01	6.74136e-05	6.23639e+02	3.79968e-01
2.40000e+01	6.71833e+02	5.94836e+00	1.12944e+02	4.38771e-05	7.42094e+02	3.79648e-01
2.60000e+01	7.88500e+02	5.95595e+00	1.32389e+02	2.95341e-05	8.70850e+02	3.79400e-01
2.80000e+01	9.14500e+02	5.96198e+00	1.53389e+02	2.04601e-05	1.00991e+03	3.79202e-01
3.00000e+01	1.04983e+03	5.96685e+00	1.75944e+02	1.45314e-05	1.15926e+03	3.79043e-01
3.20000e+01	1.19450e+03	5.97085e+00	2.00055e+02	1.05478e-05	1.31892e+03	3.78913e-01
3.40000e+01	1.34850e+03	5.97416e+00	2.25722e+02	7.80444e-06	1.48888e+03	3.78804e-01
3.60000e+01	1.51183e+03	5.97694e+00	2.52944e+02	5.87376e-06	1.66914e+03	3.78714e-01
3.80000e+01	1.68450e+03	5.97930e+00	2.81722e+02	4.48846e-06	1.85970e+03	3.78637e-01
4.00000e+01	1.86650e+03	5.98131e+00	3.12055e+02	3.47710e-06	2.06056e+03	3.78571e-01
4.20000e+01	2.05783e+03	5.98304e+00	3.43944e+02	2.72710e-06	2.27172e+03	3.78515e-01
4.40000e+01	2.25850e+03	5.98454e+00	3.77389e+02	2.16301e-06	2.49318e+03	3.78466e-01
4.60000e+01	2.46850e+03	5.98586e+00	4.12389e+02	1.73324e-06	2.72494e+03	3.78424e-01
4.80000e+01	2.68783e+03	5.98701e+00	4.48944e+02	1.40194e-06	2.96700e+03	3.78386e-01
5.00000e+01	2.91650e+03	5.98802e+00	4.87055e+02	1.14377e-06	3.21936e+03	3.78353e-01

Table A.3: One-dimensional flow with heat addition ($\gamma = 1.4$)

M	p/p^*	T/T^*	ρ/ρ^*	p_o/p_o^*	T_o/T_o^*
2.00000e-02	2.39866e+00	2.30142e-03	1.04225e+03	1.26752e+00	1.91800e-03
4.00000e-02	2.39464e+00	9.17485e-03	2.61000e+02	1.26646e+00	7.64816e-03
6.00000e-02	2.38796e+00	2.05286e-02	1.16324e+02	1.26470e+00	1.71194e-02
8.00000e-02	2.37869e+00	3.62122e-02	6.56875e+01	1.26226e+00	3.02154e-02
1.00000e-01	2.36686e+00	5.60204e-02	4.22500e+01	1.25915e+00	4.67771e-02
1.20000e-01	2.35257e+00	7.96982e-02	2.95185e+01	1.25539e+00	6.66064e-02
1.40000e-01	2.33590e+00	1.06946e-01	2.18418e+01	1.25103e+00	8.94712e-02
1.60000e-01	2.31696e+00	1.37429e-01	1.68594e+01	1.24608e+00	1.15110e-01
1.80000e-01	2.29586e+00	1.70779e-01	1.34434e+01	1.24059e+00	1.43238e-01
2.00000e-01	2.27273e+00	2.06612e-01	1.10000e+01	1.23460e+00	1.73554e-01
2.20000e-01	2.24770e+00	2.44523e-01	9.19215e+00	1.22814e+00	2.05742e-01
2.40000e-01	2.22091e+00	2.84108e-01	7.81713e+00	1.22126e+00	2.39484e-01
2.60000e-01	2.19250e+00	3.24957e-01	6.74704e+00	1.21400e+00	2.74459e-01
2.80000e-01	2.16263e+00	3.66674e-01	5.89796e+00	1.20642e+00	3.10353e-01
3.00000e-01	2.13144e+00	4.08873e-01	5.21296e+00	1.19855e+00	3.46860e-01
3.20000e-01	2.09908e+00	4.51187e-01	4.65234e+00	1.19045e+00	3.83689e-01
3.40000e-01	2.06569e+00	4.93273e-01	4.18772e+00	1.18215e+00	4.20565e-01
3.60000e-01	2.03142e+00	5.34816e-01	3.79835e+00	1.17371e+00	4.57232e-01
3.80000e-01	1.99641e+00	5.75526e-01	3.46884e+00	1.16517e+00	4.93456e-01
4.00000e-01	1.96078e+00	6.15148e-01	3.18750e+00	1.15658e+00	5.29027e-01
4.20000e-01	1.92468e+00	6.53456e-01	2.94539e+00	1.14796e+00	5.63758e-01
4.40000e-01	1.88822e+00	6.90255e-01	2.73554e+00	1.13936e+00	5.97485e-01
4.60000e-01	1.85151e+00	7.25383e-01	2.55246e+00	1.13082e+00	6.30068e-01
4.80000e-01	1.81466e+00	7.58707e-01	2.39178e+00	1.12238e+00	6.61390e-01
5.00000e-01	1.77778e+00	7.90123e-01	2.25000e+00	1.11405e+00	6.91358e-01
5.20000e-01	1.74095e+00	8.19554e-01	2.12426e+00	1.10588e+00	7.19897e-01
5.40000e-01	1.70425e+00	8.46948e-01	2.01223e+00	1.09789e+00	7.46952e-01
5.60000e-01	1.66778e+00	8.72274e-01	1.91199e+00	1.09011e+00	7.72486e-01
5.80000e-01	1.63159e+00	8.95523e-01	1.82194e+00	1.08256e+00	7.96478e-01
6.00000e-01	1.59574e+00	9.16704e-01	1.74074e+00	1.07525e+00	8.18923e-01
6.20000e-01	1.56031e+00	9.35843e-01	1.66727e+00	1.06822e+00	8.39825e-01
6.40000e-01	1.52532e+00	9.52976e-01	1.60059e+00	1.06147e+00	8.59203e-01
6.60000e-01	1.49083e+00	9.68155e-01	1.53987e+00	1.05503e+00	8.77084e-01
6.80000e-01	1.45688e+00	9.81439e-01	1.48443e+00	1.04890e+00	8.93502e-01
7.00000e-01	1.42349e+00	9.92895e-01	1.43367e+00	1.04310e+00	9.08499e-01
7.20000e-01	1.39069e+00	1.00260e+00	1.38709e+00	1.03764e+00	9.22122e-01
7.40000e-01	1.35851e+00	1.01062e+00	1.34423e+00	1.03253e+00	9.34423e-01
7.60000e-01	1.32696e+00	1.01706e+00	1.30471e+00	1.02777e+00	9.45456e-01
7.80000e-01	1.29606e+00	1.02198e+00	1.26819e+00	1.02337e+00	9.55279e-01
8.00000e-01	1.26582e+00	1.02548e+00	1.23438e+00	1.01934e+00	9.63948e-01
8.20000e-01	1.23625e+00	1.02763e+00	1.20300e+00	1.01569e+00	9.71524e-01
8.40000e-01	1.20734e+00	1.02853e+00	1.17385e+00	1.01241e+00	9.78066e-01
8.60000e-01	1.17911e+00	1.02826e+00	1.14670e+00	1.00951e+00	9.83633e-01
8.80000e-01	1.15154e+00	1.02689e+00	1.12138e+00	1.00699e+00	9.88283e-01
9.00000e-01	1.12465e+00	1.02452e+00	1.09774e+00	1.00486e+00	9.92073e-01
9.20000e-01	1.09842e+00	1.02120e+00	1.07561e+00	1.00311e+00	9.95058e-01
9.40000e-01	1.07285e+00	1.01702e+00	1.05489e+00	1.00175e+00	9.97293e-01
9.60000e-01	1.04793e+00	1.01205e+00	1.03545e+00	1.00078e+00	9.98828e-01
9.80000e-01	1.02365e+00	1.00636e+00	1.01718e+00	1.00019e+00	9.99715e-01
1.00000e+00	1.00000e+00	1.00000e+00	1.00000e+00	1.00000e+00	1.00000e+00
1.02000e+00	9.76976e-01	9.93043e-01	9.83820e-01	1.00019e+00	9.99730e-01
1.04000e+00	9.54563e-01	9.85543e-01	9.68565e-01	1.00078e+00	9.98947e-01
1.06000e+00	9.32749e-01	9.77555e-01	9.54165e-01	1.00175e+00	9.97692e-01
1.08000e+00	9.11522e-01	9.69129e-01	9.40558e-01	1.00311e+00	9.96006e-01
1.10000e+00	8.90869e-01	9.60313e-01	9.27686e-01	1.00486e+00	9.93924e-01
1.12000e+00	8.70777e-01	9.51151e-01	9.15497e-01	1.00699e+00	9.91480e-01
1.14000e+00	8.51233e-01	9.41687e-01	9.03945e-01	1.00952e+00	9.88708e-01
1.16000e+00	8.32224e-01	9.31958e-01	8.92985e-01	1.01243e+00	9.85638e-01
1.18000e+00	8.13736e-01	9.22000e-01	8.82577e-01	1.01573e+00	9.82299e-01
1.20000e+00	7.95756e-01	9.11848e-01	8.72685e-01	1.01942e+00	9.78717e-01
1.22000e+00	7.78271e-01	9.01532e-01	8.63276e-01	1.02349e+00	9.74916e-01
1.24000e+00	7.61267e-01	8.91081e-01	8.54318e-01	1.02795e+00	9.70922e-01
1.26000e+00	7.44731e-01	8.80522e-01	8.45784e-01	1.03280e+00	9.66754e-01
1.28000e+00	7.28651e-01	8.69878e-01	8.37646e-01	1.03803e+00	9.62433e-01
1.30000e+00	7.13012e-01	8.59174e-01	8.29882e-01	1.04366e+00	9.57979e-01

Table A.3: One-dimensional flow with heat addition ($\gamma = 1.4$) *continued*

M	p/p^*	T/T^*	ρ/ρ^*	p_o/p_o^*	T_o/T_o^*
1.32000e+00	6.97804e-01	8.48428e-01	8.22467e-01	1.04968e+00	9.53407e-01
1.34000e+00	6.83013e-01	8.37661e-01	8.15382e-01	1.05608e+00	9.48734e-01
1.36000e+00	6.68628e-01	8.26888e-01	8.08607e-01	1.06288e+00	9.43976e-01
1.38000e+00	6.54636e-01	8.16127e-01	8.02125e-01	1.07007e+00	9.39145e-01
1.40000e+00	6.41026e-01	8.05391e-01	7.95918e-01	1.07765e+00	9.34254e-01
1.42000e+00	6.27786e-01	7.94694e-01	7.89972e-01	1.08563e+00	9.29315e-01
1.44000e+00	6.14905e-01	7.84046e-01	7.84272e-01	1.09401e+00	9.24338e-01
1.46000e+00	6.02373e-01	7.73459e-01	7.78805e-01	1.10278e+00	9.19333e-01
1.48000e+00	5.90179e-01	7.62942e-01	7.73557e-01	1.11196e+00	9.14310e-01
1.50000e+00	5.78313e-01	7.52504e-01	7.68519e-01	1.12155e+00	9.09276e-01
1.52000e+00	5.66765e-01	7.42152e-01	7.63677e-01	1.13153e+00	9.04238e-01
1.54000e+00	5.55525e-01	7.31894e-01	7.59023e-01	1.14193e+00	8.99205e-01
1.56000e+00	5.44583e-01	7.21735e-01	7.54547e-01	1.15274e+00	8.94181e-01
1.58000e+00	5.33931e-01	7.11680e-01	7.50240e-01	1.16397e+00	8.89173e-01
1.60000e+00	5.23560e-01	7.01735e-01	7.46094e-01	1.17561e+00	8.84186e-01
1.62000e+00	5.13461e-01	6.91903e-01	7.42100e-01	1.18768e+00	8.79225e-01
1.64000e+00	5.03626e-01	6.82188e-01	7.38251e-01	1.20017e+00	8.74292e-01
1.66000e+00	4.94047e-01	6.72593e-01	7.34541e-01	1.21309e+00	8.69394e-01
1.68000e+00	4.84715e-01	6.63120e-01	7.30962e-01	1.22644e+00	8.64531e-01
1.70000e+00	4.75624e-01	6.53771e-01	7.27509e-01	1.24024e+00	8.59709e-01
1.72000e+00	4.66766e-01	6.44549e-01	7.24175e-01	1.25447e+00	8.54929e-01
1.74000e+00	4.58134e-01	6.35454e-01	7.20956e-01	1.26915e+00	8.50195e-01
1.76000e+00	4.49721e-01	6.26487e-01	7.17846e-01	1.28428e+00	8.45507e-01
1.78000e+00	4.41521e-01	6.17649e-01	7.14840e-01	1.29987e+00	8.40868e-01
1.80000e+00	4.33526e-01	6.08941e-01	7.11934e-01	1.31592e+00	8.36279e-01
1.82000e+00	4.25731e-01	6.00363e-01	7.09123e-01	1.33244e+00	8.31743e-01
1.84000e+00	4.18130e-01	5.91914e-01	7.06404e-01	1.34943e+00	8.27259e-01
1.86000e+00	4.10717e-01	5.83595e-01	7.03771e-01	1.36690e+00	8.22829e-01
1.88000e+00	4.03486e-01	5.75404e-01	7.01222e-01	1.38486e+00	8.18455e-01
1.90000e+00	3.96432e-01	5.67342e-01	6.98753e-01	1.40330e+00	8.14136e-01
1.92000e+00	3.89550e-01	5.59407e-01	6.96361e-01	1.42224e+00	8.09873e-01
1.94000e+00	3.82834e-01	5.51599e-01	6.94043e-01	1.44168e+00	8.05666e-01
1.96000e+00	3.76279e-01	5.43917e-01	6.91795e-01	1.46164e+00	8.01517e-01
1.98000e+00	3.69882e-01	5.36360e-01	6.89615e-01	1.48210e+00	7.97424e-01
2.00000e+00	3.63636e-01	5.28926e-01	6.87500e-01	1.50310e+00	7.93388e-01
2.05000e+00	3.48660e-01	5.10871e-01	6.82481e-01	1.55791e+00	7.83549e-01
2.10000e+00	3.34541e-01	4.93558e-01	6.77816e-01	1.61616e+00	7.74064e-01
2.15000e+00	3.21221e-01	4.76962e-01	6.73472e-01	1.67796e+00	7.64928e-01
2.20000e+00	3.08642e-01	4.61058e-01	6.69421e-01	1.74345e+00	7.56135e-01
2.25000e+00	2.96754e-01	4.45819e-01	6.65638e-01	1.81275e+00	7.47676e-01
2.30000e+00	2.85510e-01	4.31220e-01	6.62098e-01	1.88602e+00	7.39543e-01
2.35000e+00	2.74867e-01	4.17235e-01	6.58782e-01	1.96340e+00	7.31725e-01
2.40000e+00	2.64784e-01	4.03836e-01	6.55671e-01	2.04505e+00	7.24213e-01
2.45000e+00	2.55224e-01	3.90999e-01	6.52749e-01	2.13114e+00	7.16994e-01
2.50000e+00	2.46154e-01	3.78698e-01	6.50000e-01	2.22183e+00	7.10059e-01
2.55000e+00	2.37541e-01	3.66910e-01	6.47411e-01	2.31730e+00	7.03396e-01
2.60000e+00	2.29358e-01	3.55610e-01	6.44970e-01	2.41774e+00	6.96995e-01
2.65000e+00	2.21576e-01	3.44776e-01	6.42666e-01	2.52334e+00	6.90845e-01
2.70000e+00	2.14171e-01	3.34387e-01	6.40489e-01	2.63429e+00	6.84935e-01
2.75000e+00	2.07120e-01	3.24421e-01	6.38430e-01	2.75080e+00	6.79256e-01
2.80000e+00	2.00401e-01	3.14858e-01	6.36480e-01	2.87308e+00	6.73796e-01
2.85000e+00	1.93994e-01	3.05680e-01	6.34631e-01	3.00136e+00	6.68548e-01
2.90000e+00	1.87882e-01	2.96869e-01	6.32878e-01	3.13585e+00	6.63502e-01
2.95000e+00	1.82046e-01	2.88407e-01	6.31212e-01	3.27680e+00	6.58648e-01
3.00000e+00	1.76471e-01	2.80277e-01	6.29630e-01	3.42445e+00	6.53979e-01
3.05000e+00	1.71141e-01	2.72464e-01	6.28124e-01	3.57905e+00	6.49486e-01
3.10000e+00	1.66044e-01	2.64954e-01	6.26691e-01	3.74084e+00	6.45162e-01
3.15000e+00	1.61166e-01	2.57731e-01	6.25325e-01	3.91011e+00	6.40999e-01
3.20000e+00	1.56495e-01	2.50783e-01	6.24023e-01	4.08712e+00	6.36989e-01
3.25000e+00	1.52019e-01	2.44097e-01	6.22781e-01	4.27215e+00	6.33127e-01
3.30000e+00	1.47729e-01	2.37661e-01	6.21595e-01	4.46549e+00	6.29405e-01
3.35000e+00	1.43614e-01	2.31463e-01	6.20461e-01	4.66744e+00	6.25818e-01
3.40000e+00	1.39665e-01	2.25492e-01	6.19377e-01	4.87830e+00	6.22359e-01
3.45000e+00	1.35873e-01	2.19739e-01	6.18340e-01	5.09839e+00	6.19023e-01
3.50000e+00	1.32231e-01	2.14193e-01	6.17347e-01	5.32804e+00	6.15805e-01

Table A.3: One-dimensional flow with heat addition ($\gamma = 1.4$) *continued*

M	p/p^*	T/T^*	ρ/ρ^*	p_o/p_o^*	T_o/T_o^*
3.55000e+00	1.28731e-01	2.08845e-01	6.16396e-01	5.56756e+00	6.12699e-01
3.60000e+00	1.25366e-01	2.03686e-01	6.15484e-01	5.81730e+00	6.09701e-01
3.65000e+00	1.22128e-01	1.98709e-01	6.14609e-01	6.07761e+00	6.06807e-01
3.70000e+00	1.19012e-01	1.93904e-01	6.13769e-01	6.34884e+00	6.04010e-01
3.75000e+00	1.16012e-01	1.89264e-01	6.12963e-01	6.63137e+00	6.01309e-01
3.80000e+00	1.13122e-01	1.84783e-01	6.12188e-01	6.92557e+00	5.98698e-01
3.85000e+00	1.10337e-01	1.80454e-01	6.11444e-01	7.23181e+00	5.96174e-01
3.90000e+00	1.07652e-01	1.76269e-01	6.10728e-01	7.55050e+00	5.93732e-01
3.95000e+00	1.05063e-01	1.72223e-01	6.10038e-01	7.88205e+00	5.91371e-01
4.00000e+00	1.02564e-01	1.68310e-01	6.09375e-01	8.22685e+00	5.89086e-01
4.05000e+00	1.00152e-01	1.64525e-01	6.08736e-01	8.58534e+00	5.86875e-01
4.10000e+00	9.78234e-02	1.60862e-01	6.08120e-01	8.95794e+00	5.84733e-01
4.15000e+00	9.55737e-02	1.57316e-01	6.07526e-01	9.34511e+00	5.82660e-01
4.20000e+00	9.33998e-02	1.53883e-01	6.06954e-01	9.74729e+00	5.80651e-01
4.25000e+00	9.12981e-02	1.50557e-01	6.06401e-01	1.01649e+01	5.78705e-01
4.30000e+00	8.92658e-02	1.47335e-01	6.05868e-01	1.05985e+01	5.76818e-01
4.35000e+00	8.72997e-02	1.44213e-01	6.05353e-01	1.10486e+01	5.74989e-01
4.40000e+00	8.53971e-02	1.41186e-01	6.04855e-01	1.15155e+01	5.73215e-01
4.45000e+00	8.35553e-02	1.38251e-01	6.04374e-01	1.19999e+01	5.71494e-01
4.50000e+00	8.17717e-02	1.35404e-01	6.03909e-01	1.25023e+01	5.69825e-01
4.55000e+00	8.00440e-02	1.32642e-01	6.03460e-01	1.30231e+01	5.68205e-01
4.60000e+00	7.83699e-02	1.29961e-01	6.03025e-01	1.35629e+01	5.66632e-01
4.65000e+00	7.67472e-02	1.27359e-01	6.02603e-01	1.41223e+01	5.65104e-01
4.70000e+00	7.51738e-02	1.24833e-01	6.02196e-01	1.47017e+01	5.63621e-01
4.75000e+00	7.36479e-02	1.22379e-01	6.01801e-01	1.53019e+01	5.62179e-01
4.80000e+00	7.21674e-02	1.19995e-01	6.01418e-01	1.59234e+01	5.60779e-01
4.85000e+00	7.07307e-02	1.17679e-01	6.01047e-01	1.65667e+01	5.59418e-01
4.90000e+00	6.93361e-02	1.15428e-01	6.00687e-01	1.72325e+01	5.58094e-01
4.95000e+00	6.79819e-02	1.13239e-01	6.00338e-01	1.79213e+01	5.56807e-01
5.00000e+00	6.66667e-02	1.11111e-01	6.00000e-01	1.86339e+01	5.55556e-01
5.10000e+00	6.41471e-02	1.07027e-01	5.99353e-01	2.01328e+01	5.53153e-01
5.20000e+00	6.17665e-02	1.03160e-01	5.98743e-01	2.17344e+01	5.50877e-01
5.30000e+00	5.95150e-02	9.94956e-02	5.98167e-01	2.34442e+01	5.48718e-01
5.40000e+00	5.73833e-02	9.60194e-02	5.97622e-01	2.52679e+01	5.46670e-01
5.50000e+00	5.53633e-02	9.27192e-02	5.97107e-01	2.72113e+01	5.44725e-01
5.60000e+00	5.34474e-02	8.95836e-02	5.96620e-01	2.92806e+01	5.42877e-01
5.70000e+00	5.16284e-02	8.66020e-02	5.96158e-01	3.14821e+01	5.41118e-01
5.80000e+00	4.99002e-02	8.37646e-02	5.95719e-01	3.38223e+01	5.39444e-01
5.90000e+00	4.82567e-02	8.10625e-02	5.95303e-01	3.63079e+01	5.37849e-01
6.00000e+00	4.66926e-02	7.84872e-02	5.94907e-01	3.89459e+01	5.36329e-01
6.10000e+00	4.52028e-02	7.60311e-02	5.94531e-01	4.17436e+01	5.34879e-01
6.20000e+00	4.37828e-02	7.36871e-02	5.94173e-01	4.47084e+01	5.33494e-01
6.30000e+00	4.24283e-02	7.14484e-02	5.93831e-01	4.78479e+01	5.32172e-01
6.40000e+00	4.11353e-02	6.93091e-02	5.93506e-01	5.11700e+01	5.30907e-01
6.50000e+00	3.99002e-02	6.72633e-02	5.93195e-01	5.46830e+01	5.29698e-01
6.60000e+00	3.87197e-02	6.53057e-02	5.92899e-01	5.83953e+01	5.28541e-01
6.70000e+00	3.75905e-02	6.34315e-02	5.92615e-01	6.23154e+01	5.27433e-01
6.80000e+00	3.65097e-02	6.16359e-02	5.92344e-01	6.64524e+01	5.26371e-01
6.90000e+00	3.54746e-02	5.99147e-02	5.92085e-01	7.08154e+01	5.25352e-01
7.00000e+00	3.44828e-02	5.82640e-02	5.91837e-01	7.54138e+01	5.24376e-01
7.10000e+00	3.35317e-02	5.66798e-02	5.91599e-01	8.02574e+01	5.23438e-01
7.20000e+00	3.26193e-02	5.51588e-02	5.91371e-01	8.53562e+01	5.22538e-01
7.30000e+00	3.17435e-02	5.36977e-02	5.91152e-01	9.07204e+01	5.21673e-01
7.40000e+00	3.09023e-02	5.22933e-02	5.90942e-01	9.63605e+01	5.20842e-01
7.50000e+00	3.00940e-02	5.09429e-02	5.90741e-01	1.02287e+02	5.20042e-01
7.60000e+00	2.93169e-02	4.96437e-02	5.90547e-01	1.08512e+02	5.19273e-01
7.70000e+00	2.85694e-02	4.83931e-02	5.90361e-01	1.15047e+02	5.18532e-01
7.80000e+00	2.78500e-02	4.71888e-02	5.90182e-01	1.21902e+02	5.17819e-01
7.90000e+00	2.71573e-02	4.60286e-02	5.90010e-01	1.29090e+02	5.17131e-01
8.00000e+00	2.64901e-02	4.49103e-02	5.89844e-01	1.36624e+02	5.16469e-01
9.00000e+00	2.09790e-02	3.56497e-02	5.88477e-01	2.33884e+02	5.10979e-01
1.00000e+01	1.70213e-02	2.89724e-02	5.87500e-01	3.81615e+02	5.07017e-01
1.10000e+01	1.40845e-02	2.40032e-02	5.86777e-01	5.97736e+02	5.04067e-01
1.20000e+01	1.18460e-02	2.02072e-02	5.86227e-01	9.04054e+02	5.01812e-01
1.30000e+01	1.01010e-02	1.72431e-02	5.85799e-01	1.32665e+03	5.00051e-01

Table A.3: One-dimensional flow with heat addition ($\gamma = 1.4$) *continued*

M	p/p^*	T/T^*	ρ/ρ^*	p_o/p_o^*	T_o/T_o^*
1.40000e+01	8.71460e-03	1.48851e-02	5.85459e-01	1.89629e+03	4.98650e-01
1.50000e+01	7.59494e-03	1.29787e-02	5.85185e-01	2.64876e+03	4.97516e-01
1.60000e+01	6.67780e-03	1.14158e-02	5.84961e-01	3.62531e+03	4.96587e-01
1.70000e+01	5.91716e-03	1.01187e-02	5.84775e-01	4.87304e+03	4.95816e-01
1.80000e+01	5.27937e-03	9.03043e-03	5.84619e-01	6.44522e+03	4.95169e-01
1.90000e+01	4.73934e-03	8.10853e-03	5.84488e-01	8.40179e+03	4.94621e-01
2.00000e+01	4.27807e-03	7.32077e-03	5.84375e-01	1.08096e+04	4.94152e-01
2.20000e+01	3.53669e-03	6.05397e-03	5.84194e-01	1.72842e+04	4.93398e-01
2.40000e+01	2.97250e-03	5.08941e-03	5.84057e-01	2.65589e+04	4.92825e-01
2.60000e+01	2.53325e-03	4.33813e-03	5.83950e-01	3.94606e+04	4.92378e-01
2.80000e+01	2.18460e-03	3.74162e-03	5.83865e-01	5.69655e+04	4.92023e-01
3.00000e+01	1.90325e-03	3.26013e-03	5.83796e-01	8.02115e+04	4.91736e-01
3.20000e+01	1.67294e-03	2.86590e-03	5.83740e-01	1.10511e+05	4.91502e-01
3.40000e+01	1.48203e-03	2.53905e-03	5.83694e-01	1.49362e+05	4.91307e-01
3.60000e+01	1.32202e-03	2.26508e-03	5.83655e-01	1.98463e+05	4.91144e-01
3.80000e+01	1.18659e-03	2.03315e-03	5.83622e-01	2.59723e+05	4.91006e-01
4.00000e+01	1.07095e-03	1.83510e-03	5.83594e-01	3.35276e+05	4.90888e-01
4.20000e+01	9.71424e-04	1.66462e-03	5.83570e-01	4.27491e+05	4.90787e-01
4.40000e+01	8.85152e-04	1.51684e-03	5.83549e-01	5.38986e+05	4.90699e-01
4.60000e+01	8.09881e-04	1.38790e-03	5.83530e-01	6.72642e+05	4.90622e-01
4.80000e+01	7.43817e-04	1.27472e-03	5.83514e-01	8.31612e+05	4.90555e-01
5.00000e+01	6.85518e-04	1.17484e-03	5.83500e-01	1.01933e+06	4.90495e-01

Table A.4: One-dimensional flow with friction ($\gamma = 1.4$)

M	T/T^*	p/p^*	ρ/ρ^*	p_o/p_o^*	$4fL^*/D$
2.00000e-02	1.19990e+00	5.47701e+01	4.56454e+01	2.89421e+01	1.77845e+03
4.00000e-02	1.19962e+00	2.73817e+01	2.28254e+01	1.44815e+01	4.40352e+02
6.00000e-02	1.19914e+00	1.82508e+01	1.52200e+01	9.66591e+00	1.93031e+02
8.00000e-02	1.19847e+00	1.36843e+01	1.14182e+01	7.26161e+00	1.06718e+02
1.00000e-01	1.19760e+00	1.09435e+01	9.13783e+00	5.82183e+00	6.69216e+01
1.20000e-01	1.19655e+00	9.11559e+00	7.61820e+00	4.86432e+00	4.54080e+01
1.40000e-01	1.19531e+00	7.80932e+00	6.53327e+00	4.18240e+00	3.25113e+01
1.60000e-01	1.19389e+00	6.82907e+00	5.72003e+00	3.67274e+00	2.41978e+01
1.80000e-01	1.19227e+00	6.06618e+00	5.08791e+00	3.27793e+00	1.85427e+01
2.00000e-01	1.19048e+00	5.45545e+00	4.58258e+00	2.96352e+00	1.45333e+01
2.20000e-01	1.18850e+00	4.95537e+00	4.16945e+00	2.70760e+00	1.15961e+01
2.40000e-01	1.18633e+00	4.53829e+00	3.82548e+00	2.49556e+00	9.38648e+00
2.60000e-01	1.18399e+00	4.18505e+00	3.53470e+00	2.31729e+00	7.68757e+00
2.80000e-01	1.18147e+00	3.88199e+00	3.28571e+00	2.16555e+00	6.35721e+00
3.00000e-01	1.17878e+00	3.61906e+00	3.07017e+00	2.03507e+00	5.29925e+00
3.20000e-01	1.17592e+00	3.38874e+00	2.88179e+00	1.92185e+00	4.44674e+00
3.40000e-01	1.17288e+00	3.18529e+00	2.71577e+00	1.82288e+00	3.75195e+00
3.60000e-01	1.16968e+00	3.00422e+00	2.56841e+00	1.73578e+00	3.18012e+00
3.80000e-01	1.16632e+00	2.84200e+00	2.43673e+00	1.65870e+00	2.70545e+00
4.00000e-01	1.16279e+00	2.69582e+00	2.31840e+00	1.59014e+00	2.30849e+00
4.20000e-01	1.15911e+00	2.56338e+00	2.21151e+00	1.52890e+00	1.97437e+00
4.40000e-01	1.15527e+00	2.44280e+00	2.11449e+00	1.47401e+00	1.69152e+00
4.60000e-01	1.15128e+00	2.33256e+00	2.02606e+00	1.42463e+00	1.45091e+00
4.80000e-01	1.14714e+00	2.23135e+00	1.94514e+00	1.38010e+00	1.24534e+00
5.00000e-01	1.14286e+00	2.13809e+00	1.87083e+00	1.33984e+00	1.06906e+00
5.20000e-01	1.13843e+00	2.05187e+00	1.80237e+00	1.30339e+00	9.17418e-01
5.40000e-01	1.13387e+00	1.97192e+00	1.73910e+00	1.27032e+00	7.86625e-01
5.60000e-01	1.12918e+00	1.89755e+00	1.68047e+00	1.24029e+00	6.73571e-01
5.80000e-01	1.12435e+00	1.82820e+00	1.62600e+00	1.21301e+00	5.75683e-01
6.00000e-01	1.11940e+00	1.76336e+00	1.57527e+00	1.18820e+00	4.90822e-01
6.20000e-01	1.11433e+00	1.70261e+00	1.52792e+00	1.16565e+00	4.17197e-01
6.40000e-01	1.10914e+00	1.64556e+00	1.48363e+00	1.14515e+00	3.53299e-01
6.60000e-01	1.10383e+00	1.59187e+00	1.44213e+00	1.12654e+00	2.97853e-01
6.80000e-01	1.09842e+00	1.54126e+00	1.40316e+00	1.10965e+00	2.49775e-01
7.00000e-01	1.09290e+00	1.49345e+00	1.36651e+00	1.09437e+00	2.08139e-01
7.20000e-01	1.08727e+00	1.44823e+00	1.33198e+00	1.08057e+00	1.72149e-01
7.40000e-01	1.08155e+00	1.40537e+00	1.29941e+00	1.06814e+00	1.41122e-01
7.60000e-01	1.07573e+00	1.36470e+00	1.26863e+00	1.05700e+00	1.14468e-01
7.80000e-01	1.06982e+00	1.32605e+00	1.23951e+00	1.04705e+00	9.16722e-02
8.00000e-01	1.06383e+00	1.28928e+00	1.21192e+00	1.03823e+00	7.22900e-02
8.20000e-01	1.05775e+00	1.25423e+00	1.18575e+00	1.03046e+00	5.59317e-02
8.40000e-01	1.05160e+00	1.22080e+00	1.16090e+00	1.02370e+00	4.22564e-02
8.60000e-01	1.04537e+00	1.18888e+00	1.13728e+00	1.01787e+00	3.09651e-02
8.80000e-01	1.03907e+00	1.15835e+00	1.11480e+00	1.01294e+00	2.17945e-02
9.00000e-01	1.03270e+00	1.12913e+00	1.09338e+00	1.00886e+00	1.45124e-02
9.20000e-01	1.02627e+00	1.10114e+00	1.07295e+00	1.00560e+00	8.91334e-03
9.40000e-01	1.01978e+00	1.07430e+00	1.05346e+00	1.00311e+00	4.81545e-03
9.60000e-01	1.01324e+00	1.04854e+00	1.03484e+00	1.00136e+00	2.05714e-03
9.80000e-01	1.00664e+00	1.02379e+00	1.01704e+00	1.00034e+00	4.94695e-04
1.00000e+00	1.00000e+00	1.00000e+00	1.00000e+00	1.00000e+00	0.00000e+00
1.02000e+00	9.93312e-01	9.77108e-01	9.83687e-01	1.00033e+00	4.58691e-04
1.04000e+00	9.86582e-01	9.55066e-01	9.68055e-01	1.00131e+00	1.76850e-03
1.06000e+00	9.79816e-01	9.33827e-01	9.53064e-01	1.00291e+00	3.83785e-03
1.08000e+00	9.73015e-01	9.13347e-01	9.38678e-01	1.00512e+00	6.58460e-03
1.10000e+00	9.66184e-01	8.93588e-01	9.24863e-01	1.00793e+00	9.93500e-03
1.12000e+00	9.59325e-01	8.74510e-01	9.11589e-01	1.01131e+00	1.38227e-02
1.14000e+00	9.52441e-01	8.56080e-01	8.98827e-01	1.01527e+00	1.81881e-02
1.16000e+00	9.45537e-01	8.38265e-01	8.86549e-01	1.01978e+00	2.29773e-02
1.18000e+00	9.38615e-01	8.21035e-01	8.74731e-01	1.02484e+00	2.81419e-02
1.20000e+00	9.31677e-01	8.04362e-01	8.63348e-01	1.03044e+00	3.36381e-02
1.22000e+00	9.24727e-01	7.88219e-01	8.52380e-01	1.03657e+00	3.94262e-02
1.24000e+00	9.17768e-01	7.72582e-01	8.41806e-01	1.04323e+00	4.54705e-02
1.26000e+00	9.10802e-01	7.57428e-01	8.31606e-01	1.05041e+00	5.17387e-02
1.28000e+00	9.03832e-01	7.42735e-01	8.21762e-01	1.05810e+00	5.82014e-02
1.30000e+00	8.96861e-01	7.28483e-01	8.12258e-01	1.06630e+00	6.48321e-02

Table A.4: One-dimensional flow with friction ($\gamma = 1.4$) *continued*

M	T/T^*	p/p^*	ρ/ρ^*	p_o/p_o^*	$4fL^*/D$
1.32000e+00	8.89891e-01	7.14652e-01	8.03078e-01	1.07502e+00	7.16067e-02
1.34000e+00	8.82924e-01	7.01224e-01	7.94207e-01	1.08424e+00	7.85035e-02
1.36000e+00	8.75964e-01	6.88183e-01	7.85630e-01	1.09396e+00	8.55027e-02
1.38000e+00	8.69011e-01	6.75513e-01	7.77335e-01	1.10419e+00	9.25863e-02
1.40000e+00	8.62069e-01	6.63198e-01	7.69309e-01	1.11493e+00	9.97382e-02
1.42000e+00	8.55139e-01	6.51224e-01	7.61541e-01	1.12616e+00	1.06943e-01
1.44000e+00	8.48224e-01	6.39577e-01	7.54019e-01	1.13790e+00	1.14189e-01
1.46000e+00	8.41326e-01	6.28245e-01	7.46732e-01	1.15015e+00	1.21462e-01
1.48000e+00	8.34446e-01	6.17216e-01	7.39672e-01	1.16290e+00	1.28753e-01
1.50000e+00	8.27586e-01	6.06478e-01	7.32828e-01	1.17617e+00	1.36050e-01
1.52000e+00	8.20749e-01	5.96021e-01	7.26192e-01	1.18994e+00	1.43346e-01
1.54000e+00	8.13935e-01	5.85833e-01	7.19755e-01	1.20423e+00	1.50631e-01
1.56000e+00	8.07146e-01	5.75906e-01	7.13509e-01	1.21904e+00	1.57899e-01
1.58000e+00	8.00384e-01	5.66229e-01	7.07447e-01	1.23438e+00	1.65143e-01
1.60000e+00	7.93651e-01	5.56794e-01	7.01561e-01	1.25023e+00	1.72357e-01
1.62000e+00	7.86947e-01	5.47593e-01	6.95844e-01	1.26663e+00	1.79535e-01
1.64000e+00	7.80275e-01	5.38617e-01	6.90291e-01	1.28355e+00	1.86673e-01
1.66000e+00	7.73635e-01	5.29858e-01	6.84895e-01	1.30102e+00	1.93766e-01
1.68000e+00	7.67028e-01	5.21310e-01	6.79650e-01	1.31904e+00	2.00811e-01
1.70000e+00	7.60456e-01	5.12966e-01	6.74550e-01	1.33761e+00	2.07803e-01
1.72000e+00	7.53920e-01	5.04817e-01	6.69590e-01	1.35674e+00	2.14740e-01
1.74000e+00	7.47421e-01	4.96859e-01	6.64765e-01	1.37643e+00	2.21620e-01
1.76000e+00	7.40960e-01	4.89086e-01	6.60070e-01	1.39670e+00	2.28438e-01
1.78000e+00	7.34538e-01	4.81490e-01	6.55500e-01	1.41755e+00	2.35195e-01
1.80000e+00	7.28155e-01	4.74067e-01	6.51052e-01	1.43898e+00	2.41886e-01
1.82000e+00	7.21813e-01	4.66811e-01	6.46720e-01	1.46101e+00	2.48512e-01
1.84000e+00	7.15512e-01	4.59717e-01	6.42501e-01	1.48365e+00	2.55070e-01
1.86000e+00	7.09253e-01	4.52781e-01	6.38390e-01	1.50689e+00	2.61560e-01
1.88000e+00	7.03037e-01	4.45996e-01	6.34385e-01	1.53076e+00	2.67979e-01
1.90000e+00	6.96864e-01	4.39360e-01	6.30482e-01	1.55526e+00	2.74328e-01
1.92000e+00	6.90735e-01	4.32867e-01	6.26676e-01	1.58039e+00	2.80606e-01
1.94000e+00	6.84650e-01	4.26513e-01	6.22965e-01	1.60617e+00	2.86812e-01
1.96000e+00	6.78610e-01	4.20295e-01	6.19347e-01	1.63261e+00	2.92946e-01
1.98000e+00	6.72616e-01	4.14208e-01	6.15817e-01	1.65972e+00	2.99008e-01
2.00000e+00	6.66667e-01	4.08248e-01	6.12372e-01	1.68750e+00	3.04997e-01
2.05000e+00	6.51997e-01	3.93884e-01	6.04120e-01	1.75999e+00	3.19650e-01
2.10000e+00	6.37620e-01	3.80243e-01	5.96348e-01	1.83694e+00	3.33851e-01
2.15000e+00	6.23539e-01	3.67277e-01	5.89020e-01	1.91854e+00	3.47602e-01
2.20000e+00	6.09756e-01	3.54940e-01	5.82102e-01	2.00497e+00	3.60910e-01
2.25000e+00	5.96273e-01	3.43194e-01	5.75566e-01	2.09644e+00	3.73783e-01
2.30000e+00	5.83090e-01	3.32002e-01	5.69383e-01	2.19313e+00	3.86230e-01
2.35000e+00	5.70207e-01	3.21328e-01	5.63529e-01	2.29528e+00	3.98262e-01
2.40000e+00	5.57621e-01	3.11142e-01	5.57981e-01	2.40310e+00	4.09889e-01
2.45000e+00	5.45331e-01	3.01414e-01	5.52718e-01	2.51683e+00	4.21123e-01
2.50000e+00	5.33333e-01	2.92119e-01	5.47723e-01	2.63672e+00	4.31977e-01
2.55000e+00	5.21626e-01	2.83230e-01	5.42976e-01	2.76301e+00	4.42461e-01
2.60000e+00	5.10204e-01	2.74725e-01	5.38462e-01	2.89598e+00	4.52588e-01
2.65000e+00	4.99064e-01	2.66583e-01	5.34166e-01	3.03588e+00	4.62370e-01
2.70000e+00	4.88202e-01	2.58783e-01	5.30074e-01	3.18301e+00	4.71819e-01
2.75000e+00	4.77612e-01	2.51307e-01	5.26174e-01	3.33766e+00	4.80947e-01
2.80000e+00	4.67290e-01	2.44138e-01	5.22455e-01	3.50012e+00	4.89765e-01
2.85000e+00	4.57230e-01	2.37259e-01	5.18905e-01	3.67072e+00	4.98284e-01
2.90000e+00	4.47427e-01	2.30655e-01	5.15514e-01	3.84977e+00	5.06516e-01
2.95000e+00	4.37876e-01	2.24313e-01	5.12274e-01	4.03760e+00	5.14471e-01
3.00000e+00	4.28571e-01	2.18218e-01	5.09175e-01	4.23457e+00	5.22159e-01
3.05000e+00	4.19507e-01	2.12359e-01	5.06210e-01	4.44102e+00	5.29591e-01
3.10000e+00	4.10678e-01	2.06723e-01	5.03371e-01	4.65731e+00	5.36777e-01
3.15000e+00	4.02077e-01	2.01300e-01	5.00650e-01	4.88383e+00	5.43724e-01
3.20000e+00	3.93701e-01	1.96080e-01	4.98043e-01	5.12096e+00	5.50444e-01
3.25000e+00	3.85542e-01	1.91052e-01	4.95542e-01	5.36909e+00	5.56944e-01
3.30000e+00	3.77596e-01	1.86209e-01	4.93142e-01	5.62865e+00	5.63232e-01
3.35000e+00	3.69857e-01	1.81540e-01	4.90838e-01	5.90004e+00	5.69317e-01
3.40000e+00	3.62319e-01	1.77038e-01	4.88625e-01	6.18370e+00	5.75207e-01
3.45000e+00	3.54977e-01	1.72696e-01	4.86498e-01	6.48007e+00	5.80908e-01
3.50000e+00	3.47826e-01	1.68505e-01	4.84452e-01	6.78962e+00	5.86429e-01

Table A.4: One-dimensional flow with friction ($\gamma = 1.4$) *continued*

M	T/T^*	p/p^*	ρ/ρ^*	p_o/p_o^*	$4fL^*/D$
3.55000e+00	3.40861e-01	1.64460e-01	4.82484e-01	7.11281e+00	5.91776e-01
3.60000e+00	3.34076e-01	1.60554e-01	4.80590e-01	7.45011e+00	5.96955e-01
3.65000e+00	3.27466e-01	1.56780e-01	4.78767e-01	7.80203e+00	6.01973e-01
3.70000e+00	3.21027e-01	1.53133e-01	4.77010e-01	8.16907e+00	6.06836e-01
3.75000e+00	3.14754e-01	1.49608e-01	4.75317e-01	8.55174e+00	6.11549e-01
3.80000e+00	3.08642e-01	1.46199e-01	4.73684e-01	8.95059e+00	6.16119e-01
3.85000e+00	3.02686e-01	1.42901e-01	4.72110e-01	9.36614e+00	6.20551e-01
3.90000e+00	2.96883e-01	1.39710e-01	4.70590e-01	9.79897e+00	6.24849e-01
3.95000e+00	2.91227e-01	1.36621e-01	4.69124e-01	1.02496e+01	6.29019e-01
4.00000e+00	2.85714e-01	1.33631e-01	4.67707e-01	1.07188e+01	6.33065e-01
4.05000e+00	2.80341e-01	1.30734e-01	4.66339e-01	1.12069e+01	6.36992e-01
4.10000e+00	2.75103e-01	1.27928e-01	4.65016e-01	1.17147e+01	6.40804e-01
4.15000e+00	2.69997e-01	1.25208e-01	4.63738e-01	1.22427e+01	6.44506e-01
4.20000e+00	2.65018e-01	1.22571e-01	4.62502e-01	1.27916e+01	6.48101e-01
4.25000e+00	2.60163e-01	1.20014e-01	4.61306e-01	1.33622e+01	6.51593e-01
4.30000e+00	2.55428e-01	1.17535e-01	4.60148e-01	1.39549e+01	6.54986e-01
4.35000e+00	2.50810e-01	1.15129e-01	4.59027e-01	1.45706e+01	6.58284e-01
4.40000e+00	2.46305e-01	1.12794e-01	4.57942e-01	1.52099e+01	6.61489e-01
4.45000e+00	2.41911e-01	1.10527e-01	4.56890e-01	1.58735e+01	6.64605e-01
4.50000e+00	2.37624e-01	1.08326e-01	4.55872e-01	1.65622e+01	6.67635e-01
4.55000e+00	2.33440e-01	1.06188e-01	4.54884e-01	1.72767e+01	6.70582e-01
4.60000e+00	2.29358e-01	1.04112e-01	4.53926e-01	1.80178e+01	6.73448e-01
4.65000e+00	2.25373e-01	1.02094e-01	4.52998e-01	1.87862e+01	6.76238e-01
4.70000e+00	2.21484e-01	1.00132e-01	4.52096e-01	1.95828e+01	6.78952e-01
4.75000e+00	2.17687e-01	9.82252e-02	4.51222e-01	2.04084e+01	6.81595e-01
4.80000e+00	2.13980e-01	9.63708e-02	4.50373e-01	2.12637e+01	6.84167e-01
4.85000e+00	2.10360e-01	9.45671e-02	4.49548e-01	2.21497e+01	6.86672e-01
4.90000e+00	2.06825e-01	9.28123e-02	4.48748e-01	2.30671e+01	6.89112e-01
4.95000e+00	2.03373e-01	9.11047e-02	4.47970e-01	2.40169e+01	6.91488e-01
5.00000e+00	2.00000e-01	8.94427e-02	4.47214e-01	2.50000e+01	6.93804e-01
5.10000e+00	1.93486e-01	8.62491e-02	4.45764e-01	2.70696e+01	6.98260e-01
5.20000e+00	1.87266e-01	8.32197e-02	4.44393e-01	2.92833e+01	7.02494e-01
5.30000e+00	1.81324e-01	8.03436e-02	4.43095e-01	3.16491e+01	7.06522e-01
5.40000e+00	1.75644e-01	7.76109e-02	4.41865e-01	3.41748e+01	7.10354e-01
5.50000e+00	1.70213e-01	7.50125e-02	4.40698e-01	3.68690e+01	7.14004e-01
5.60000e+00	1.65017e-01	7.25397e-02	4.39590e-01	3.97402e+01	7.17483e-01
5.70000e+00	1.60043e-01	7.01848e-02	4.38538e-01	4.27974e+01	7.20800e-01
5.80000e+00	1.55280e-01	6.79406e-02	4.37537e-01	4.60500e+01	7.23965e-01
5.90000e+00	1.50716e-01	6.58002e-02	4.36585e-01	4.95075e+01	7.26988e-01
6.00000e+00	1.46341e-01	6.37577e-02	4.35677e-01	5.31798e+01	7.29875e-01
6.10000e+00	1.42146e-01	6.18071e-02	4.34813e-01	5.70772e+01	7.32636e-01
6.20000e+00	1.38122e-01	5.99431e-02	4.33988e-01	6.12102e+01	7.35277e-01
6.30000e+00	1.34258e-01	5.81607e-02	4.33201e-01	6.55899e+01	7.37804e-01
6.40000e+00	1.30548e-01	5.64554e-02	4.32449e-01	7.02274e+01	7.40225e-01
6.50000e+00	1.26984e-01	5.48228e-02	4.31730e-01	7.51343e+01	7.42544e-01
6.60000e+00	1.23558e-01	5.32589e-02	4.31042e-01	8.03227e+01	7.44768e-01
6.70000e+00	1.20265e-01	5.17600e-02	4.30384e-01	8.58049e+01	7.46901e-01
6.80000e+00	1.17096e-01	5.03225e-02	4.29754e-01	9.15935e+01	7.48948e-01
6.90000e+00	1.14047e-01	4.89432e-02	4.29150e-01	9.77017e+01	7.50914e-01
7.00000e+00	1.11111e-01	4.76190e-02	4.28571e-01	1.04143e+02	7.52802e-01
7.10000e+00	1.08284e-01	4.63472e-02	4.28016e-01	1.10931e+02	7.54617e-01
7.20000e+00	1.05559e-01	4.51249e-02	4.27483e-01	1.18080e+02	7.56363e-01
7.30000e+00	1.02934e-01	4.39497e-02	4.26971e-01	1.25605e+02	7.58042e-01
7.40000e+00	1.00402e-01	4.28192e-02	4.26479e-01	1.33520e+02	7.59658e-01
7.50000e+00	9.79592e-02	4.17312e-02	4.26006e-01	1.41841e+02	7.61214e-01
7.60000e+00	9.56023e-02	4.06837e-02	4.25552e-01	1.50585e+02	7.62713e-01
7.70000e+00	9.33271e-02	3.96747e-02	4.25114e-01	1.59767e+02	7.64158e-01
7.80000e+00	9.11300e-02	3.87022e-02	4.24693e-01	1.69403e+02	7.65551e-01
7.90000e+00	8.90076e-02	3.77647e-02	4.24287e-01	1.79511e+02	7.66895e-01
8.00000e+00	8.69565e-02	3.68605e-02	4.23896e-01	1.90109e+02	7.68192e-01
9.00000e+00	6.97674e-02	2.93484e-02	4.20660e-01	3.27189e+02	7.78985e-01
1.00000e+01	5.71429e-02	2.39046e-02	4.18330e-01	5.35938e+02	7.86831e-01
1.10000e+01	4.76190e-02	1.98380e-02	4.16598e-01	8.41909e+02	7.92704e-01
1.20000e+01	4.02685e-02	1.67225e-02	4.15275e-01	1.27621e+03	7.97212e-01
1.30000e+01	3.44828e-02	1.42843e-02	4.14243e-01	1.87608e+03	8.00743e-01

Table A.4: One-dimensional flow with friction ($\gamma = 1.4$) *continued*

M	T/T^*	p/p^*	ρ/ρ^*	p_o/p_o^*	$4fL^*/D$
1.40000e+01	2.98507e-02	1.23410e-02	4.13423e-01	2.68538e+03	8.03561e-01
1.50000e+01	2.60870e-02	1.07676e-02	4.12759e-01	3.75525e+03	8.05844e-01
1.60000e+01	2.29885e-02	9.47623e-03	4.12216e-01	5.14455e+03	8.07719e-01
1.70000e+01	2.04082e-02	8.40336e-03	4.11765e-01	6.92053e+03	8.09277e-01
1.80000e+01	1.82371e-02	7.50249e-03	4.11386e-01	9.15928e+03	8.10586e-01
1.90000e+01	1.63934e-02	6.73878e-03	4.11066e-01	1.19464e+04	8.11696e-01
2.00000e+01	1.48148e-02	6.08581e-03	4.10792e-01	1.53773e+04	8.12646e-01
2.20000e+01	1.22699e-02	5.03499e-03	4.10352e-01	2.46065e+04	8.14175e-01
2.40000e+01	1.03270e-02	4.23425e-03	4.10016e-01	3.78324e+04	8.15340e-01
2.60000e+01	8.81057e-03	3.61018e-03	4.09755e-01	5.62360e+04	8.16248e-01
2.80000e+01	7.60456e-03	3.11443e-03	4.09548e-01	8.12118e+04	8.16970e-01
3.00000e+01	6.62983e-03	2.71413e-03	4.09381e-01	1.14385e+05	8.17553e-01
3.20000e+01	5.83090e-03	2.38626e-03	4.09244e-01	1.57631e+05	8.18031e-01
3.40000e+01	5.16796e-03	2.11437e-03	4.09130e-01	2.13090e+05	8.18427e-01
3.60000e+01	4.61184e-03	1.88640e-03	4.09035e-01	2.83189e+05	8.18759e-01
3.80000e+01	4.14079e-03	1.69339e-03	4.08954e-01	3.70653e+05	8.19040e-01
4.00000e+01	3.73832e-03	1.52854e-03	4.08886e-01	4.78532e+05	8.19280e-01
4.20000e+01	3.39175e-03	1.38664e-03	4.08826e-01	6.10212e+05	8.19487e-01
4.40000e+01	3.09119e-03	1.26360e-03	4.08775e-01	7.69432e+05	8.19666e-01
4.60000e+01	2.82885e-03	1.15624e-03	4.08730e-01	9.60308e+05	8.19823e-01
4.80000e+01	2.59853e-03	1.06199e-03	4.08691e-01	1.18734e+06	8.19960e-01
5.00000e+01	2.39521e-03	9.78818e-04	4.08656e-01	1.45546e+06	8.20081e-01

Table A.5: Prandtl-Meyer function and Mach angle ($\gamma = 1.4$)

M	ν	μ
1.00000e+00	0.00000e+00	9.00000e+01
1.02000e+00	1.25688e-01	7.86351e+01
1.04000e+00	3.50983e-01	7.40576e+01
1.06000e+00	6.36687e-01	7.06300e+01
1.08000e+00	9.68040e-01	6.78084e+01
1.10000e+00	1.33620e+00	6.53800e+01
1.12000e+00	1.73504e+00	6.32345e+01
1.14000e+00	2.15996e+00	6.13056e+01
1.16000e+00	2.60735e+00	5.95497e+01
1.18000e+00	3.07426e+00	5.79362e+01
1.20000e+00	3.55823e+00	5.64427e+01
1.22000e+00	4.05720e+00	5.50520e+01
1.24000e+00	4.56936e+00	5.37507e+01
1.26000e+00	5.09315e+00	5.25280e+01
1.28000e+00	5.62720e+00	5.13752e+01
1.30000e+00	6.17029e+00	5.02849e+01
1.32000e+00	6.72133e+00	4.92509e+01
1.34000e+00	7.27937e+00	4.82682e+01
1.36000e+00	7.84351e+00	4.73321e+01
1.38000e+00	8.41297e+00	4.64387e+01
1.40000e+00	8.98702e+00	4.55847e+01
1.42000e+00	9.56502e+00	4.47670e+01
1.44000e+00	1.01464e+01	4.39830e+01
1.46000e+00	1.07305e+01	4.32302e+01
1.48000e+00	1.13169e+01	4.25066e+01
1.50000e+00	1.19052e+01	4.18103e+01
1.52000e+00	1.24949e+01	4.11395e+01
1.54000e+00	1.30856e+01	4.04927e+01
1.56000e+00	1.36770e+01	3.98683e+01
1.58000e+00	1.42686e+01	3.92652e+01
1.60000e+00	1.48604e+01	3.86822e+01
1.62000e+00	1.54518e+01	3.81181e+01
1.64000e+00	1.60427e+01	3.75719e+01
1.66000e+00	1.66328e+01	3.70427e+01
1.68000e+00	1.72220e+01	3.65296e+01
1.70000e+00	1.78099e+01	3.60319e+01
1.72000e+00	1.83964e+01	3.55487e+01
1.74000e+00	1.89814e+01	3.50795e+01
1.76000e+00	1.95646e+01	3.46235e+01
1.78000e+00	2.01458e+01	3.41802e+01
1.80000e+00	2.07251e+01	3.37490e+01
1.82000e+00	2.13021e+01	3.33293e+01
1.84000e+00	2.18768e+01	3.29207e+01
1.86000e+00	2.24492e+01	3.25227e+01
1.88000e+00	2.30190e+01	3.21349e+01
1.90000e+00	2.35861e+01	3.17569e+01
1.92000e+00	2.41506e+01	3.13882e+01
1.94000e+00	2.47123e+01	3.10285e+01
1.96000e+00	2.52711e+01	3.06774e+01
1.98000e+00	2.58269e+01	3.03347e+01
2.00000e+00	2.63798e+01	3.00000e+01
2.05000e+00	2.77484e+01	2.91964e+01
2.10000e+00	2.90971e+01	2.84369e+01
2.15000e+00	3.04253e+01	2.77177e+01
2.20000e+00	3.17325e+01	2.70357e+01
2.25000e+00	3.30184e+01	2.63878e+01
2.30000e+00	3.42828e+01	2.57715e+01
2.35000e+00	3.55255e+01	2.51843e+01
2.40000e+00	3.67465e+01	2.46243e+01
2.45000e+00	3.79459e+01	2.40895e+01
2.50000e+00	3.91236e+01	2.35782e+01
2.55000e+00	4.02798e+01	2.30888e+01
2.60000e+00	4.14147e+01	2.26199e+01
2.65000e+00	4.25285e+01	2.21702e+01
2.70000e+00	4.36215e+01	2.17385e+01

Table A.5: Prandtl-Meyer function and Mach angle ($\gamma = 1.4$) *continued*

M	ν	μ
2.75000e+00	4.46938e+01	2.13237e+01
2.80000e+00	4.57459e+01	2.09248e+01
2.85000e+00	4.67779e+01	2.05410e+01
2.90000e+00	4.77903e+01	2.01713e+01
2.95000e+00	4.87833e+01	1.98149e+01
3.00000e+00	4.97573e+01	1.94712e+01
3.05000e+00	5.07127e+01	1.91395e+01
3.10000e+00	5.16497e+01	1.88191e+01
3.15000e+00	5.25688e+01	1.85094e+01
3.20000e+00	5.34703e+01	1.82100e+01
3.25000e+00	5.43546e+01	1.79202e+01
3.30000e+00	5.52220e+01	1.76397e+01
3.35000e+00	5.60728e+01	1.73680e+01
3.40000e+00	5.69075e+01	1.71046e+01
3.45000e+00	5.77264e+01	1.68493e+01
3.50000e+00	5.85298e+01	1.66015e+01
3.55000e+00	5.93180e+01	1.63611e+01
3.60000e+00	6.00915e+01	1.61276e+01
3.65000e+00	6.08504e+01	1.59008e+01
3.70000e+00	6.15953e+01	1.56804e+01
3.75000e+00	6.23263e+01	1.54660e+01
3.80000e+00	6.30438e+01	1.52575e+01
3.85000e+00	6.37481e+01	1.50547e+01
3.90000e+00	6.44395e+01	1.48572e+01
3.95000e+00	6.51183e+01	1.46649e+01
4.00000e+00	6.57848e+01	1.44775e+01
4.05000e+00	6.64393e+01	1.42949e+01
4.10000e+00	6.70820e+01	1.41170e+01
4.15000e+00	6.77132e+01	1.39434e+01
4.20000e+00	6.83332e+01	1.37741e+01
4.25000e+00	6.89423e+01	1.36090e+01
4.30000e+00	6.95406e+01	1.34477e+01
4.35000e+00	7.01285e+01	1.32903e+01
4.40000e+00	7.07062e+01	1.31366e+01
4.45000e+00	7.12738e+01	1.29864e+01
4.50000e+00	7.18317e+01	1.28396e+01
4.55000e+00	7.23801e+01	1.26961e+01
4.60000e+00	7.29192e+01	1.25559e+01
4.65000e+00	7.34491e+01	1.24187e+01
4.70000e+00	7.39701e+01	1.22845e+01
4.75000e+00	7.44824e+01	1.21532e+01
4.80000e+00	7.49863e+01	1.20247e+01
4.85000e+00	7.54818e+01	1.18989e+01
4.90000e+00	7.59691e+01	1.17757e+01
4.95000e+00	7.64486e+01	1.16551e+01
5.00000e+00	7.69202e+01	1.15370e+01
5.10000e+00	7.78409e+01	1.13077e+01
5.20000e+00	7.87324e+01	1.10875e+01
5.30000e+00	7.95962e+01	1.08757e+01
5.40000e+00	8.04332e+01	1.06719e+01
5.50000e+00	8.12448e+01	1.04757e+01
5.60000e+00	8.20319e+01	1.02866e+01
5.70000e+00	8.27956e+01	1.01042e+01
5.80000e+00	8.35368e+01	9.92819e+00
5.90000e+00	8.42565e+01	9.75826e+00
6.00000e+00	8.49555e+01	9.59407e+00
6.10000e+00	8.56347e+01	9.43534e+00
6.20000e+00	8.62948e+01	9.28180e+00
6.30000e+00	8.69366e+01	9.13320e+00
6.40000e+00	8.75608e+01	8.98930e+00
6.50000e+00	8.81682e+01	8.84988e+00
6.60000e+00	8.87592e+01	8.71474e+00
6.70000e+00	8.93346e+01	8.58368e+00
6.80000e+00	8.98950e+01	8.45652e+00
6.90000e+00	9.04408e+01	8.33308e+00

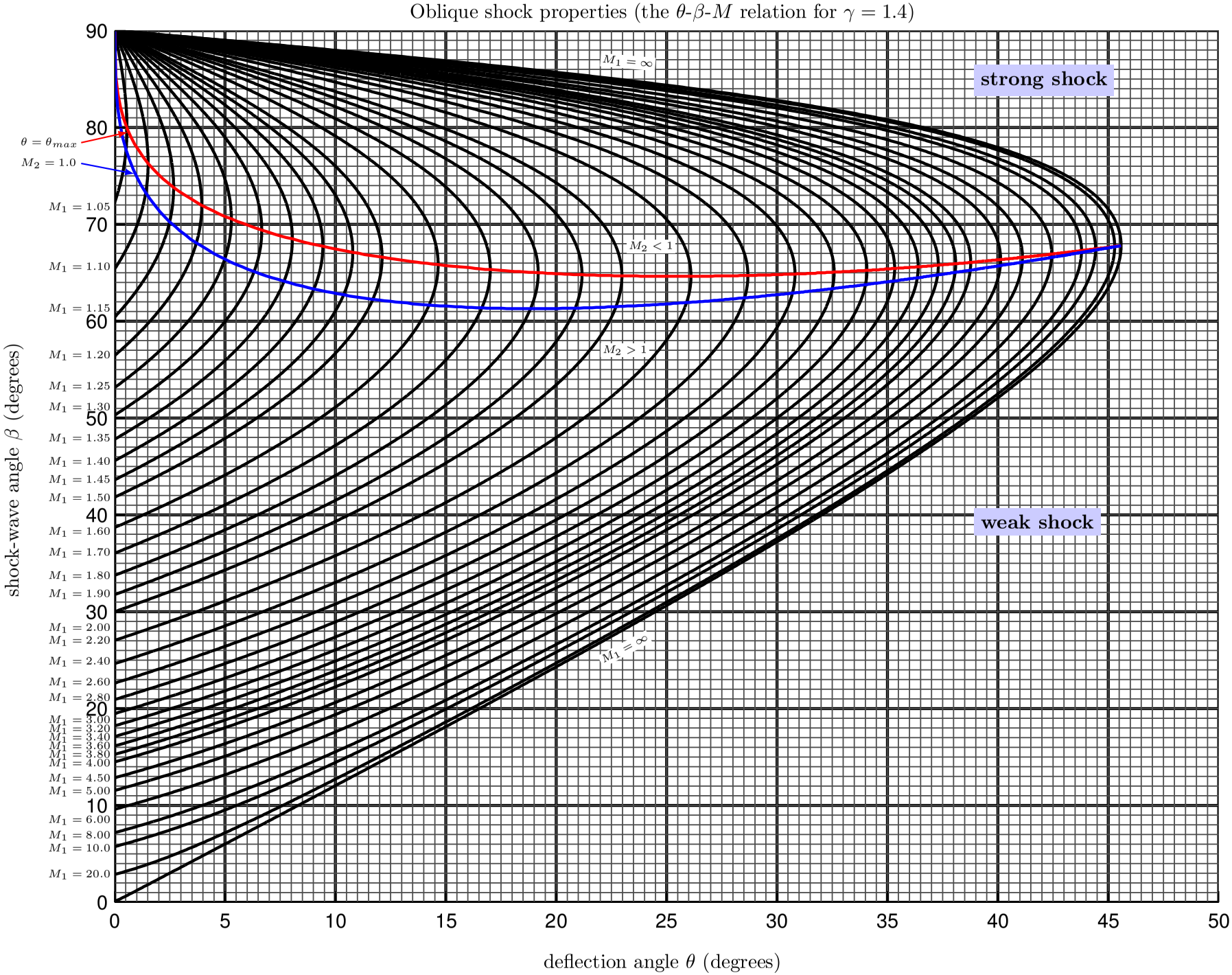
Table A.5: Prandtl-Meyer function and Mach angle ($\gamma = 1.4$) *continued*

M	ν	μ
7.00000e+00	9.09727e+01	8.21321e+00
7.10000e+00	9.14912e+01	8.09675e+00
7.20000e+00	9.19966e+01	7.98356e+00
7.30000e+00	9.24896e+01	7.87349e+00
7.40000e+00	9.29704e+01	7.76643e+00
7.50000e+00	9.34397e+01	7.66226e+00
7.60000e+00	9.38977e+01	7.56084e+00
7.70000e+00	9.43448e+01	7.46209e+00
7.80000e+00	9.47814e+01	7.36589e+00
7.90000e+00	9.52080e+01	7.27214e+00
8.00000e+00	9.56247e+01	7.18076e+00
9.00000e+00	9.93181e+01	6.37937e+00
1.00000e+01	1.02316e+02	5.73917e+00
1.10000e+01	1.04796e+02	5.21591e+00
1.20000e+01	1.06879e+02	4.78019e+00
1.30000e+01	1.08652e+02	4.41173e+00
1.40000e+01	1.10180e+02	4.09604e+00
1.50000e+01	1.11509e+02	3.82255e+00
1.60000e+01	1.12676e+02	3.58332e+00
1.70000e+01	1.13708e+02	3.37229e+00
1.80000e+01	1.14628e+02	3.18474e+00
1.90000e+01	1.15452e+02	3.01696e+00
2.00000e+01	1.16195e+02	2.86598e+00
2.20000e+01	1.17481e+02	2.60525e+00
2.40000e+01	1.18555e+02	2.38802e+00
2.60000e+01	1.19465e+02	2.20423e+00
2.80000e+01	1.20247e+02	2.04671e+00
3.00000e+01	1.20924e+02	1.91021e+00
3.20000e+01	1.21518e+02	1.79078e+00
3.40000e+01	1.22042e+02	1.68541e+00
3.60000e+01	1.22508e+02	1.59175e+00
3.80000e+01	1.22925e+02	1.50796e+00
4.00000e+01	1.23300e+02	1.43254e+00
4.20000e+01	1.23640e+02	1.36431e+00
4.40000e+01	1.23949e+02	1.30229e+00
4.60000e+01	1.24232e+02	1.24566e+00
4.80000e+01	1.24491e+02	1.19375e+00
5.00000e+01	1.24729e+02	1.14599e+00

Appendix B

Oblique Shock Properties

The figure on next page gives a graphical representation of the θ-β-M relation (Eqn. 4.17) for $\gamma = 1.4$. The figure shows iso-M_1 lines in the $\theta\beta$-plane. The $M_2 = 1.0$-line is obtained using Eqns. 4.7, 4.10, and 4.12.


Oblique shock properties (the θ-β-M relation for γ = 1.4)
shock-wave angle β (degrees)
deflection angle θ (degrees)
strong shock
weak shock
M1 = ∞
M2 < 1
M2 > 1
θ = θmax
M2 = 1.0
M1 = 1.05
M1 = 1.10
M1 = 1.15
M1 = 1.20
M1 = 1.25
M1 = 1.30
M1 = 1.35
M1 = 1.40
M1 = 1.45
M1 = 1.50
M1 = 1.60
M1 = 1.70
M1 = 1.80
M1 = 1.90
M1 = 2.00
M1 = 2.20
M1 = 2.40
M1 = 2.60
M1 = 2.80
M1 = 3.00
M1 = 3.20
M1 = 3.40
M1 = 3.60
M1 = 3.80
M1 = 4.00
M1 = 4.50
M1 = 5.00
M1 = 6.00
M1 = 8.00
M1 = 10.0
M1 = 20.0
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
35
40
45
50