

**VOLUME I
PERFORMANCE FLIGHT TESTING**

**ANNEX 6B
NACA 1135**

EQUATIONS, TABLES, and CHARTS for COMPRESSIBLE FLOW

FOR

SUPERSONIC AERODYNAMICS

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**Current as of
JANUARY 1991**

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REPORT 1135

EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

By AMES RESEARCH STAFF

**Ames Aeronautical Laboratory
Moffett Field, Calif.**

National Advisory Committee for Aeronautics

Headquarters, 1724 F Street NW, Washington 25, D. C.

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REPORT 1135

EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW ¹

By AMES RESEARCH STAFF

SUMMARY

This report, which is a revision and extension of NACA TN 1428, presents a compilation of equations, tables, and charts useful in the analysis of high-speed flow of a compressible fluid. The equations provide relations for continuous one-dimensional flow, normal and oblique shock waves, and Prandtl-Meyer expansions for both perfect and imperfect gases. The tables present useful dimensionless ratios for continuous one-dimensional flow and for normal shock waves as functions of Mach number for air considered as a perfect gas. One series of charts presents the characteristics of the flow of air (considered a perfect gas) for oblique shock waves and for cones in a supersonic air stream. A second series shows the effects of caloric imperfections on continuous one-dimensional flow and on the flow through normal and oblique shock waves.

INTRODUCTION

The practical analysis of compressible flow involves frequent application of a few basic results. A convenient compilation of equations, tables, and charts embodying these results is therefore of great assistance in both research and design. The present report makes one of the first such compilations (ref. 1) more readily available in a revised and extended form. The revisions include a complete rewriting of the lists of equations, as well as the correction of certain typographical errors which appeared in the earlier work. The extensions are primarily in the directions dictated by increasing flight speeds, that is, to higher Mach numbers and to higher temperatures with the accompanying gaseous imperfections.

Compilations similar to those of reference 1 have been given in other publications, as, for example, references 2 through 6. These references have been utilized in extending the tables and charts to higher values of the Mach number. The extension to imperfect gases is based on the relations presented in references 7 and 8.

SYMBOLS AND NOTATION

PRIMARY SYMBOLS

speed of sound
cross-sectional area of stream tube or channel

C_N	normal-force coefficient for cones, $\frac{\text{normal force}}{q_\infty S_b}$
c_p	specific heat at constant pressure
c_v	specific heat at constant volume
h	enthalpy per unit mass, $u + pv$
l	characteristic reference length
M	Mach number, $\frac{V}{a}$
p	pressure ²
q	dynamic pressure, $\rho V^2/2$
q	heat added per unit mass
R	gas constant
R	Reynolds number, $\frac{\rho V l}{\mu}$
S_b	base area of cone
s	entropy per unit mass
T	absolute temperature ²
u	internal energy per unit mass
v	specific volume, $\frac{1}{\rho}$
u, v	velocity components parallel and perpendicular respectively, to free-stream flow direction
$\tilde{u}, \tilde{v}$	velocity components normal and tangential, respectively, to oblique shock wave
V	speed of flow
V_m	maximum speed obtainable by expanding to zero absolute temperature
w	external work performed per unit mass
α	angle of attack
β	$\sqrt{M^2 - 1}$
γ	ratio of specific heats, $\frac{c_p}{c_v}$
δ	angle of flow deflection across an oblique shock wave
θ	shock-wave angle measured from upstream flow direction
Θ	molecular vibrational-energy constant
μ	Mach angle, $\sin^{-1} \frac{1}{M}$
μ	absolute viscosity
ν	Prandtl-Meyer angle (angle through which a supersonic stream is turned to expand from $M=1$ to $M>1$)

¹Supersedes NACA TN 1428, "Notes and Tables for Use in the Analysis of Supersonic Flow" by the Staff of the Ames 1- by 3-foot Supersonic Wind-Tunnel Section, 1947.
² When used without subscripts, p , ρ , and T denote static pressure, static density, and static temperature, respectively.

ξ	pressure ratio across a shock wave, $\frac{p_2}{p_1}$
ρ	mass density ²
σ	semivertex angle of cone

SUBSCRIPTS

∞	free-stream conditions
1	conditions just upstream of a shock wave
2	conditions just downstream of a shock wave
t	total conditions (i. e., conditions that would exist if the gas were brought to rest isentropically)
*	critical conditions (i. e., conditions where the local speed is equal to the local speed of sound)
c	conditions on the surface of a cone
r	reference (or datum) values
perf	quantity evaluated for a gas which is both thermally and calorically perfect
therm perf	quantity evaluated for a gas which is thermally perfect but calorically imperfect
$()_p$	derivative evaluated at constant pressure
$()_s$	derivative evaluated at constant entropy
$()_T$	derivative evaluated at constant temperature
$()_v$	derivative evaluated at constant specific volume
$()_{rev}$	quantity evaluated over a reversible path

NOTATION

The notation in brackets [] after many of the equations signifies that the equation is valid only within certain limitations. For example:

[perf]	means that the equation is restricted to a gas which is both thermally and calorically perfect. (By "thermally perfect" it is meant that the gas obeys the thermal equation of state $p = \rho RT$. By "calorically perfect" it is meant that the specific heats c_p and c_v are constant.)
[therm perf]	means that the only restriction on the gas is that it must be thermally perfect. Equations so marked may be used for calorically imperfect gases. (They are, of course, also valid for completely perfect gases.)
[isen]	means that the flow process must take place isentropically. Equations so marked may not be applied to the flow across a shock wave.
[adiab]	means that the only restriction on the flow process is that it must take place adiabatically—that is, without heat transfer. (Such a flow process may or may not be isentropic depending on whether it is or is not reversible.) Equations so marked may be applied to the flow across a shock wave.

An equation without notation has no restrictions beyond those basic to the study of thermodynamics and/or inviscid compressible flow.

FUNDAMENTAL RELATIONS

THERMODYNAMICS

THERMAL EQUATIONS OF STATE

A thermal equation of state is an equation of the form

$$p = p(v, T) \quad (1)$$

Several of the more commonly used thermal equations of state are the following:

Equation for thermally perfect gas

$$p = \frac{RT}{v} = \rho RT \text{ [therm perf]} \quad (2)$$

or

$$\frac{dp}{p} - \frac{dv}{v} - \frac{dT}{T} = 0 \text{ [therm perf]} \quad (3)$$

Equations for thermally imperfect gas

Van der Waals' equation (ref. 9)

$$p = \frac{RT}{v-b} - \frac{a}{v^2} \quad (4)$$

where a is the intermolecular-force constant and b the molecular-size constant (see ref. 9, pp. 390 et seq. for numerical values).

Berthelot's equation (ref. 7)

$$p = \frac{RT}{v-b} - \frac{c}{v^2 T} \quad (5)$$

where b is the molecular-size constant and c is the intermolecular-force constant (see ref. 7 for numerical values).

Beattie-Bridgeman equation (ref. 10)

$$p = \frac{RT}{v^2} \left(1 - \frac{c}{vT^3} \right) \left[v + B_0 \left(1 - \frac{b}{v} \right) \right] - \frac{A_0}{v^2} \left(1 - \frac{a}{v} \right) \quad (6)$$

where a , A_0 , b , B_0 , and c are constants for a given gas (see ref. 10, p. 270 for numerical values).

CALORIC EQUATION OF STATE

A caloric equation of state is an equation of the form

$$u = u(v, T) \quad (7)$$

It can be shown that

$$du = c_v dT + \left[T \left(\frac{\partial p}{\partial T} \right)_v - p \right] dv \quad (8)$$

$$du = c_v dT \text{ [therm perf]} \quad (8)$$

If the gas is calorically perfect—that is, the specific heats are constant—equation (8b) can be integrated to obtain

$$u = c_v T + u_r \text{ [perf]} \quad (9)$$

² When used without subscripts, p , ρ , and T denote static pressure, static density, and static temperature, respectively.

ENERGY RELATIONS

The law of conservation of energy gives

$$\left. \begin{aligned} dq &= du + dw \quad (\text{first law of thermodynamics}) \\ &= du + p \, dv = dh - v \, dp \end{aligned} \right\} \quad (10a)$$

$$\left. \begin{aligned} dq &= c_p \, dT + p \, dv \\ &= c_p \, dT - v \, dp \end{aligned} \right\} \quad [\text{therm perf}] \quad (10b)$$

SPECIFIC HEATS

The specific heats at constant pressure and constant volume are defined by

$$c_p \equiv \left(\frac{\partial q}{\partial T} \right)_p = \left(\frac{\partial h}{\partial T} \right)_p \quad (11)$$

$$c_v \equiv \left(\frac{\partial q}{\partial T} \right)_v = \left(\frac{\partial u}{\partial T} \right)_v \quad (12)$$

It can be shown that

$$c_p - c_v = \left[\left(\frac{\partial u}{\partial v} \right)_T + p \right] \left(\frac{\partial v}{\partial T} \right)_p = -T \frac{\left(\frac{\partial p}{\partial T} \right)_v^2}{\left(\frac{\partial p}{\partial v} \right)_T} \quad (13a)$$

$$c_p - c_v = R \quad [\text{therm perf}] \quad (13b)$$

The ratio of specific heats is defined as

$$\gamma \equiv \frac{c_p}{c_v} \quad (14)$$

According to the kinetic theory of gases, for many gases over a moderate range of temperature,

$$\gamma = \frac{n+2}{n} \quad (15)$$

where n is the number of effective degrees of freedom of the gas molecule. Useful relations for thermally perfect gases are

$$c_p = \frac{dh}{dT} = c_v + R = \frac{\gamma R}{\gamma - 1} \quad [\text{therm perf}] \quad (16)$$

$$c_v = \frac{du}{dT} = c_p - R = \frac{R}{\gamma - 1} \quad [\text{therm perf}] \quad (17)$$

ENTHALPY

The enthalpy of a gas is defined by

$$h \equiv u + pv \quad (18)$$

It follows that

$$\begin{aligned} dh &= du + p \, dv + v \, dp = dq + v \, dp \\ &= \left[c_v + v \left(\frac{\partial p}{\partial T} \right)_v \right] dT + \left[v \left(\frac{\partial p}{\partial v} \right)_T + T \left(\frac{\partial p}{\partial T} \right)_v \right] dv \end{aligned} \quad (19a)$$

$$dh = (c_v + R) dT = c_p dT \quad [\text{therm perf}] \quad (19b)$$

$$h = (c_v + R) T - u_v = c_p T + u_v \quad [\text{perf}] \quad (20)$$

ENTROPY

The entropy is defined by

$$ds \equiv \left(\frac{dq}{T} \right)_{rev} \quad (21)$$

It follows that

$$ds = \left(\frac{du + dw}{T} \right)_{rev} = \left(\frac{du + p \, dv}{T} \right)_{rev} = c_v \frac{dT}{T} + \left(\frac{\partial p}{\partial T} \right)_v dv \quad (22a)$$

$$\left. \begin{aligned} ds &= c_v \frac{dT}{T} + R \frac{dv}{v} \\ &= c_v \frac{dT}{T} - R \frac{dp}{p} \\ &= c_p \frac{dT}{T} - R \frac{dp}{p} \\ &= c_v \frac{dp}{p} - c_p \frac{dp}{p} \end{aligned} \right\} \quad [\text{therm perf}] \quad (22b)$$

$$\left. \begin{aligned} s - s_r &= c_v \ln \frac{T}{T_r} - R \ln \frac{p}{p_r} \\ &= c_p \ln \frac{T}{T_r} - R \ln \frac{p}{p_r} \\ &= c_v \ln \frac{p}{p_r} - c_p \ln \frac{p}{p_r} \end{aligned} \right\} \quad [\text{perf}] \quad (23a)$$

$$\left. \begin{aligned} s - s_r &= c_v \ln \frac{T/T_r}{(\rho/\rho_r)^{\gamma-1}} \\ &= c_p \ln \frac{T/T_r}{(p/p_r)^{(\gamma-1)/\gamma}} \\ &= c_v \ln \frac{p/p_r}{(\rho/\rho_r)^{\gamma}} \end{aligned} \right\} \quad [\text{perf}] \quad (23b)$$

$$\frac{p}{\rho^{\gamma}} = \frac{p_r}{\rho_r^{\gamma}} e^{(s-s_r)/c_v} \quad [\text{perf}] \quad (24)$$

The second law of thermodynamics requires that

$$s - s_r \geq 0 \quad [\text{adiab}] \quad (25)$$

CONTINUOUS ONE-DIMENSIONAL FLOW

BASIC EQUATIONS AND DEFINITIONS

The basic equations for the continuous flow of an inviscid non-heat-conducting gas along a streamline are as follows:
Thermal equation of state

$$\frac{p}{\rho} = RT \quad [\text{therm perf}] \quad (26)$$

Dynamic equation

$$\frac{1}{\rho} dp + V dV = 0 \quad (27)$$

Energy equation

$$\left. \begin{aligned} du + d\left(\frac{p}{\rho}\right) + VdV &= 0 \\ dh + VdV &= 0 \end{aligned} \right\} \text{[adiab]} \quad (28a)$$

$$\left. \begin{aligned} c_p dT + VdV &= 0 \\ \frac{\gamma}{\gamma-1} d\left(\frac{p}{\rho}\right) + VdV &= 0 \end{aligned} \right\} \text{[adiab, therm perf]} \quad (28b)$$

Additional useful variables are defined as follows:

Speed of sound

$$a \equiv \sqrt{\left(\frac{\partial p}{\partial \rho}\right)_t} = \sqrt{\gamma \left(\frac{\partial p}{\partial \rho}\right)_t} \quad (29a)$$

$$= \sqrt{\gamma \frac{p}{\rho}} = \sqrt{\gamma RT} \quad \text{[therm perf]} \quad (29b)$$

$$\begin{aligned} &\cong 49.0 \sqrt{T} \text{ ft/sec for air} \\ &\text{if } T \text{ is in degrees Rankine} \\ &(\text{=degrees Fahrenheit} + 459.6) \end{aligned} \quad (29c)$$

Mach number

$$M \equiv \frac{V}{a} \quad (30)$$

Dynamic pressure

$$q \equiv \frac{1}{2} \rho V^2 \quad (31a)$$

$$= \frac{\gamma}{2} p M^2 \quad \text{[therm perf]} \quad (31b)$$

INTEGRATED FORMS OF ENERGY EQUATION

The energy equation (28) can be integrated at once to obtain

$$h + \frac{V^2}{2} = \text{constant} = h_t \quad \text{[adiab]} \quad (32a)$$

$$\left. \begin{aligned} c_p T + \frac{V^2}{2} &= c_p T_t \\ \frac{\gamma}{\gamma-1} \left(\frac{p}{\rho}\right) + \frac{V^2}{2} &= \frac{\gamma}{\gamma-1} \left(\frac{p_t}{\rho_t}\right) \\ \frac{a^2}{\gamma-1} + \frac{V^2}{2} &= \frac{a_t^2}{\gamma-1} \\ \frac{a^2}{\gamma-1} + \frac{V^2}{2} &= \frac{1}{2} \left(\frac{\gamma+1}{\gamma-1}\right) a_*^2 \\ \frac{a^2}{\gamma-1} + \frac{V^2}{2} &= \frac{V_m^2}{2} \end{aligned} \right\} \text{[adiab, perf]} \quad (32b)$$

The three reference speeds a_t , a_* , and V_m are related by

$$\left. \begin{aligned} \left(\frac{a_t}{a_*}\right)^2 &= \frac{\gamma+1}{2} \\ \left(\frac{V_m}{a_*}\right)^2 &= \frac{\gamma+1}{\gamma-1} \\ \left(\frac{V_m}{a_t}\right)^2 &= \frac{2}{\gamma-1} \end{aligned} \right\} \text{[adiab, perf]} \quad (33)$$

PRESSURE-DENSITY RELATION

From equations (27) and (28b) it follows that

$$\frac{p}{\rho^\gamma} = \text{constant} = \frac{p_t}{\rho_t^\gamma} \quad \text{[isen, perf]} \quad (34)$$

from which

$$\frac{p}{p_t} = \left(\frac{\rho}{\rho_t}\right)^\gamma = \left(\frac{T}{T_t}\right)^{\frac{\gamma}{\gamma-1}} = \left(\frac{a}{a_t}\right)^{\frac{2\gamma}{\gamma-1}} \quad \text{[isen, perf]} \quad (35)$$

BERNOULLI'S EQUATION

Combination of equations (32b) and (35) gives Bernoulli's equation for compressible flow in the form

$$\frac{\gamma}{\gamma-1} \left(\frac{p_t}{\rho_t}\right) \left(\frac{p}{p_t}\right)^{\frac{\gamma-1}{\gamma}} + \frac{V^2}{2} = \frac{\gamma}{\gamma-1} \left(\frac{p_t}{\rho_t}\right) \quad \text{[isen, perf]} \quad (36)$$

RELATIONS BETWEEN LOCAL AND FREE-STREAM CONDITIONS

With the aid of the foregoing equations it can be shown that

$$\frac{T}{T_\infty} = 1 - \frac{\gamma-1}{2} M_\infty^2 \left[\left(\frac{V}{V_\infty}\right)^2 - 1 \right] \quad \text{[adiab, perf]} \quad (37)$$

$$\frac{p}{p_\infty} = \left\{ 1 - \frac{\gamma-1}{2} M_\infty^2 \left[\left(\frac{V}{V_\infty}\right)^2 - 1 \right] \right\}^{\frac{\gamma}{\gamma-1}} \quad \text{[isen, perf]} \quad (38)$$

$$\frac{\rho}{\rho_\infty} = \left\{ 1 - \frac{\gamma-1}{2} M_\infty^2 \left[\left(\frac{V}{V_\infty}\right)^2 - 1 \right] \right\}^{\frac{1}{\gamma-1}} \quad \text{[isen perf]} \quad (39)$$

In small-disturbance theory, where it is assumed $(V - V_\infty) \ll V_\infty$, these equations take on the simplified form

$$\frac{T}{T_\infty} \cong 1 - (\gamma-1) M_\infty^2 \frac{V - V_\infty}{V_\infty} \quad \text{[adiab, perf]} \quad (40)$$

$$\frac{p}{p_\infty} \cong 1 - \gamma M_\infty^2 \frac{V - V_\infty}{V_\infty} \quad \text{[isen, perf]} \quad (41)$$

$$\frac{\rho}{\rho_\infty} \cong 1 - M_\infty^2 \frac{V - V_\infty}{V_\infty} \quad \text{[isen, perf]} \quad (42)$$

USEFUL RATIOS

On the basis of the above results, useful relations can be derived expressing various dimensionless ratios as function of a single parameter. These relations are given below grouped according to which of the various parameter (M , V/a_* , V/a_t , or V/V_m) is used as the independent variable. In each case the second form of the equation applies for $\gamma = \frac{7}{5}$.

Parameter M .—

$$\frac{T}{T_t} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1} = \left(1 + \frac{M^2}{5}\right)^{-1} \quad \text{[adiab, perf]} \quad (43)$$

$$\frac{p}{p_t} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-\frac{\gamma}{\gamma-1}} = \left(1 + \frac{M^2}{5}\right)^{-\frac{7}{2}} \quad \text{[isen, perf]} \quad (44)$$

$$\frac{\rho}{\rho_t} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-\frac{1}{\gamma-1}} = \left(1 + \frac{M^2}{5}\right)^{-\frac{5}{2}} \quad \text{[isen, perf]} \quad (45)$$

$$\frac{a}{a_t} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-\frac{1}{2}} = \left(1 + \frac{M^2}{5}\right)^{-\frac{1}{2}} \quad \text{[adiab, perf]} \quad (46)$$

$$\frac{q}{p} = \frac{\gamma}{2} M^2 = \frac{7}{10} M^2 \quad [\text{therm perf}] \quad (47)$$

$$\frac{q}{p_i} = \frac{\gamma}{2} M^2 \left(1 + \frac{\gamma-1}{2} M^2\right)^{-\frac{\gamma}{\gamma-1}} = \frac{7}{10} M^2 \left(1 + \frac{M^2}{5}\right)^{-\frac{7}{2}} \quad [\text{isen, perf}] \quad (48)$$

$$\left(\frac{V}{a_i}\right)^2 = M^2 \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1} = M^2 \left(1 + \frac{M^2}{5}\right)^{-1} \quad [\text{adiab, perf}] \quad (49)$$

$$\left(\frac{V}{a_*}\right)^2 = \frac{\gamma+1}{2} M^2 \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1} = \frac{6M^2}{5} \left(1 + \frac{M^2}{5}\right)^{-1} \quad [\text{adiab, perf}] \quad (50)$$

$$\left(\frac{V}{V_m}\right)^2 = \frac{\gamma-1}{2} M^2 \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1} = \frac{M^2}{5} \left(1 + \frac{M^2}{5}\right)^{-1} \quad [\text{adiab, perf}] \quad (51)$$

Parameter $\frac{V}{a_*}$ —

$$\frac{T}{T_i} = 1 - \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*}\right)^2 = 1 - \frac{1}{6} \left(\frac{V}{a_*}\right)^2 \quad [\text{adiab, perf}] \quad (52)$$

$$\frac{p}{p_i} = \left[1 - \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*}\right)^2\right]^{\frac{\gamma}{\gamma-1}} = \left[1 - \frac{1}{6} \left(\frac{V}{a_*}\right)^2\right]^{\frac{7}{2}} \quad [\text{isen, perf}] \quad (53)$$

$$\frac{\rho}{\rho_i} = \left[1 - \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*}\right)^2\right]^{\frac{1}{\gamma-1}} = \left[1 - \frac{1}{6} \left(\frac{V}{a_*}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen, perf}] \quad (54)$$

$$\frac{a}{a_i} = \left[1 - \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*}\right)^2\right]^{\frac{1}{2}} = \left[1 - \frac{1}{6} \left(\frac{V}{a_*}\right)^2\right]^{\frac{1}{2}} \quad [\text{adiab, perf}] \quad (55)$$

$$\frac{q}{p} = \frac{\gamma}{\gamma+1} \left(\frac{V}{a_*}\right)^2 \left[1 - \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*}\right)^2\right]^{-1} = \frac{7}{12} \left(\frac{V}{a_*}\right)^2 \left[1 - \frac{1}{6} \left(\frac{V}{a_*}\right)^2\right]^{-1} \quad [\text{adiab, perf}] \quad (56)$$

$$\frac{q}{p_i} = \frac{\gamma}{\gamma+1} \left(\frac{V}{a_*}\right)^2 \left[1 - \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*}\right)^2\right]^{\frac{1}{\gamma-1}} = \frac{7}{12} \left(\frac{V}{a_*}\right)^2 \left[1 - \frac{1}{6} \left(\frac{V}{a_*}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen, perf}] \quad (57)$$

$$M^2 = \frac{2}{\gamma+1} \left(\frac{V}{a_*}\right)^2 \left[1 - \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*}\right)^2\right]^{-1} = \frac{5}{6} \left(\frac{V}{a_*}\right)^2 \left[1 - \frac{1}{6} \left(\frac{V}{a_*}\right)^2\right]^{-1} \quad [\text{adiab, perf}] \quad (58)$$

$$\left(\frac{V}{a_i}\right)^2 = \frac{2}{\gamma+1} \left(\frac{V}{a_*}\right)^2 = \frac{5}{6} \left(\frac{V}{a_*}\right)^2 \quad [\text{adiab, perf}] \quad (59)$$

$$\left(\frac{V}{V_m}\right)^2 = \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*}\right)^2 = \frac{1}{6} \left(\frac{V}{a_*}\right)^2 \quad [\text{adiab, perf}] \quad (60)$$

Parameter $\frac{V}{a_i}$ —

$$\frac{T}{T_i} = 1 - \frac{\gamma-1}{2} \left(\frac{V}{a_i}\right)^2 = 1 - \frac{1}{5} \left(\frac{V}{a_i}\right)^2 \quad [\text{adiab, perf}] \quad (61)$$

$$\frac{p}{p_i} = \left[1 - \frac{\gamma-1}{2} \left(\frac{V}{a_i}\right)^2\right]^{\frac{\gamma}{\gamma-1}} = \left[1 - \frac{1}{5} \left(\frac{V}{a_i}\right)^2\right]^{\frac{7}{2}} \quad [\text{isen, perf}] \quad (62)$$

$$\frac{\rho}{\rho_i} = \left[1 - \frac{\gamma-1}{2} \left(\frac{V}{a_i}\right)^2\right]^{\frac{1}{\gamma-1}} = \left[1 - \frac{1}{5} \left(\frac{V}{a_i}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen, perf}] \quad (63)$$

$$\frac{a}{a_i} = \left[1 - \frac{\gamma-1}{2} \left(\frac{V}{a_i}\right)^2\right]^{\frac{1}{2}} = \left[1 - \frac{1}{5} \left(\frac{V}{a_i}\right)^2\right]^{\frac{1}{2}} \quad [\text{adiab, perf}] \quad (64)$$

$$\frac{q}{p} = \frac{\gamma}{2} \left(\frac{V}{a_i}\right)^2 \left[1 - \frac{\gamma-1}{2} \left(\frac{V}{a_i}\right)^2\right]^{-1} = \frac{7}{10} \left(\frac{V}{a_i}\right)^2 \left[1 - \frac{1}{5} \left(\frac{V}{a_i}\right)^2\right]^{-1} \quad [\text{adiab, perf}] \quad (65)$$

$$\frac{q}{p_i} = \frac{\gamma}{2} \left(\frac{V}{a_i}\right)^2 \left[1 - \frac{\gamma-1}{2} \left(\frac{V}{a_i}\right)^2\right]^{\frac{1}{\gamma-1}} = \frac{7}{10} \left(\frac{V}{a_i}\right)^2 \left[1 - \frac{1}{5} \left(\frac{V}{a_i}\right)^2\right]^{\frac{5}{2}} \quad [\text{isen, perf}] \quad (66)$$

$$M^2 = \left(\frac{V}{a_i}\right)^2 \left[1 - \frac{\gamma-1}{2} \left(\frac{V}{a_i}\right)^2\right]^{-1} = \left(\frac{V}{a_i}\right)^2 \left[1 - \frac{1}{5} \left(\frac{V}{a_i}\right)^2\right]^{-1} \quad [\text{adiab, perf}] \quad (67)$$

$$\left(\frac{V}{a_*}\right)^2 = \frac{\gamma+1}{2} \left(\frac{V}{a_i}\right)^2 = \frac{6}{5} \left(\frac{V}{a_i}\right)^2 \quad [\text{adiab, perf}] \quad (68)$$

$$\left(\frac{V}{V_m}\right)^2 = \frac{\gamma-1}{2} \left(\frac{V}{a_i}\right)^2 = \frac{1}{5} \left(\frac{V}{a_i}\right)^2 \quad [\text{adiab, perf}] \quad (69)$$

Parameter $\frac{V}{V_m}$.—

$$\frac{T}{T_t} = 1 - \left(\frac{V}{V_m} \right)^2 \quad [\text{adiab, perf}] \quad (70)$$

$$\frac{p}{p_t} = \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{\frac{\gamma}{\gamma-1}} = \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \quad (71)$$

$$\frac{\rho}{\rho_t} = \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{\frac{1}{\gamma-1}} = \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \quad (72)$$

$$\frac{a}{a_t} = \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{\frac{1}{2}} \quad [\text{adiab, perf}] \quad (73)$$

$$\begin{aligned} \frac{q}{p} &= \frac{\gamma}{\gamma-1} \left(\frac{V}{V_m} \right)^2 \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{-1} \\ &= \frac{7}{2} \left(\frac{V}{V_m} \right)^2 \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{-1} \quad [\text{adiab, perf}] \quad (74) \end{aligned}$$

$$\begin{aligned} \frac{q}{p_t} &= \frac{\gamma}{\gamma-1} \left(\frac{V}{V_m} \right)^2 \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{-\frac{1}{\gamma-1}} \\ &= \frac{7}{2} \left(\frac{V}{V_m} \right)^2 \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \quad (75) \end{aligned}$$

$$\begin{aligned} M^2 &= \frac{2}{\gamma+1} \left(\frac{V}{V_m} \right)^2 \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{-1} \\ &= \frac{5}{6} \left(\frac{V}{V_m} \right)^2 \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{-1} \quad [\text{adiab, perf}] \quad (76) \end{aligned}$$

$$\left(\frac{V}{a_t} \right)^2 = \frac{2}{\gamma-1} \left(\frac{V}{V_m} \right)^2 = 5 \left(\frac{V}{V_m} \right)^2 \quad [\text{adiab, perf}] \quad (77)$$

$$\left(\frac{V}{a_*} \right)^2 = \frac{\gamma+1}{\gamma-1} \left(\frac{V}{V_m} \right)^2 = 6 \left(\frac{V}{V_m} \right)^2 \quad [\text{adiab, perf}] \quad (78)$$

Tables I and II list numerical values of the following ratios with Mach number M as the independent variable:

$$\frac{p}{p_t}, \frac{\rho}{\rho_t}, \frac{T}{T_t}, \frac{q}{p_t}, \frac{V}{a_*}$$

STREAM-TUBE-AREA RELATIONS

If it is assumed that the density and speed are uniform across any section of a given stream tube, then the equation of continuity is

$$\rho V A = \text{constant} = \rho_* a_* A_* \quad (79)$$

By combining this and certain of the foregoing equations, the area ratio A_*/A can be expressed as a function of any one of the four parameters used above. The final equations are

$$\begin{aligned} \frac{A_*}{A} &= \left(\frac{\gamma+1}{2} \right)^{\frac{\gamma+1}{2(\gamma-1)}} M \left(1 + \frac{\gamma-1}{2} M^2 \right)^{-\frac{\gamma+1}{2(\gamma-1)}} \\ &= \frac{216}{125} M \left(1 + \frac{M^2}{5} \right)^{-3} \quad [\text{isen, perf}] \quad (80) \end{aligned}$$

$$\begin{aligned} \frac{A_*}{A} &= \left(\frac{\gamma+1}{2} \right)^{\frac{1}{\gamma-1}} \left(\frac{V}{a_*} \right) \left[1 - \frac{\gamma-1}{\gamma+1} \left(\frac{V}{a_*} \right)^2 \right]^{\frac{1}{\gamma-1}} \\ &= \left(\frac{6}{5} \right)^{\frac{5}{2}} \left(\frac{V}{a_*} \right) \left[1 - \frac{1}{6} \left(\frac{V}{a_*} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \end{aligned}$$

$$\begin{aligned} \frac{A_*}{A} &= \left(\frac{\gamma+1}{2} \right)^{\frac{\gamma+1}{2(\gamma-1)}} \left(\frac{V}{a_t} \right) \left[1 - \frac{\gamma-1}{2} \left(\frac{V}{a_t} \right)^2 \right]^{\frac{1}{\gamma-1}} \\ &= \frac{216}{125} \left(\frac{V}{a_t} \right) \left[1 - \frac{1}{5} \left(\frac{V}{a_t} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \quad (82) \end{aligned}$$

$$\begin{aligned} \frac{A_*}{A} &= \left(\frac{2}{\gamma-1} \right)^{\frac{1}{2}} \left(\frac{\gamma+1}{2} \right)^{\frac{\gamma+1}{2(\gamma-1)}} \left(\frac{V}{V_m} \right) \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{\frac{1}{\gamma-1}} \\ &= \frac{1}{5^{\frac{1}{2}}} \left(\frac{216}{125} \right) \left(\frac{V}{V_m} \right) \left[1 - \left(\frac{V}{V_m} \right)^2 \right]^{\frac{5}{2}} \quad [\text{isen, perf}] \quad (83) \end{aligned}$$

Numerical values of A_*/A as a function of M are given in tables I and II.

Equation (79) combined with equations (26), (29b), (45) and (46) can be employed to obtain the mass-flow rate per unit area ρV along a stream tube as a function of Mach number, total temperature, and total pressure. Numerical values can be obtained conveniently from chart 1 where the variation with Mach number of the mass-flow rate per unit cross-sectional area is presented for various total temperature and a total pressure of 1 pound per square inch absolute.

SHOCK WAVES

NORMAL SHOCK WAVES

BASIC EQUATIONS

The previous relations for isentropic flow are valid on either side of a shock wave, but not across it, because at the shock wave the flow quantities have discontinuities. Jump

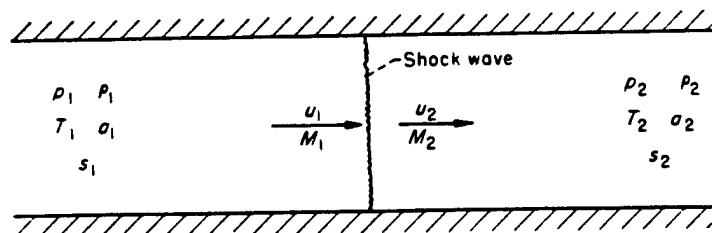


FIGURE 1.—Notation for normal shock wave.

conditions for a steady normal shock wave (fig. 1) result from requiring conservation of

$$\text{mass:} \quad \rho_1 u_1 = \rho_2 u_2 \quad (84)$$

$$\text{momentum:} \quad p_1 + \rho_1 u_1^2 = p_2 + \rho_2 u_2^2 \quad (85)$$

$$\text{energy:}^3 \quad \frac{1}{2} u_1^2 + h_1 = \frac{1}{2} u_2^2 + h_2 \quad [\text{adiab}]$$

³ The actual relation for conservation of energy is $\rho_1 u_1 \left(\frac{1}{2} u_1^2 + h_1 \right) = \rho_2 u_2 \left(\frac{1}{2} u_2^2 + h_2 \right)$; reduces to the above form in view of equation (84).

$$\left. \begin{aligned} \frac{1}{2} u_1^2 + c_p T_1 &= \frac{1}{2} u_2^2 + c_p T_2 \\ \frac{1}{2} u_1^2 + \frac{\gamma}{\gamma-1} \frac{p_1}{\rho_1} &= \frac{1}{2} u_2^2 + \frac{\gamma}{\gamma-1} \frac{p_2}{\rho_2} \\ \frac{1}{2} u_1^2 + \frac{1}{\gamma-1} a_1^2 &= \frac{1}{2} u_2^2 + \frac{1}{\gamma-1} a_2^2 \end{aligned} \right\} \text{[adiab, perf]} \quad (86b)$$

together with the requirement that the entropy does not decrease:

$$\Delta s \equiv s_2 - s_1 \geq 0 \quad (87)$$

It follows immediately from the energy relation (86) that total enthalpy, total temperature, and total speed of sound are constant across the shock and hence (from the previous relations (33) for adiabatic flow) also the critical speed of sound and limiting speed:

$$h_{t_1} = h_{t_2} \quad \text{[adiab]} \quad (88a)$$

$$\left. \begin{aligned} T_{t_1} &= T_{t_2} \\ a_{t_1} &= a_{t_2} \\ a_{*1} &= a_{*2} \\ V_{m_1} &= V_{m_2} \end{aligned} \right\} \text{[adiab, perf]} \quad (88b)$$

Combining equations (84) to (86) leads to Prandtl's relation

$$u_1 u_2 = a_{*}^2 = \frac{p_2 - p_1}{\rho_2 - \rho_1} \quad \text{[adiab, perf]} \quad (89)$$

which implies that the flow is supersonic ahead of the shock wave and subsonic behind (the reverse possibility is ruled out by the requirement of nondecreasing entropy), and to the Rankine-Hugoniot relations

$$\frac{p_2}{p_1} = \frac{(\gamma+1) \rho_2 - (\gamma-1) \rho_1}{(\gamma+1) \rho_1 - (\gamma-1) \rho_2} \quad \text{[adiab, perf]} \quad (90)$$

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma+1) p_2 + (\gamma-1) p_1}{(\gamma+1) p_1 + (\gamma-1) p_2} \quad \text{[adiab, perf]} \quad (91)$$

$$\frac{p_2 - p_1}{\rho_2 - \rho_1} = \gamma \frac{p_2 + p_1}{\rho_2 + \rho_1} \quad \text{[adiab, perf]} \quad (92)$$

USEFUL RELATIONS

Many relations for normal shock waves are conveniently expressed in terms of either upstream Mach number M_1 or the static-pressure ratio across the shock $\xi \equiv p_2/p_1$. The following relations apply to adiabatic flow of a completely perfect fluid. The last form of each equation holds for $\gamma=7/5$.

Parameter M_1 .—

$$\frac{p_2}{p_1} \equiv \xi = \frac{2\gamma M_1^2 - (\gamma-1)}{\gamma+1} = \frac{7M_1^2 - 1}{6} \quad (93)$$

$$\frac{\rho_2}{\rho_1} = \frac{u_1}{u_2} = \frac{u_1^2}{u_2^2} = \frac{a_{*}^2}{a_2^2} = \frac{(\gamma+1) M_1^2}{(\gamma-1) M_1^2 + 2} = \frac{6M_1^2}{M_1^2 + 5} \quad (94)$$

$$\frac{T_2}{T_1} = \frac{a_2^2}{a_1^2} = \frac{[2\gamma M_1^2 - (\gamma-1)] [(\gamma-1) M_1^2 + 2]}{(\gamma+1)^2 M_1^2} = \frac{(7M_1^2 - 1)(M_1^2 + 5)}{36M_1^2} \quad (95)$$

$$M_2^2 = \frac{(\gamma-1) M_1^2 + 2}{2\gamma M_1^2 - (\gamma-1)} = \frac{M_1^2 + 5}{7M_1^2 - 1} \quad (96)$$

$$\frac{p_2}{p_1} = \frac{2\gamma M_1^2 - (\gamma-1)}{\gamma+1} \left[\frac{2}{(\gamma-1) M_1^2 + 2} \right]^{\frac{\gamma}{\gamma-1}} = \frac{7M_1^2 - 1}{6} \left(\frac{5}{M_1^2 + 5} \right)^{\frac{7}{2}} \quad (97)$$

$$\frac{p_2}{p_{t_2}} = \left[\frac{4\gamma M_1^2 - 2(\gamma-1)}{(\gamma+1)^2 M_1^2} \right]^{\frac{\gamma}{\gamma-1}} = \left[\frac{5(7M_1^2 - 1)}{36M_1^2} \right]^{\frac{7}{2}} \quad (98)$$

$$\frac{p_{t_2}}{p_{t_1}} = \frac{\rho_{t_2}}{\rho_{t_1}} = e^{-\frac{\Delta s}{R}} = \left[\frac{(\gamma+1) M_1^2}{(\gamma-1) M_1^2 + 2} \right]^{\frac{\gamma}{\gamma-1}} \left[\frac{\gamma+1}{2\gamma M_1^2 - (\gamma-1)} \right]^{\frac{1}{\gamma-1}} = \left(\frac{6M_1^2}{M_1^2 + 5} \right)^{\frac{7}{2}} \left(\frac{6}{7M_1^2 - 1} \right)^{\frac{5}{2}} \quad (99)$$

$$\frac{p_{t_2}}{p_1} = \left[\frac{(\gamma+1) M_1^2}{2} \right]^{\frac{\gamma}{\gamma-1}} \left[\frac{\gamma+1}{2\gamma M_1^2 - (\gamma-1)} \right]^{\frac{1}{\gamma-1}} = \left(\frac{6M_1^2}{5} \right)^{\frac{7}{2}} \left(\frac{6}{7M_1^2 - 1} \right)^{\frac{5}{2}} \quad (100)$$

(Rayleigh pitot formula)

$$\begin{aligned} \frac{\Delta s}{c_p} &= (\gamma-1) \frac{\Delta s}{R} = -(\gamma-1) \ln \left(\frac{p_{t_2}}{p_{t_1}} \right) \\ &= \ln \left[\frac{2\gamma M_1^2 - (\gamma-1)}{\gamma+1} \right] - \gamma \ln \left[\frac{(\gamma+1) M_1^2}{(\gamma-1) M_1^2 + 2} \right] \\ &= \ln \left(\frac{7M_1^2 - 1}{6} \right) - \frac{7}{5} \ln \left(\frac{6M_1^2}{M_1^2 + 5} \right) \end{aligned} \quad (101)$$

$$\frac{p_2 - p_1}{q_1} = \frac{4(M_1^2 - 1)}{(\gamma+1) M_1^2} = \frac{5(M_1^2 - 1)}{3M_1^2} \quad (102)$$

Numerical values from equations (93), (94), (95), (96), (99), and (100) (with $\gamma=7/5$) are given in table II.

For weak shock waves (M_1 only slightly greater than unity) the following series are useful:

$$\begin{aligned} \frac{p_{t_2}}{p_{t_1}} &= 1 - \frac{2\gamma}{3(\gamma+1)^2} (M_1^2 - 1)^3 + \frac{2\gamma^2}{(\gamma+1)^3} (M_1^2 - 1)^4 + \dots \\ &= 1 - \frac{35}{216} (M_1^2 - 1)^3 + \frac{245}{864} (M_1^2 - 1)^4 + \dots \end{aligned} \quad (103)$$

$$\begin{aligned} \frac{\Delta s}{R} &= \frac{1}{\gamma-1} \frac{\Delta s}{c_p} = \frac{2\gamma}{3(\gamma+1)^2} (M_1^2 - 1)^3 - \frac{2\gamma^2}{(\gamma+1)^3} (M_1^2 - 1)^4 + \dots \\ &= \frac{35}{216} (M_1^2 - 1)^3 - \frac{245}{864} (M_1^2 - 1)^4 + \dots \end{aligned} \quad (104)$$

Parameter $\xi \equiv p_2/p_1$.—

$$M_1^2 = \frac{(\gamma+1)\xi + (\gamma-1)}{2\gamma} = \frac{6\xi+1}{7} \quad (105)$$

$$\frac{\rho_2}{\rho_1} = \frac{u_1}{u_2} = \frac{(\gamma+1)\xi + (\gamma-1)}{(\gamma-1)\xi + (\gamma+1)} = \frac{6\xi+1}{\xi+6} \quad (106)$$

$$\frac{T_2}{T_1} = \frac{a_2^2}{a_1^2} = \xi \frac{(\gamma-1)\xi + (\gamma+1)}{(\gamma+1)\xi + (\gamma-1)} = \xi \frac{\xi+6}{6\xi+1} \quad (107)$$

$$M_2^2 = \frac{(\gamma-1)\xi + (\gamma+1)}{2\gamma\xi} = \frac{\xi+6}{7\xi} \quad (108)$$

$$\frac{p_2}{p_1} = \xi \frac{p_1}{p_1} = \xi \left\{ \frac{4\gamma}{(\gamma+1)[(\gamma-1)\xi + (\gamma+1)]} \right\}^{\frac{\gamma}{\gamma-1}} = \xi \left[\frac{35}{6(\xi+6)} \right]^{\frac{\gamma}{\gamma-1}} \quad (109)$$

$$\frac{p_2}{p_1} = \xi \frac{p_1}{p_1} = \left\{ \frac{4\gamma\xi}{(\gamma+1)[(\gamma+1)\xi + (\gamma-1)]} \right\}^{\frac{\gamma}{\gamma-1}} = \left[\frac{35\xi}{6(6\xi+1)} \right]^{\frac{\gamma}{\gamma-1}} \quad (110)$$

$$\begin{aligned} \frac{p_{t2}}{p_{t1}} &= \frac{\rho_{t2}}{\rho_{t1}} = e^{-\frac{\Delta s}{R}} = \xi^{-\frac{1}{\gamma-1}} \left[\frac{(\gamma+1)\xi + (\gamma-1)}{(\gamma-1)\xi + (\gamma+1)} \right]^{\frac{\gamma}{\gamma-1}} \\ &= \left(\frac{1}{\xi} \right)^{\frac{5}{2}} \left(\frac{6\xi+1}{\xi+6} \right)^{\frac{\gamma}{2}} \end{aligned} \quad (111)$$

$$\begin{aligned} \frac{\Delta s}{c_p} &= (\gamma-1) \frac{\Delta s}{R} = -(\gamma-1) \ln \left(\frac{p_2}{p_1} \right) = \ln \xi - \\ &\quad \gamma \ln \left[\frac{(\gamma+1)\xi + (\gamma-1)}{(\gamma-1)\xi + (\gamma+1)} \right] = \ln \xi - \frac{7}{5} \ln \left(\frac{6\xi+1}{\xi+6} \right) \end{aligned} \quad (112)$$

For weak shock waves (ξ only slightly greater than unity)

$$\begin{aligned} \frac{p_2}{p_1} &= 1 - \frac{\gamma+1}{12\gamma^2} (\xi-1)^3 + \frac{\gamma+1}{8\gamma^2} (\xi-1)^4 + \dots \\ &= 1 - \frac{5}{49} (\xi-1)^3 + \frac{15}{98} (\xi-1)^4 + \dots \end{aligned} \quad (113)$$

$$\begin{aligned} \frac{\Delta s}{R} &= \frac{1}{\gamma-1} \frac{\Delta s}{c_p} = \frac{\gamma+1}{12\gamma^2} (\xi-1)^3 - \frac{\gamma+1}{8\gamma^2} (\xi-1)^4 + \dots \\ &= \frac{5}{49} (\xi-1)^3 - \frac{15}{98} (\xi-1)^4 + \dots \end{aligned} \quad (114)$$

In unsteady flow a normal shock wave acts at each instant as a steady shock. Hence all the above relations are valid across a moving normal shock wave if instantaneous velocities are measured relative to the shock.

OBLIQUE SHOCK WAVES

In general, a three-dimensional shock wave will be curved, and will separate two regions of nonuniform flow. However, the shock transition at each point takes place instantaneously, so that it is sufficient to consider an arbitrarily small neighborhood of the point. In such a neighborhood

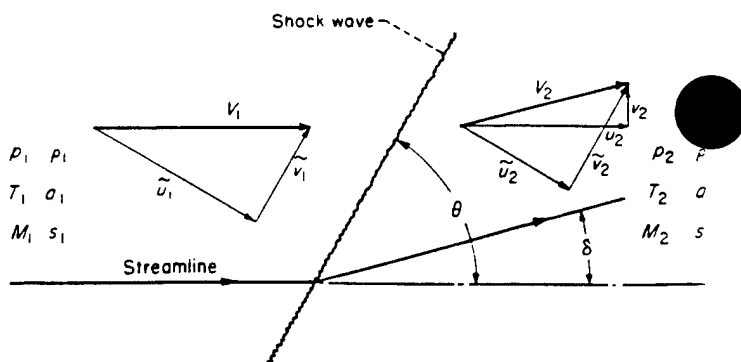


FIGURE 2.—Notation for oblique shock wave.

the shock wave may be regarded as plane to any desired degree of accuracy, and the flows on either side as uniform and parallel. Moreover, with the proper orientation of axes the flow is locally two-dimensional. Hence it is sufficient to consider a straight oblique shock wave in a uniform parallel two-dimensional stream, as shown in figure 2

BASIC EQUATIONS

For a steady oblique shock wave, jump conditions result from requiring conservation of

$$\text{mass:} \quad \rho_1 \tilde{u}_1 = \rho_2 \tilde{u}_2 \quad (115)$$

$$\text{normal momentum:} \quad p_1 + \rho_1 \tilde{u}_1^2 = p_2 + \rho_2 \tilde{u}_2^2 \quad (116)$$

$$\text{tangential momentum:} \quad \rho_1 \tilde{u}_1 \tilde{v}_1 = \rho_2 \tilde{u}_2 \tilde{v}_2 \quad (117)$$

$$\text{energy:} \quad \frac{1}{2} (\tilde{u}_1^2 + \tilde{v}_1^2) + h_1 = \frac{1}{2} (\tilde{u}_2^2 + \tilde{v}_2^2) + h_2 \text{ [adiab]} \quad (118a)$$

$$\left. \begin{aligned} \frac{1}{2} (\tilde{u}_1^2 + \tilde{v}_1^2) + c_p T_1 &= \frac{1}{2} (\tilde{u}_2^2 + \tilde{v}_2^2) + c_p T_2 \\ \frac{1}{2} (\tilde{u}_1^2 + \tilde{v}_1^2) + \frac{\gamma}{\gamma-1} \frac{p_1}{\rho_1} &= \frac{1}{2} (\tilde{u}_2^2 + \tilde{v}_2^2) + \frac{\gamma}{\gamma-1} \frac{p_2}{\rho_2} \\ \frac{1}{2} (\tilde{u}_1^2 + \tilde{v}_1^2) + \frac{1}{\gamma-1} a_1^2 &= \frac{1}{2} (\tilde{u}_2^2 + \tilde{v}_2^2) + \frac{1}{\gamma-1} a_2^2 \end{aligned} \right\} \text{[adiab, perf]} \quad (118b)$$

together with the requirement that the entropy does not decrease:

$$\Delta s \equiv s_2 - s_1 \geq 0 \quad (119)$$

Again it follows from the energy relation (118) that total enthalpy, total temperature, and total speed of sound are constant across the shock and hence also the critical speed of sound and limiting speed:

$$h_{t1} = h_{t2} \text{ [adiab]} \quad (120)$$

$$\left. \begin{aligned} T_{t1} &= T_{t2} \\ a_{t1} &= a_{t2} \\ a_{*1} &= a_{*2} \\ V_{m1} &= V_{m2} \end{aligned} \right\} \text{[adiab, perf]}$$

* Compare remark for normal shock waves, footnote on page 6.

CONNECTION WITH NORMAL SHOCK

comparison of equation (115) with (117) shows that tangential velocity is constant across the shock wave:

$$\bar{v}_1 = \bar{v}_2 \quad [\text{adiab}] \quad (122)$$

so that the change in velocity is normal to the shock. It follows that

$$\frac{1}{2} \bar{v}_1^2 = \frac{1}{2} \bar{v}_2^2$$

so that the energy equation (118a) reduces to

$$\frac{1}{2} \bar{u}_1^2 + h_1 = \frac{1}{2} \bar{u}_2^2 + h_2 \quad [\text{adiab}] \quad (123)$$

Now equations (115), (116), and (123) involve only the component of velocity $\bar{u}$ normal to the shock, and are identical with equations (84), (85), and (86) for normal shock waves. Hence an oblique shock wave acts as a normal shock to the component of flow perpendicular to it, while the tangential component is unchanged. This is also clear physically from the "sweepback principle" that the oblique flow is reduced to the normal flow by a uniform translation of axes (Galilean transformation).

Because the speed of sound depends on the tangential velocity, Prandtl's relation differs from that for normal shock waves (see ref. 11, pp. 302-303):

$$\bar{u}_1 \bar{u}_2 = a_*^2 - \frac{\gamma-1}{\gamma+1} \bar{v}^2 \quad [\text{adiab, perf}] \quad (124)$$

where a_* and $\bar{v}$ can be evaluated on either side of the shock.

The Rankine-Hugoniot relations are the same as for normal shock waves:

$$\frac{p_2}{p_1} = \frac{(\gamma+1)p_2 - (\gamma-1)p_1}{(\gamma+1)p_1 - (\gamma-1)p_2} \quad [\text{adiab, perf}] \quad (125)$$

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma+1)p_2 + (\gamma-1)p_1}{(\gamma+1)p_1 + (\gamma-1)p_2} \quad [\text{adiab, perf}] \quad (126)$$

$$\frac{p_2 - p_1}{\rho_2 - \rho_1} = \gamma \frac{p_2 + p_1}{\rho_2 + \rho_1} \quad [\text{adiab, perf}] \quad (127)$$

USEFUL RELATIONS

Because an oblique shock wave acts as a normal shock to the flow perpendicular to it, the previous relations for normal shocks (except those for ratios of static to total pressures) apply to oblique shocks if M_1 and M_2 are replaced by their normal components $M_1 \sin \theta$ and $M_2 \sin(\theta - \delta)$. This gives most of the following relations; the remainder are derived from them by using the kinematic condition that the stream turns through an angle δ , together with the various isentropic-flow relations.

Parameters M_1 and θ .—

$$\frac{p_2}{p_1} = \xi = \frac{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)}{\gamma+1} = \frac{7M_1^2 \sin^2 \theta - 1}{6} \quad (128)$$

$$\frac{\rho_2}{\rho_1} = \frac{\bar{u}_1}{\bar{u}_2} = \frac{(\gamma+1)M_1^2 \sin^2 \theta}{(\gamma-1)M_1^2 \sin^2 \theta + 2} = \frac{6M_1^2 \sin^2 \theta}{M_1^2 \sin^2 \theta + 5} \quad (129)$$

$$\begin{aligned} \frac{T_2}{T_1} &= \frac{a_2^2}{a_1^2} = \frac{[2\gamma M_1^2 \sin^2 \theta - (\gamma-1)][(\gamma-1)M_1^2 \sin^2 \theta + 2]}{(\gamma+1)^2 M_1^2 \sin^2 \theta} \\ &= \frac{(7M_1^2 \sin^2 \theta - 1)(M_1^2 \sin^2 \theta + 5)}{36M_1^2 \sin^2 \theta} \end{aligned} \quad (130)$$

$$M_2^2 \sin^2(\theta - \delta) = \frac{(\gamma-1)M_1^2 \sin^2 \theta + 2}{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)} = \frac{M_1^2 \sin^2 \theta + 5}{7M_1^2 \sin^2 \theta - 1} \quad (131)$$

$$\begin{aligned} M_2^2 &= \frac{(\gamma+1)^2 M_1^4 \sin^2 \theta - 4(M_1^2 \sin^2 \theta - 1)(\gamma M_1^2 \sin^2 \theta + 1)}{[2\gamma M_1^2 \sin^2 \theta - (\gamma-1)][(\gamma-1)M_1^2 \sin^2 \theta + 2]} \\ &= \frac{36M_1^4 \sin^2 \theta - 5(M_1^2 \sin^2 \theta - 1)(7M_1^2 \sin^2 \theta + 5)}{(7M_1^2 \sin^2 \theta - 1)(M_1^2 \sin^2 \theta + 5)} \end{aligned} \quad (132)$$

$$\frac{\bar{u}_2}{V_1} = \frac{(\gamma-1)M_1^2 \sin^2 \theta + 2}{(\gamma+1)M_1^2 \sin^2 \theta} \sin \theta = \frac{M_1^2 \sin^2 \theta + 5}{6M_1^2 \sin^2 \theta} \sin \theta \quad (133)$$

$$\frac{\bar{v}_2}{V_1} = \frac{\bar{v}_1}{V_1} = \cos \theta \quad (134)$$

$$\frac{u_2}{V_1} = 1 - \frac{2(M_1^2 \sin^2 \theta - 1)}{(\gamma+1)M_1^2} = 1 - \frac{5(M_1^2 \sin^2 \theta - 1)}{6M_1^2} \quad (135)$$

$$\frac{v_2}{V_1} = \frac{2(M_1^2 \sin^2 \theta - 1)}{(\gamma+1)M_1^2} \cot \theta = \frac{5(M_1^2 \sin^2 \theta - 1)}{6M_1^2} \cot \theta \quad (136)$$

$$\begin{aligned} \frac{V_2^2}{V_1^2} &= 1 - 4 \frac{(M_1^2 \sin^2 \theta - 1)(\gamma M_1^2 \sin^2 \theta + 1)}{(\gamma+1)^2 M_1^4 \sin^2 \theta} \\ &= 1 - \frac{5}{36} \frac{(M_1^2 \sin^2 \theta - 1)(7M_1^2 \sin^2 \theta + 5)}{M_1^4 \sin^2 \theta} \end{aligned} \quad (137)$$

$$\begin{aligned} \cot \delta &= \tan \theta \left[\frac{(\gamma+1)M_1^2}{2(M_1^2 \sin^2 \theta - 1)} - 1 \right] \\ &= \tan \theta \left[\frac{6M_1^2}{5(M_1^2 \sin^2 \theta - 1)} - 1 \right] \end{aligned} \quad (138)$$

$$\tan \delta = \frac{2 \cot \theta (M_1^2 \sin^2 \theta - 1)}{2 + M_1^2 (\gamma + 1 - 2 \sin^2 \theta)} = \frac{5 \cot \theta (M_1^2 \sin^2 \theta - 1)}{5 + M_1^2 (6 - 5 \sin^2 \theta)} \quad (139a)$$

$$= \frac{M_1^2 \sin 2\theta - 2 \cot \theta}{2 + M_1^2 (\gamma + \cos 2\theta)} = 5 \frac{M_1^2 \sin 2\theta - 2 \cot \theta}{10 + M_1^2 (7 + 5 \cos 2\theta)} \quad (139b)$$

$$\begin{aligned} \frac{p_2}{p_{t1}} &= \frac{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)}{(\gamma+1)} \left[\frac{2}{(\gamma-1)M_1^2 + 2} \right]^{\frac{\gamma}{\gamma-1}} \\ &= \frac{7M_1^2 \sin^2 \theta - 1}{6} \left(\frac{5}{M_1^2 + 5} \right)^{\frac{7}{2}} \end{aligned} \quad (140)$$

$$\begin{aligned} \frac{p_2}{p_{t2}} &= \left\{ 2 \frac{[2\gamma M_1^2 \sin^2 \theta - (\gamma-1)][(\gamma-1)M_1^2 \sin^2 \theta + 2]}{(\gamma+1)^2 M_1^2 \sin^2 \theta [(\gamma-1)M_1^2 + 2]} \right\}^{\frac{\gamma}{\gamma-1}} \\ &= \left[5 \frac{(7M_1^2 \sin^2 \theta - 1)(M_1^2 \sin^2 \theta + 5)}{36M_1^2 \sin^2 \theta (M_1^2 + 5)} \right]^{\frac{7}{2}} \end{aligned} \quad (141)$$

$$\frac{p_{t_2}}{p_{t_1}} = \frac{\rho_{t_2}}{\rho_{t_1}} = e^{-\frac{\Delta s}{R}}$$

$$= \left[\frac{(\gamma+1)M_1^2 \sin^2 \theta}{(\gamma-1)M_1^2 \sin^2 \theta + 2} \right]^{\frac{\gamma}{\gamma-1}} \left[\frac{\gamma+1}{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)} \right]^{\frac{1}{\gamma-1}}$$

$$= \left(\frac{6M_1^2 \sin^2 \theta}{M_1^2 \sin^2 \theta + 5} \right)^{7/2} \left(\frac{6}{7M_1^2 \sin^2 \theta - 1} \right)^{5/2} \quad (142)$$

$$\frac{p_{t_2}}{p_1} = \left[\frac{\gamma+1}{2\gamma M_1^2 \sin^2 \theta - (\gamma-1)} \right]^{\frac{1}{\gamma-1}} \times$$

$$\left\{ \frac{(\gamma+1)M_1^2 \sin^2 \theta [(\gamma-1)M_1^2 + 2]}{2[(\gamma-1)M_1^2 \sin^2 \theta + 2]} \right\}^{\frac{\gamma}{\gamma-1}}$$

$$= \left(\frac{6}{7M_1^2 \sin^2 \theta - 1} \right)^{5/2} \left[\frac{6M_1^2 \sin^2 \theta (M_1^2 + 5)}{5(M_1^2 \sin^2 \theta + 5)} \right]^{7/2} \quad (143)$$

$$\frac{\Delta s}{c_r} = (\gamma-1) \frac{\Delta s}{R} = -(\gamma-1) \ln \left(\frac{p_{t_2}}{p_{t_1}} \right)$$

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

$$\gamma \ln \left[\frac{(\gamma+1)M_1^2 \sin^2 \theta}{(\gamma-1)M_1^2 \sin^2 \theta + 2} \right]$$

$$= \ln \left(\frac{7M_1^2 \sin^2 \theta - 1}{6} \right) - \frac{7}{5} \ln \left(\frac{6M_1^2 \sin^2 \theta}{M_1^2 \sin^2 \theta + 5} \right) \quad (144)$$

$$\frac{p_2 - p_1}{q_1} = \frac{4(M_1^2 \sin^2 \theta - 1)}{(\gamma+1)M_1^2} = \frac{5}{3} \frac{M_1^2 \sin^2 \theta - 1}{M_1^2} \quad (145)$$

Values of the following ratios for oblique shock waves can be read from table II, provided $M_1 \sin \theta$ is used instead of M_1 in the first column:

$$\frac{p_2}{p_1}, \frac{\rho_2}{\rho_1}, \frac{T_2}{T_1}, \frac{p_{t_2}}{p_{t_1}}$$

For weak shock waves ($M_1 \sin \theta$ only slightly greater than unity) the following series are obtained from equations (103) and (104) by replacing M_1 by $M_1 \sin \theta$:

$$\frac{p_{t_2}}{p_{t_1}} = 1 - \frac{2\gamma}{3(\gamma+1)^2} (M_1^2 \sin^2 \theta - 1)^3 + \frac{2\gamma^2}{(\gamma+1)^3} (M_1^2 \sin^2 \theta - 1)^4 + \dots$$

$$= 1 - \frac{35}{216} (M_1^2 \sin^2 \theta - 1)^3 + \frac{245}{864} (M_1^2 \sin^2 \theta - 1)^4 + \dots \quad (146)$$

$$\frac{\Delta s}{R} = \frac{1}{\gamma-1} \frac{\Delta s}{c_r} = \frac{2\gamma}{3(\gamma+1)^2} (M_1^2 \sin^2 \theta - 1)^3 -$$

$$\frac{2\gamma^2}{(\gamma+1)^3} (M_1^2 \sin^2 \theta - 1)^4 + \dots$$

$$= \frac{35}{216} (M_1^2 \sin^2 \theta - 1)^3 - \frac{245}{864} (M_1^2 \sin^2 \theta - 1)^4 + \dots \quad (147)$$

Parameters θ and δ .—

$$\frac{1}{M_1^2} = \sin^2 \theta - \frac{\gamma+1}{2} \frac{\sin \theta \sin \delta}{\cos(\theta-\delta)} = \sin^2 \theta - \frac{\gamma+1}{2} \frac{\tan \delta}{\tan \delta + \cot \theta}$$

$$= \sin^2 \theta - \frac{\gamma+1}{2} \frac{\tan \theta}{\tan \theta - \cot \delta} \quad (148a)$$

$$M_1^2 = \frac{2(\cot \theta + \tan \delta)}{\sin 2\theta - \tan \delta (\gamma + \cos 2\theta)}$$

$$= \frac{10(\cot \theta + \tan \delta)}{5 \sin 2\theta - \tan \delta (7 + 5 \cos 2\theta)} \quad (148b)$$

$$\frac{p_2 - p_1}{q_1} = 2 \frac{\sin \theta \sin \delta}{\cos(\theta-\delta)}$$

$$= 2 \frac{\tan \delta}{\tan \delta + \cot \theta} = 2 \frac{\tan \theta}{\tan \theta - \cot \delta} \quad (149a)$$

$$\frac{\rho_2 - \rho_1}{\rho_2} = \frac{\sin \delta}{\sin \theta \cos(\theta-\delta)} \quad (149b)$$

Parameters M_1 and δ .—

No convenient explicit relations exist. However, the value of $\sin^2 \theta$ can be found by solving the following cubic equation (ref. 12):

$$\sin^6 \theta + b \sin^4 \theta + c \sin^2 \theta + d = 0 \quad (150a)$$

where

$$\left. \begin{aligned} b &= -\frac{M_1^2 + 2}{M_1^2} - \gamma \sin^2 \delta \\ c &= \frac{2M_1^2 + 1}{M_1^4} + \left[\frac{(\gamma+1)^2}{4} + \frac{\gamma-1}{M_1^2} \right] \sin^2 \delta \\ d &= -\frac{\cos^2 \delta}{M_1^4} \end{aligned} \right\} \quad (150b)$$

The smallest of the three roots corresponds to a decrease in entropy and should be disregarded.

For weak shock waves (small deflections δ) the following series are useful (note that δ must be measured in radians):

$$\frac{p_2}{p_1} = 1 + \frac{\gamma M_1^2}{(M_1^2 - 1)^{1/2}} \delta + \gamma M_1^2 \frac{(\gamma+1)M_1^4 - 4(M_1^2 - 1)}{4(M_1^2 - 1)^2} \delta^2 +$$

$$\frac{\gamma M_1^2}{(M_1^2 - 1)^{7/2}} \left[\frac{(\gamma+1)^2}{32} M_1^8 - \frac{7+12\gamma-3\gamma^2}{24} M_1^6 + \right.$$

$$\left. \frac{3}{4} (\gamma+1)M_1^4 - M_1^2 + \frac{2}{3} \right] \delta^3 + \dots \quad (151)$$

$$\frac{p_2 - p_1}{q_1} = \frac{2}{(M_1^2 - 1)^{1/2}} \delta + \frac{(\gamma+1)M_1^4 - 4(M_1^2 - 1)}{2(M_1^2 - 1)^2} \delta^2 +$$

$$\frac{1}{(M_1^2 - 1)^{7/2}} \left[\frac{(\gamma+1)^2}{16} M_1^8 - \frac{7+12\gamma-3\gamma^2}{12} M_1^6 + \right.$$

$$\left. \frac{3}{2} (\gamma+1)M_1^4 - 2M_1^2 + \frac{4}{3} \right] \delta^3 + \dots \quad (152)$$

$$= 1 + \frac{M_1^2}{(M_1^2 - 1)^{1/2}} \delta + M_1^2 \frac{(3 - \gamma)M_1^2(M_1^2 - 2) + 4}{4(M_1^2 - 1)^2} \delta^2 + \dots \quad (153)$$

$$\frac{T_2}{T_1} = 1 + \frac{(\gamma - 1)M_1^2}{(M_1^2 - 1)^{1/2}} \delta + (\gamma - 1)M_1^2 \frac{(\gamma + 1)M_1^4 - 2(M_1^2 + 2)(M_1^2 - 1)}{4(M_1^2 - 1)^2} \delta^2 + \dots \quad (154)$$

Since flow through weak shock waves is nearly isentropic, compressions through small angles can also be calculated with the aid of table II by regarding them as reversed Prandtl-Meyer expansions (see later section). The resulting numerical accuracy is greater than that obtained by retaining terms up to δ^2 in the above series, and nearly equal to that obtained by retaining terms up to δ^3 .

Charts 2, 3, and 4 show the variation of shock-wave angle, pressure coefficient across a shock wave, and downstream Mach number with flow-deflection angle for various upstream Mach numbers.

Parameter $\xi \equiv p_2/p_1$.—

$$M_1^2 \sin^2 \theta = \frac{(\gamma + 1)\xi + (\gamma - 1)}{2\gamma} = \frac{6\xi + 1}{7} \quad (155)$$

$$M_2^2 \sin^2 (\theta - \delta) = \frac{(\gamma - 1)\xi + (\gamma + 1)}{2\gamma\xi} = \frac{\xi + 6}{7\xi} \quad (156)$$

$$M_2^2 = \frac{M_1^2[(\gamma + 1)\xi + (\gamma - 1)] - 2(\xi^2 - 1)}{\xi[(\gamma - 1)\xi + (\gamma + 1)]} = \frac{M_1^2(6\xi + 1) - 5(\xi^2 - 1)}{\xi(6\xi + 1)} \quad (157)$$

$$\frac{p_2}{p_1} = \frac{(\gamma + 1)\xi + (\gamma - 1)}{(\gamma - 1)\xi + (\gamma + 1)} = \frac{6\xi + 1}{\xi + 6} \quad (158)$$

$$\frac{T_2}{T_1} = \frac{a_2^2}{a_1^2} = \xi \frac{(\gamma - 1)\xi + (\gamma + 1)}{(\gamma + 1)\xi + (\gamma - 1)} = \xi \frac{\xi + 6}{6\xi + 1} \quad (159)$$

$$\tan^2 \delta = \left(\frac{\xi - 1}{\gamma M_1^2 - \xi + 1} \right)^2 \frac{2\gamma M_1^2 - (\gamma - 1) - (\gamma + 1)\xi}{(\gamma + 1)\xi + (\gamma - 1)} = \left[\frac{5(\xi - 1)}{7M_1^2 - 5(\xi - 1)} \right]^2 \frac{7M_1^2 - (6\xi + 1)}{6\xi + 1} \quad (160)$$

$$\begin{aligned} \frac{p_{t_2}}{p_{t_1}} = \frac{\rho_{t_2}}{\rho_{t_1}} = e^{-\frac{\Delta s}{R}} &= \left[\frac{(\gamma + 1)\xi + (\gamma - 1)}{(\gamma - 1)\xi + (\gamma + 1)} \right]^{\frac{\gamma}{\gamma - 1}} \xi^{-\frac{1}{\gamma - 1}} \\ &= \left(\frac{6\xi + 1}{\xi + 6} \right)^{7/2} \xi^{-5/2} \end{aligned} \quad (161)$$

$$\frac{V_2^2}{V_1^2} = 1 - \frac{2(\xi^2 - 1)}{M_1^2[(\gamma + 1)\xi + (\gamma - 1)]} = 1 - \frac{5(\xi^2 - 1)}{M_1^2(6\xi + 1)} \quad (162)$$

For weak shock waves, equations (113) and (114) apply to oblique as well as normal shocks.

SHOCK POLAR

The velocities associated with an oblique shock wave are conveniently represented in the velocity-vector (hodograph) plane. For a given Mach number ahead of the shock wave, all possible velocity vectors behind the shock lie on a single curve.

Only the closed loop represents real shock waves with non-decreasing entropy, and forms Busemann's shock polar (fig. 3). Its equation is

$$v_2^2 = (V_1 - u_2)^2 \frac{u_2 - \frac{a^*}{V_1}}{\frac{2}{\gamma + 1} V_1 + \frac{a^*}{V_1} - u_2} \quad (163)$$

Other forms of this equation convenient for computation are, given V_1 and M_1 ,

$$\begin{aligned} \left(\frac{v_2}{V_1} \right)^2 &= \left(1 - \frac{u_2}{V_1} \right)^2 \frac{(M_1^2 - 1) - \frac{\gamma + 1}{2} M_1^2 \left(1 - \frac{u_2}{V_1} \right)}{1 + \frac{\gamma + 1}{2} M_1^2 \left(1 - \frac{u_2}{V_1} \right)} \\ &= \left(1 - \frac{u_2}{V_1} \right)^2 \frac{5(M_1^2 - 1) - 6M_1^2 \left(1 - \frac{u_2}{V_1} \right)}{5 + 6M_1^2 \left(1 - \frac{u_2}{V_1} \right)} \end{aligned} \quad (164a)$$

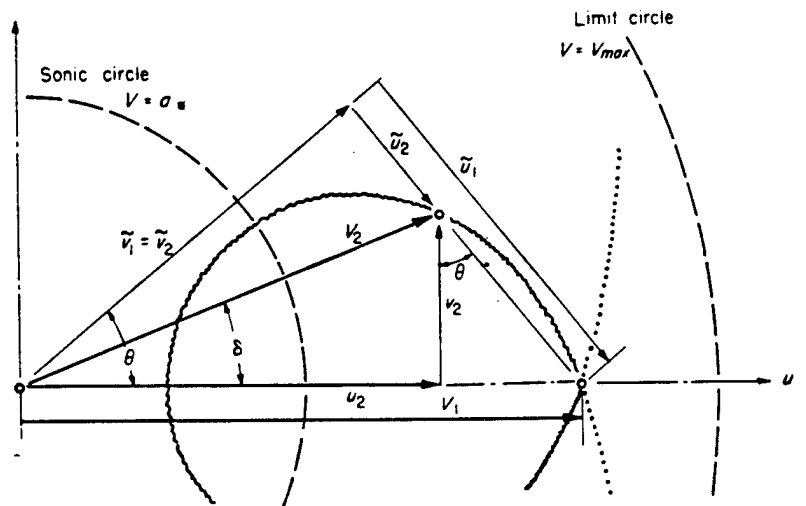
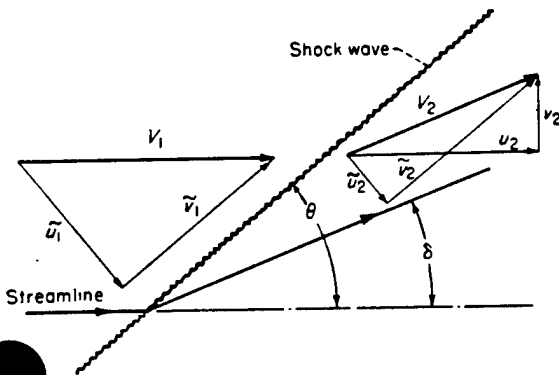


FIGURE 3.—Shock polar.

given a_* and V_1 ,

$$\begin{aligned} \left(\frac{V_2}{a_*}\right)^2 &= \left(\frac{V_1}{a_*} - \frac{u_2}{a_*}\right)^2 \frac{\frac{V_1}{a_*} \frac{u_2}{a_*} - 1}{1 + \frac{2}{\gamma+1} \left(\frac{V_1}{a_*}\right)^2 - \frac{V_1}{a_*} \frac{u_2}{a_*}} \\ &= \left(\frac{V_1}{a_*} - \frac{u_2}{a_*}\right)^2 \frac{6 \left(\frac{V_1}{a_*} \frac{u_2}{a_*} - 1\right)}{5 \left(\frac{V_1}{a_*}\right)^2 - 6 \left(\frac{V_1}{a_*} \frac{u_2}{a_*} - 1\right)} \quad (164b) \end{aligned}$$

and given V_1 and V_m ,

$$\begin{aligned} \left(\frac{v_2}{V_m}\right)^2 &= \left(\frac{V_1}{V_m} - \frac{u_2}{V_m}\right)^2 \frac{\frac{V_1}{V_m} \frac{u_2}{V_m} - \frac{\gamma-1}{\gamma+1}}{\frac{2}{\gamma+1} \left(\frac{V_1}{V_m}\right)^2 + \frac{\gamma-1}{\gamma+1} - \frac{V_1}{V_m} \frac{u_2}{V_m}} \\ &= \left(\frac{V_1}{V_m} - \frac{u_2}{V_m}\right)^2 \frac{\left(6 \frac{V_1}{V_m} \frac{u_2}{V_m} - 1\right)}{5 \left(\frac{V_1}{V_m}\right)^2 - \left(6 \frac{V_1}{V_m} \frac{u_2}{V_m} - 1\right)} \quad (164c) \end{aligned}$$

The shock-wave angle θ and wedge angle δ are given in terms of the velocity components by

$$\tan \theta = \frac{V_1 - u_2}{v_2} = \frac{\tilde{u}_1}{\tilde{v}_1} \quad (165)$$

$$\tan \delta = \frac{v_2}{u_2} \quad (166)$$

The shock-wave angle θ_* for sonic flow behind the shock is found (by setting $M_2=1$ in eq. (132)) to be given by

$$\begin{aligned} \sin^2 \theta_* &= \frac{1}{4\gamma M_1^2} \{(\gamma+1)M_1^2 - (3-\gamma) + \\ &\quad \sqrt{(\gamma+1)[(\gamma+1)M_1^4 - 2(3-\gamma)M_1^2 + (\gamma+9)]}\} \\ &= \frac{1}{7M_1^2} [3M_1^2 - 2 + \sqrt{3(3M_1^4 - 4M_1^2 + 13)}] \quad (167) \end{aligned}$$

The shock-wave angle $\theta_{i_{max}}$ for maximum stream deflection behind the shock is given by

$$\begin{aligned} \sin^2 \theta_{i_{max}} &= \frac{1}{4\gamma M_1^2} \{(\gamma+1) M_1^2 - 4 + \\ &\quad \sqrt{(\gamma+1)[(\gamma+1) M_1^4 + 8(\gamma-1) M_1^2 + 16]}\} \\ &= \frac{1}{7M_1^2} [3M_1^2 - 5 + \sqrt{3(3M_1^4 + 4M_1^2 + 20)}] \quad (168) \end{aligned}$$

For small deflection angles (hence Mach numbers close to unity), the deflection angle (radians) for sonic flow behind the shock is given approximately in terms of the upstream Mach number by

$$\delta_* = \frac{1}{\sqrt{2}(\gamma+1)} \frac{(M_1^2-1)^{3/2}}{M_1^2} = 0.2946 \frac{(M_1^2-1)^{3/2}}{M_1^2} \quad (169)$$

The maximum stream deflection angle for a specified upstream Mach number is given approximately by

$$\delta_{max} = \frac{4}{3\sqrt{3}(\gamma+1)} \frac{(M_1^2-1)^{3/2}}{M_1^2} = 0.3208 \frac{(M_1^2-1)^{3/2}}{M_1^2} \quad (170)$$

In unsteady flow all the above relations are valid across a moving oblique shock wave if instantaneous velocities r measured relative to the shock.

SUPERSONIC FLOW PAST WEDGES AND CONES

A shock wave forms ahead of any body in supersonic flight and remains fixed relative to the body if the flight is steady. It stands ahead of blunt shapes, but may be attached to pointed shapes.

Just at the tip of a pointed airfoil or body of revolution the flow is the same as for the initially tangent wedge or cone. The bow wave is attached at sufficiently high Mach numbers for a wedge of semivertex angle δ less than $\sin^{-1}(1/\gamma) = 45.6^\circ$ for $\gamma=7/5$, and for a circular cone of semivertex angle σ less than 57.5° for $\gamma=1.405$. Below these limits, the wave is attached above a minimum Mach number whose dependence upon nose angle is shown for wedges and cones in figure 4. (These values can be applied to pointed airfoils and bodies of revolution which are not concave.) Also shown in figure 4 are the slightly higher Mach numbers above which the velocity behind the shock wave is supersonic, and for the cone the still higher Mach number above which the flow is supersonic even at the surface. (For wedges these last two coincide.) For thin wedges, these Mach numbers are given approximately by equations (169) and (170).

FLOW PAST WEDGES

If the bow shock wave is attached to a wedge, it is straight and the flow behind the shock consists of uniform stream parallel to either face of the wedge. The flow pattern above the upper face (fig. 5) may be regarded as obtained from the straight oblique shock-wave pattern of figure 2 by replacing the streamline behind the shock wave with a solid wall. Flow quantities are determined by the oblique-shock-wave relations, equations (115) to (170). As noted previously, table II can also be applied if $M_1 \sin \theta$ is used in place of M_1 in the first column.

The flows above and below the wedge are independent, so that inclined wedges can be treated if neither face exceeds the attachment angle shown in figure 4. However, if the angle of attack exceeds the semivertex angle, the flow over the upper (leeward) surface is given by a Prandtl-Meyer expansion (see fig. 4) rather than by the shock relations.

It is clear from the shock polar (fig. 3) that two different shock waves and flow patterns are theoretically possible for a given wedge and Mach number. However, it is believed that only the weaker shock wave (larger u_2 and smaller θ) can occur attached to an isolated convex body.

Charts 2, 3, and 4 show the dependence of shock-wave angle, surface pressure coefficient, and downstream Mach number upon wedge angle for various free-stream Mach numbers.

FLOW PAST CONES

If the bow shock wave is attached to an uninclined circular cone, the shock wave too has the form of a circular cone. Flow quantities are constant on all concentric conical surfaces lying between the shock wave and the body, and so depend upon only one space variable. The transition across the shock wave is governed by the oblique-shock relations,

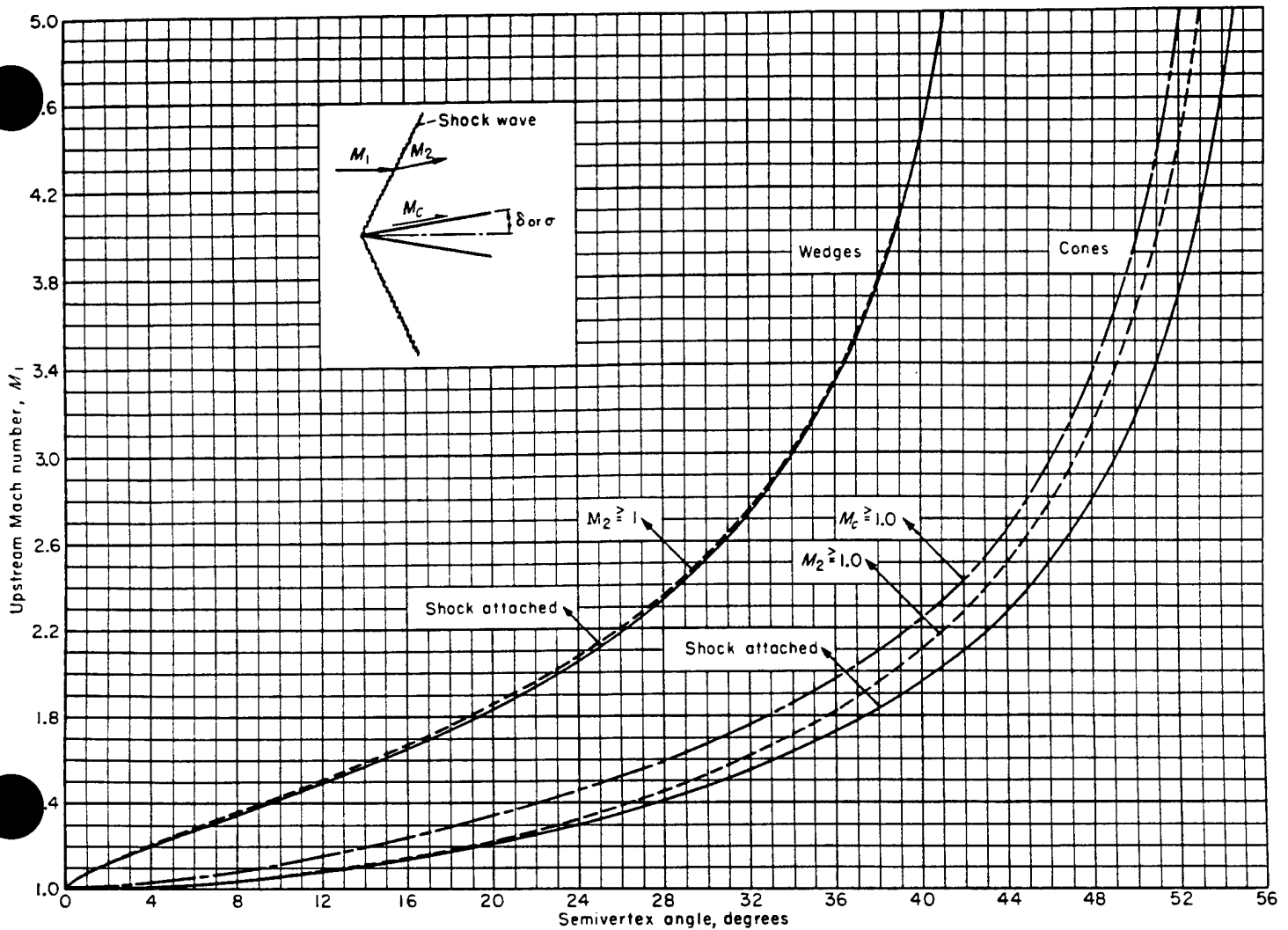


FIGURE 4.—Upstream Mach numbers for shock attachment and for supersonic flow behind shock wave on wedges and cones, and for supersonic flow at surface of cones.

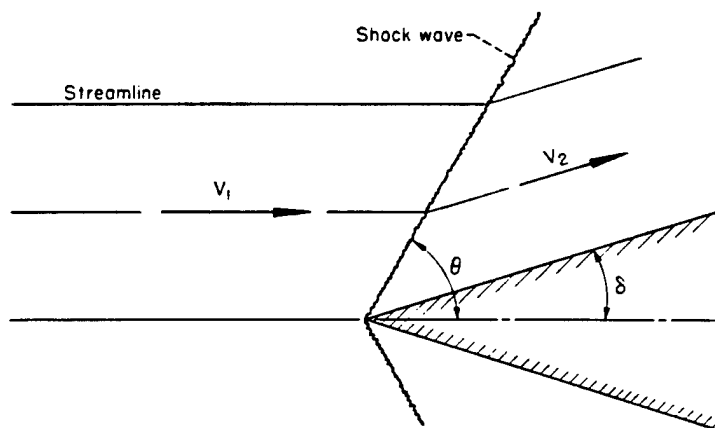


FIGURE 5.—Flow past a wedge.

and is followed by a continuous isentropic compression to face conditions, as indicated in figure 6. The flow quantities have been extensively tabulated in reference 6 for $\gamma=1.405$ and for $\gamma=4/3$. As in the case of wedges, two solutions exist for each cone and Mach number, but it is believed that only the weaker shock wave can occur on an isolated convex body. Charts 5, 6, and 7 show the dependence of shock-wave angle, surface-pressure coefficient, and

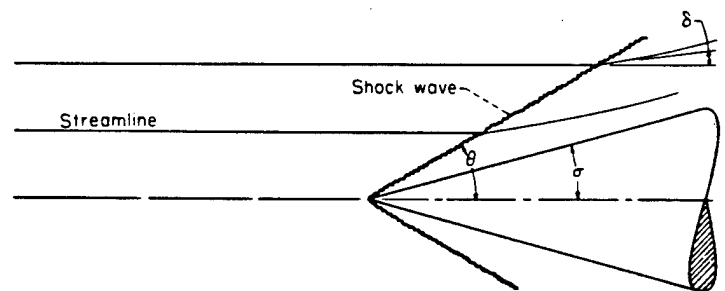


FIGURE 6.—Flow past a cone.

surface Mach number on cone semivertex angle for various free-stream Mach numbers.

The effects of slightly inclining a cone have been considered by Stone (ref. 13) and numerical results are tabulated in reference 14. Chart 8 shows the variation with Mach number of the initial slope of the normal-force curve for various cone angles. Stone has also sought an approximation for larger inclinations by retaining squares as well as first powers of angle of attack (ref. 15), and numerical results have been tabulated (ref. 16); however, these results are not free of error (see refs. 17 and 18).

PRANDTL-MEYER EXPANSION

A uniform two-dimensional supersonic stream flowing over a convex bend expands isentropically. Convenient relations are found by considering the special case of a stream at Mach number unity flowing around a sharp corner (fig. 7).

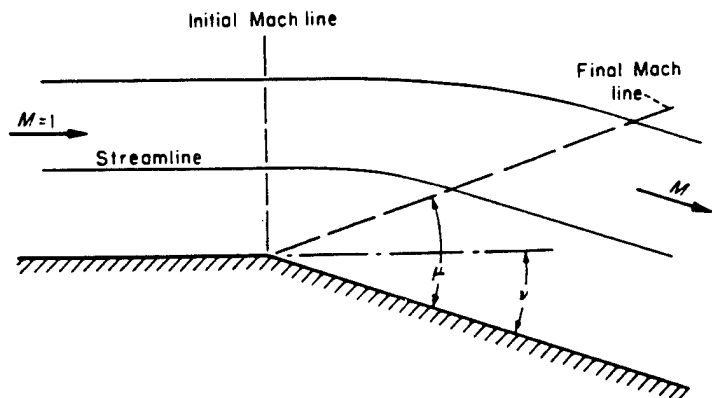


FIGURE 7.—Prandtl-Meyer expansion around a corner.

For a perfect gas, the Prandtl-Meyer angle ν through which the stream turns in expanding from $M=1$ to a supersonic Mach number M is

$$\nu = \sqrt{\frac{\gamma+1}{\gamma-1}} \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1} (M^2-1)} - (90^\circ - \mu) \quad (171a)$$

$$= \sqrt{\frac{\gamma+1}{\gamma-1}} \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1} (M^2-1)} - \cos^{-1} \frac{1}{M} \quad (171b)$$

$$= \sqrt{\frac{\gamma+1}{\gamma-1}} \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1} (M^2-1)} - \tan^{-1} \sqrt{M^2-1} \quad (171c)$$

(For $\gamma=7/5$, $\sqrt{\frac{\gamma+1}{\gamma-1}}=2.4495$, and $\sqrt{\frac{\gamma-1}{\gamma+1}}=0.40825$.) The maximum expansion angle, for $M=\infty$, is

$$\nu_{\max} = \left(\sqrt{\frac{\gamma+1}{\gamma-1}} - 1 \right) \times 90^\circ = 130.45^\circ \text{ for } \gamma=7/5 \quad (172)$$

The ratio of static to total pressure, corresponding to Mach number M is given by

$$\left(\frac{p}{p_t} \right)^{\frac{\gamma-1}{\gamma}} = \frac{1}{\gamma+1} \left\{ 1 + \cos \left[2 \sqrt{\frac{\gamma-1}{\gamma+1}} (\nu + 90^\circ - \mu) \right] \right\} \quad (173a)$$

$$= \frac{1}{\gamma+1} \left\{ 1 + \cos \left[2 \sqrt{\frac{\gamma-1}{\gamma+1}} \left(\nu + \cos^{-1} \frac{1}{M} \right) \right] \right\} \quad (173b)$$

$$= \frac{1}{\gamma+1} \left\{ 1 + \cos \left[2 \sqrt{\frac{\gamma-1}{\gamma+1}} (\nu + \tan^{-1} \sqrt{M^2-1}) \right] \right\} \quad (173c)$$

which falls to zero as $\nu \rightarrow \nu_{\max}$. Numerical values of ν , μ , and p/p_t are given in table II as functions of M .

These relations and the values in table II apply to a uniform stream flowing past any convex surface in the ab-

sence of external disturbances. (They also give a very good approximation at all Mach numbers when, as on an airfoil, external disturbances arise only from interaction with a shock wave, and are disregarded.) If flow quantities known at one point, the values at any second point can be read from table II by identifying the change in flow angle between the two points with $\Delta\nu = \nu_2 - \nu_1$, as indicated in figure 8.

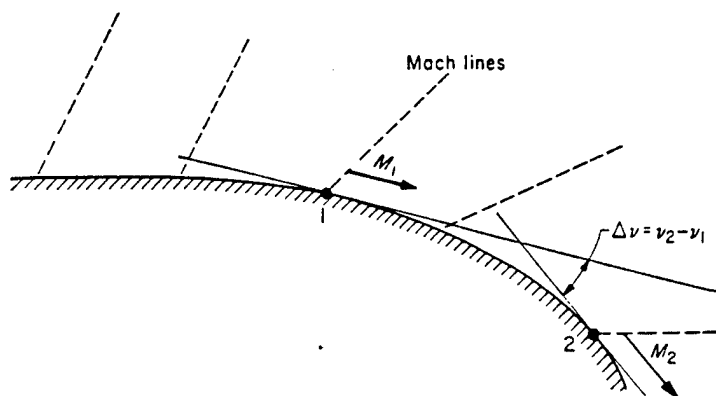


FIGURE 8.—Prandtl-Meyer expansion over a convex surface.

For expansions through small angles $\Delta\nu$, the ratio of final to initial static pressures is given by the following series ($\Delta\nu$ in radians):

$$\frac{p_2}{p_1} = 1 - \frac{\gamma M_1^2}{\sqrt{M_1^2-1}} (\Delta\nu) + \gamma M_1^2 \frac{(\gamma+1)}{4(M_1^2-1)^2} (\Delta\nu)^2 - \frac{\gamma M_1^2}{2(M_1^2-1)^{7/2}} \left[\frac{\gamma+1}{6} M_1^8 - \frac{5+7\gamma-2\gamma^2}{6} M_1^6 + \frac{5}{3} (\gamma+1) M_1^4 - 2M_1^2 + \frac{4}{3} \right] (\Delta\nu)^3 + \dots \quad (174)$$

Up to and including the term in $(\Delta\nu)^2$ this series is identical with that for compression through an oblique shock wave (eq. (151) with $\delta = -\Delta\nu$).

IMPERFECT-GAS EFFECTS

Methods for calculating the flow of a calorically imperfect, thermally imperfect gas and a calorically imperfect, thermally perfect gas at temperatures up to 5000° R are described in this section. The equations presented are in substantially the same form as those given in references 7 and 8. Effects of gaseous imperfections, such as molecular dissociation, which become important at temperatures greater than about 5000° R are not considered.

Atmospheric and wind-tunnel air flows are of primary concern here. In such flows air generally exhibits only caloric imperfections to any appreciable degree. Consequently, numerical results are presented only for the flow of a calorically imperfect, thermally perfect diatomic gas.

THERMODYNAMICS

EQUATIONS OF STATE

The thermal equation of state used here for a calorically and thermally imperfect gas is the Berthelot equation

(5)). The thermal equation of state used for a calorically imperfect, thermally perfect gas is equation (2). The caloric equation of state used for a calorically and thermally perfect gas is equation (8a). The caloric equation of state used for a calorically imperfect, thermally perfect gas is equation (8b).

SPECIFIC HEATS

The assumption of a simple harmonic vibrator is used to account for the contribution of the vibrational heat capacity to the specific heats. The equations for the specific heats at constant volume and constant pressure, respectively, are (see ref. 7)

$$c_v = (c_v)_{\text{perf}} \left\{ 1 + (\gamma_{\text{perf}} - 1) \left[\left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2} + \frac{2c_p}{RT^2} \right] \right\} \quad (175)$$

$$c_v = (c_v)_{\text{perf}} \left\{ 1 + (\gamma_{\text{perf}} - 1) \left[\left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2} \right] \right\} [\text{therm perf}] \quad (176)$$

$$c_p = (c_p)_{\text{perf}} \left\{ 1 + \frac{\gamma_{\text{perf}} - 1}{\gamma_{\text{perf}}} \left[\left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2} + \frac{2c_p}{RT^2} \left(1 + \frac{\frac{2-b_p}{1-b_p} + \frac{c_p}{2RT^2}}{\frac{1}{(1-b_p)^2} - \frac{2c_p}{RT^2}} \right) \right] \right\} \quad (177)$$

$$(c_p)_{\text{perf}} \left\{ 1 + \frac{\gamma_{\text{perf}} - 1}{\gamma_{\text{perf}}} \left[\left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2} \right] \right\} [\text{therm perf}] \quad (178)$$

The ratio of specific heats is then

$$\gamma = \gamma_{\text{perf}} \times \left[\frac{1 + \frac{\gamma_{\text{perf}} - 1}{\gamma_{\text{perf}}} \left\{ \left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2} + \frac{2c_p}{RT^2} \left[1 + \frac{\frac{2-b_p}{1-b_p} + \frac{c_p}{2RT^2}}{\frac{1}{(1-b_p)^2} - \frac{2c_p}{RT^2}} \right] \right\}}{1 + (\gamma_{\text{perf}} - 1) \left[\left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2} + \frac{2c_p}{RT^2} \right]} \right] \quad (179)$$

or, for a thermally perfect gas,

$$\gamma = 1 + \frac{\gamma_{\text{perf}} - 1}{1 + (\gamma_{\text{perf}} - 1) \left[\left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2} \right]} [\text{therm perf}] \quad (180)$$

The following values of γ are for temperatures from 400° R to 5000° R, with $\Theta = 5500^\circ \text{R}$ (see ref. 7). For engineering purposes, these are a satisfactory approximation for air.

VARIATION OF RATIO OF SPECIFIC HEATS WITH TEMPERATURE

T, °R	γ	T, °R	γ	T, °R	γ
500	1.400	1300	1.361	2200	1.322
600	1.399	1400	1.355	2400	1.317
700	1.396	1500	1.349	2600	1.313
800	1.392	1600	1.344	2800	1.309
900	1.387	1700	1.339	3000	1.306
1000	1.381	1800	1.335	3500	1.301
1100	1.375	1900	1.331	4000	1.298
1200	1.368	2000	1.328	4500	1.295
				5000	1.294

CONTINUOUS ONE-DIMENSIONAL FLOW

BASIC EQUATIONS AND DEFINITIONS

Basic equations pertinent to this section are equations (26), (27), (28), (29), (30), and (31). The equations for the speed of sound are (see ref. 7)

$$a^2 = RT \left\{ \frac{1}{(1-b_p)^2} - \frac{2c_p}{RT^2} + \frac{(\gamma_{\text{perf}} - 1) \left(\frac{c_p}{RT^2} + \frac{1}{1-b_p} \right)^2}{1 + (\gamma_{\text{perf}} - 1) \left[\left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2} + \frac{2c_p}{RT^2} \right]} \right\} \quad (181)$$

and

$$a^2 = RT \left\{ 1 + \frac{\gamma_{\text{perf}} - 1}{1 + (\gamma_{\text{perf}} - 1) \left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2}} \right\} [\text{therm perf}] \quad (182)$$

INTEGRATED FORMS OF ENERGY EQUATION

The integrated forms of the energy equation are (see ref. 7)

$$V^2 = 2RT_i \left[\frac{1 - \frac{T}{T_i}}{\gamma_{\text{perf}} - 1} + \frac{\Theta}{T_i} \left(\frac{1}{e^{\Theta/T_i} - 1} - \frac{1}{e^{\Theta/T} - 1} \right) + \frac{2c}{RT_i} \left(\frac{p}{T} - \frac{p_i}{T_i} \right) + \frac{1}{RT_i} \left(\frac{p_i}{\rho_i} - \frac{p}{\rho} \right) \right] [\text{adiab}] \quad (183)$$

and

$$V^2 = 2RT_i \left[\frac{\gamma_{\text{perf}}}{\gamma_{\text{perf}} - 1} \left(1 - \frac{T}{T_i} \right) + \frac{\Theta}{T_i} \left(\frac{1}{e^{\Theta/T_i} - 1} - \frac{1}{e^{\Theta/T} - 1} \right) \right] [\text{adiab, therm perf}] \quad (184)$$

In terms of Mach number these equations become, respectively.

$$M^2 = \frac{2T_t \left[\frac{1 - \frac{T}{T_t}}{\gamma_{\text{pert}} - 1} + \frac{\Theta}{T_t} \left(\frac{1}{e^{\Theta/T_t} - 1} - \frac{1}{e^{\Theta/T} - 1} \right) + \frac{2c}{RT_t} \left(\frac{\rho}{T} - \frac{\rho_t}{T_t} \right) + \frac{1}{RT_t} \left(\frac{p_t}{\rho_t} - \frac{p}{\rho} \right) \right]}{T \left\{ \frac{1}{(1 - b\rho)^2} - \frac{2c\rho}{RT^2} + \frac{(\gamma_{\text{pert}} - 1) \left(\frac{c\rho}{RT^2} + \frac{1}{1 - b\rho} \right)^2}{1 + (\gamma_{\text{pert}} - 1) \left[\left(\frac{\Theta}{T} \right)^2 \frac{e^{\Theta/T}}{(e^{\Theta/T} - 1)^2} + \frac{2c\rho}{RT^2} \right]} \right\}} \quad [\text{adiab}] \quad (185)$$

and

$$M^2 = \frac{2T_t}{\gamma T} \left[\frac{\gamma_{\text{pert}}}{\gamma_{\text{pert}} - 1} \left(1 - \frac{T}{T_t} \right) + \frac{\Theta}{T_t} \left(\frac{1}{e^{\Theta/T_t} - 1} - \frac{1}{e^{\Theta/T} - 1} \right) \right] \quad [\text{adiab, therm perf}] \quad (186)$$

where γ is given by equation (180).

The variations of $\frac{\left(\frac{V}{a_*}\right)_{\text{therm perf}}}{\left(\frac{V}{a_*}\right)_{\text{pert}}}$ and $\frac{\left(\frac{T}{T_t}\right)_{\text{therm perf}}}{\left(\frac{T}{T_t}\right)_{\text{pert}}}$ with Mach number for several values of total temperature T_t are given in charts 9 and 10.

PRESSURE AND DENSITY RELATIONS

For isentropic flow, the relations between density and temperature are (see ref. 7)

$$\left(\frac{\rho}{\rho_t} \right) \left(\frac{1 - b\rho_t}{1 - b\rho} \right) = \left(\frac{e^{\Theta/T_t} - 1}{e^{\Theta/T} - 1} \right) \left(\frac{T}{T_t} \right)^{\frac{1}{\gamma_{\text{pert}} - 1}} \exp \left[\frac{c\rho_t}{RT_t^2} - \frac{c\rho}{RT^2} + \left(\frac{\Theta}{T} \right) \frac{e^{\Theta/T}}{e^{\Theta/T} - 1} - \left(\frac{\Theta}{T_t} \right) \frac{e^{\Theta/T_t}}{e^{\Theta/T_t} - 1} \right] \quad [\text{isen}] \quad (187)$$

and, for a thermally perfect gas,

$$\frac{\rho}{\rho_t} = \left(\frac{e^{\Theta/T_t} - 1}{e^{\Theta/T} - 1} \right) \left(\frac{T}{T_t} \right)^{\frac{1}{\gamma_{\text{pert}} - 1}} \exp \left[\left(\frac{\Theta}{T} \right) \frac{e^{\Theta/T}}{e^{\Theta/T} - 1} - \left(\frac{\Theta}{T_t} \right) \frac{e^{\Theta/T_t}}{e^{\Theta/T_t} - 1} \right] \quad [\text{isen, therm perf}]$$

The variation of $\frac{\left(\frac{\rho}{\rho_t}\right)_{\text{therm perf}}}{\left(\frac{\rho}{\rho_t}\right)_{\text{pert}}}$ with Mach number for several total temperatures is presented in chart 11.

For the isentropic flow of a thermally imperfect, calorically imperfect gas, the relation between pressure, density, and temperature can be obtained by a trial-and-error procedure using equations (5) and (187).⁵ For the isentropic flow of a thermally perfect gas, the relation between pressure and temperature is

$$\frac{p}{p_t} = \left(\frac{e^{\Theta/T_t} - 1}{e^{\Theta/T} - 1} \right) \left(\frac{T}{T_t} \right)^{\frac{\gamma_{\text{pert}}}{\gamma_{\text{pert}} - 1}} \exp \left[\left(\frac{\Theta}{T} \right) \frac{e^{\Theta/T}}{e^{\Theta/T} - 1} - \left(\frac{\Theta}{T_t} \right) \frac{e^{\Theta/T_t}}{e^{\Theta/T_t} - 1} \right] \quad [\text{isen, therm perf}] \quad (189)$$

The relation between dynamic and static pressure for a thermally imperfect gas can be obtained by a trial-and-error procedure using equations (5), (31a), (183), and (187). The relation between dynamic and static pressure for a thermally perfect gas can be obtained with equations (31b) and (186), and is

$$\frac{q}{p} = \frac{\gamma_{\text{pert}}}{\gamma_{\text{pert}} - 1} \left(\frac{T_t}{T} - 1 \right) + \frac{\Theta}{T} \left(\frac{1}{e^{\Theta/T_t} - 1} - \frac{1}{e^{\Theta/T} - 1} \right) \quad [\text{adiab, therm perf}] \quad (190)$$

The variations of $\frac{\left(\frac{p}{p_t}\right)_{\text{therm perf}}}{\left(\frac{p}{p_t}\right)_{\text{pert}}}$ and $\frac{\left(\frac{q}{p_t}\right)_{\text{therm perf}}}{\left(\frac{q}{p_t}\right)_{\text{pert}}}$ with Mach

number for several total temperatures are given in charts 12 and 13.

STREAM-TUBE-AREA RELATIONS

The stream-tube-area relation is given by equation (79) or, in more convenient form,

$$\frac{A}{A_*} = \frac{\rho_* a_*}{\rho a M} \quad (191)$$

This ratio can be evaluated for a thermally imperfect gas with the aid of equations (187), (181), (5), and (185), and for a thermally perfect gas with the aid of equations (188)

(182), and (186). The variation of $\frac{\left(\frac{A}{A_*}\right)_{\text{therm perf}}}{\left(\frac{A}{A_*}\right)_{\text{pert}}}$ with

number for several values of total temperature is presented in chart 14.

⁵ In this, as in many of the cases to be presented, no direct solution for flow properties is possible if the gas exhibits both thermal and caloric imperfections. Approximate solutions of this type can be obtained, however, if the degree of imperfection is small (see ref. 7).

NORMAL SHOCK WAVES

requirements for conservation of mass, momentum, and energy across a normal shock wave are given by equations (84), (85), and (86a). The energy relation can be written

$$\frac{u_2^2}{2} - \frac{u_1^2}{2} + \frac{R}{\gamma_{\text{pert}} - 1} (T_2 - T_1) - \left(\frac{2c\rho_2}{T_2} - \frac{2c\rho_1}{T_1} \right) + \left(\frac{p_2}{\rho_2} - \frac{p_1}{\rho_1} \right) + R\theta \left(\frac{1}{e^{\theta/T_2} - 1} - \frac{1}{e^{\theta/T_1} - 1} \right) = 0 \quad [\text{adiab}] \quad (192)$$

or, for a thermally perfect gas,

$$\frac{u_2^2}{2} - \frac{u_1^2}{2} + \left(\frac{\gamma_{\text{pert}}}{\gamma_{\text{pert}} - 1} \right) R(T_2 - T_1) + R\theta \left(\frac{1}{e^{\theta/T_2} - 1} - \frac{1}{e^{\theta/T_1} - 1} \right) = 0 \quad [\text{adiab, therm perf}] \quad (193)$$

No explicit equation has been found to relate the temperature downstream of a normal shock wave in thermally imperfect air to the upstream conditions. A trial-and-error procedure, starting with assumed values of ρ_2 and T_2 and involving equations (5), (84), (85), and (192), can be used to determine the downstream temperature.

For the flow of a thermally perfect gas, the simultaneous solution of equations (84), (85), (193), and (2) yields the defining relation from which the temperature behind the shock wave can be found:

$$\left(u_1 + \frac{RT_1}{u_1} \right)^2 - \left(u_1 + \frac{RT_1}{u_1} \right) \sqrt{\left(u_1 + \frac{RT_1}{u_1} \right)^2 - 4RT_2 - 2RT_2 - 2u_1^2 + \left(\frac{\gamma_{\text{pert}}}{\gamma_{\text{pert}} - 1} \right) 4R(T_2 - T_1) - 4R\theta \left(\frac{1}{e^{\theta/T_2} - 1} - \frac{1}{e^{\theta/T_1} - 1} \right)} = 0 \quad [\text{adiab, therm perf}] \quad (194)$$

Since the total temperature T_t remains constant across a shock wave, other flow parameters behind the shock wave can be found with the aid of previously presented one-dimensional flow relations. The variations of

$$\frac{\left(\frac{T_2}{T_1} \right)_{\text{therm perf}}}{\left(\frac{T_2}{T_1} \right)_{\text{pert}}}, \frac{\left(\frac{\rho_2}{\rho_1} \right)_{\text{therm perf}}}{\left(\frac{\rho_2}{\rho_1} \right)_{\text{pert}}}, \frac{\left(\frac{p_2}{p_1} \right)_{\text{therm perf}}}{\left(\frac{p_2}{p_1} \right)_{\text{pert}}}, \frac{\left(\frac{p_2}{p_1} \right)_{\text{therm perf}}}{\left(\frac{p_2}{p_1} \right)_{\text{pert}}}, \frac{M_{2,\text{therm perf}}}{M_{2,\text{pert}}}, \text{ and } \frac{\left(\frac{p_{t2}}{p_{t1}} \right)_{\text{therm perf}}}{\left(\frac{p_{t2}}{p_{t1}} \right)_{\text{pert}}}$$

upstream Mach number for several total temperatures presented in charts 15 through 20, respectively.

OBLIQUE SHOCK WAVES

For a thermally imperfect gas, no simple equations can be found to relate the values of the flow parameters across oblique shock waves. In general, trial-and-error procedure, starting with assumed values of ρ_2 and T_2 , and involving the relations for the conservation of mass, momentum, and energy, must be used. (See eqs. (115), (116), (117), and (118a) as well as equations (5) and (183).) For a thermally perfect gas, the Mach number downstream of an oblique shock wave can be found with the aid of the energy equation (see eqs. (118a) and (186)), thus

$$M_2^2 = \frac{2T_1}{\gamma_2 T_2} \left[\frac{\gamma_1 M_1^2}{2} + \left(\frac{\gamma_{\text{pert}}}{\gamma_{\text{pert}} - 1} \right) \left(1 - \frac{T_2}{T_1} \right) + \frac{\theta}{T_1} \left(\frac{1}{e^{\theta/T_1} - 1} - \frac{1}{e^{\theta/T_2} - 1} \right) \right] \quad [\text{adiab, therm perf}] \quad (195)$$

where γ_1 and γ_2 are the functions of T_1 and T_2 , respectively, given by equation (180). The pressure ratio across the shock is given by

$$\frac{p_2}{p_1} = \frac{1}{2} \left\{ (1 + \gamma_2 M_2^2) - \frac{T_1}{T_2} (1 + \gamma_1 M_1^2) + \sqrt{\left[(1 + \gamma_2 M_2^2) - \frac{T_1}{T_2} (1 + \gamma_1 M_1^2) \right]^2 + 4 \frac{T_1}{T_2}} \right\} \quad [\text{adiab, therm perf}] \quad (196)$$

The density ratio can be determined from the equation of state (eq. (2)) with the aid of the pressure and temperature ratios. The shock-wave and deflection angles are given by (see ref. 8)

$$\sin^2 \theta = \frac{\left(\frac{\gamma_2}{\gamma_1} \right) \left(\frac{T_2}{T_1} \right) \left(\frac{M_2}{M_1} \right)^2 - 1}{\left(\frac{\rho_1}{\rho_2} \right)^2 - 1} \quad [\text{adiab, therm perf}] \quad (197)$$

and

$$\cot \delta = \tan \theta \left(\frac{\gamma_1 M_1^2}{\frac{p_2}{p_1} - 1} - 1 \right) \quad [\text{adiab, therm perf}] \quad (198)$$

respectively.

The variation of θ with δ for various values of M_1 and T_1 is presented in chart 21. In addition, the variations of

$$\frac{(M_2)_{\text{therm perf}}}{(M_2)_{\text{pert}}} \text{ and } \frac{\left(\frac{p_2 - p_1}{q_1} \right)_{\text{therm perf}}}{\left(\frac{p_2 - p_1}{q_1} \right)_{\text{pert}}} \text{ with } \delta \text{ for various } M_1 \text{ and } T_1$$

are presented in charts 22 and 23.

Values of the ratios

$$\frac{p_2}{p_1}, \frac{\rho_2}{\rho_1}, \frac{T_2}{T_1}, \frac{p_{t2}}{p_{t1}}$$

for the flow of a thermally perfect gas across an oblique shock wave can be determined from the normal-shock relations,

provided that $M_1 \sin \theta$ is used instead of M_1 and that the static temperature T_1 just upstream of the shock wave is the same for the oblique shock wave as for the normal shock wave.

PRANDTL-MEYER EXPANSION

The Prandtl-Meyer angle for the flow of an imperfect gas can be found by graphically integrating the equation (see ref. 8)

$$\nu = - \int_{p_0}^p \frac{dp}{\rho V^2 \tan \mu} \quad [\text{isen}] \quad (199)$$

The relations between p , ρ , V , and μ can be found with the

aid of equations (5), (187), (183), and (185). For a thermally perfect gas this equation becomes (see, again, ref. 8)

$$\nu = - \int_{p_0}^p \frac{\sin 2\mu}{2\gamma p} dp \quad [\text{isen, therm perf}] \quad (200)$$

The relations between γ , p , and μ can be found with the aid of equations (180), (189), and (186) using the temperature as a parameter. The graphical integration of equation (200) has been carried out, and the variations of $\nu_{\text{therm perf}}$ and $\frac{\nu_{\text{therm perf}}}{\nu_{\text{perf}}}$ with Mach number for various values of total temperature are presented in chart 24.

APPENDIX A

VISCOSITY AND THERMODYNAMIC CONSTANTS FOR AIR

VISCOSITY

The viscosity of air is nearly independent of pressure; the variation with absolute temperature, between temperatures of about 300° R and 900° R, may be approximated by the formula

$$\frac{\mu}{\mu_r} = \left(\frac{T}{T_r} \right)^{0.76} \quad (\text{A1})$$

For a wider range of temperatures, between about 180° R and 3400° R, Sutherland's formula (see ref. 19) is more accurate:

$$\frac{\mu}{\mu_r} = \frac{T_r + 198.6}{T + 198.6} \left(\frac{T}{T_r} \right)^{3/2} \quad (\text{A2})$$

The viscosity of air, as determined from this relation, may be expressed as

$$\mu = 2.270 \frac{T^{3/2}}{T + 198.6} \times 10^{-8} \frac{\text{lb sec}}{\text{ft}^2} \quad (\text{A3})$$

This latter equation has been employed in the calculations of Reynolds number (chart 25).

THERMODYNAMIC CONSTANTS

The value of γ employed for air, when treated as a completely perfect gas, is 7/5. This simple value, which has been employed in table I, table II, charts 1 to 4, and chart 25, is a good approximation to the more precise values obtained from spectroscopic measurements (see ref. 20). Values of c_p , c_v , and R for air, consistent with the approximation $\gamma = 7/5$, are

$$c_p = 6006 \text{ ft}^2/\text{sec}^2 \text{ } ^\circ\text{R}$$

$$c_v = 4290 \text{ ft}^2/\text{sec}^2 \text{ } ^\circ\text{R}$$

$$R = 1716 \text{ ft}^2/\text{sec}^2 \text{ } ^\circ\text{R}$$

APPENDIX B

REYNOLDS NUMBER

Reynolds number is defined as

$$R = \frac{\rho V l}{\mu} \quad (\text{B1})$$

For sea-level conditions,

$$R \cong 10,000 \text{ (} V \text{ in mph) (} l \text{ in ft)} \quad (\text{B2})$$

In a wind tunnel (subsonic or supersonic), if isentropic expansion is assumed from a total pressure p_t and equation

(A2) is used for the variation of viscosity with temperature, the Reynolds number per unit reference length is given by

$$\frac{R}{l} = \frac{p_t M}{\mu_t} \sqrt{\frac{\gamma}{(\gamma-1)c_p T_t}} \left(\frac{T_t}{T} \right)^{\frac{\gamma-2}{\gamma-1}} \frac{T}{T_t} + \frac{198.6}{T_t} \quad [\text{perf}] \quad (\text{B3})$$

The Reynolds number per unit length for $p_t = 1$ psia has been plotted in chart 25 as a function of M for various total temperatures T_t .

APPENDIX C

PRESSURE CONVERSION FACTORS AND CONSTANTS

Multiply by to obtain	lb in. ²	lb ft. ²	in. H ₂ O at 70° F	in. Hg at 70° F	cm. Hg at 70° F	Standard atmos- pheres
lb/in. ²	1	0.006944	0.03607	0.4892	0.1926	14.70
lb/ft. ²	144	1	5.194	70.45	27.74	2117
in. H ₂ O (70° F)	27.73	.1925	1	13.56	5.340	407.6
in. Hg (70° F)	2.044	.01420	.07373	1	.3937	30.05
cm. Hg (70° F)	5.192	.03605	.1873	2.540	1	76.33
Standard atmospheres	.06804	.0004725	.002453	.03328	.01310	1

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Table 2.39 Dry Air, Coefficients of Viscosity. F. C. Moreau comp., National Bureau of Standards. Dec. 1950.

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TABLES

The tables that follow contain numerical values for certain quantities often required for the solution of problems in compressible flow. The symbols used in these tables are the same as those used in the preceding sections. For convenience, however, the symbols are redefined at the end of table II.

To conserve space, a modified computing-machine notation has been adopted to indicate the position of the decimal point in the tabulated quantities. The location of the decimal point is governed by the following rules:

- (a) A group of digits followed by $-n$ indicates that the decimal point should be n places to the left of the first digit.

Example: $.3268_{-3} = .0003268$

- (b) A group of digits followed by $+n$ indicates that the decimal point should be n places to the right of the last digit.

Example: $3268_{+3} = 3,268,000$

- (c) A group of digits without a suffix indicates that the decimal point is correctly located as printed.

TABLE I.—SUBSONIC FLOW

The ratios given by equations (43), (44), (45), (48), (50), and (83) are given as functions of Mach number. If, at a point in an isentropic flow, any one of these ratios or the Mach number is known, then all other ratios for that point can be read or interpolated from the table. In addition, the parameter $\beta = \sqrt{M^2 - 1}$, which is sometimes more convenient to use than the Mach number itself, is also tabulated.

TABLE II.—SUPERSONIC FLOW

The ratios given in table I for subsonic flow are also given in table II for supersonic flow. The Mach angle μ and the Prandtl-Meyer angle ν are also given as functions of Mach number. In addition to these point functions for isentropic flow, the normal-shock relations given by equations (93), (94), (95), (96), (99), and (100) are tabulated as functions of the Mach number M_1 ahead of the shock wave. Although these values are for normal shock waves, the values of p_2/p_1 , ρ_2/ρ_1 , T_2/T_1 , and p_{t2}/p_{t1} may also be used for oblique shock waves, provided $M_1 \sin \theta$ is used instead of M_1 in the first column.

TABLE I.—SUBSONIC FLOW

 $\gamma = 7/5$

M	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A_*}$	$\frac{V}{a_*}$	M	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A_*}$	$\frac{V}{a_*}$
0	1.0000	1.0000	1.0000	1.0000	0	∞	0	0.50	0.8430	0.8852	0.9524	0.8660	0.1475	1.3398	0.53452
.01	.9999	1.0000	1.0000	1.0000	.7000	57.8738	.01095	.51	.8374	.8809	.9506	.8602	.1525	1.3212	.54469
.02	.9997	.9998	.9999	.9999	.2799	28.9421	.02191	.52	.8317	.8766	.9487	.8542	.1574	1.3034	.55483
.03	.9994	.9996	.9998	.9998	.6296	19.3005	.03286	.53	.8259	.8723	.9468	.8480	.1624	1.2865	.56493
.04	.9989	.9992	.9997	.9992	.1119	14.4815	.04381	.54	.8201	.8679	.9449	.8417	.1674	1.2703	.57501
.05	.9983	.9988	.9995	.9987	.1747	11.5914	.05476	.55	.8142	.8634	.9430	.8352	.1724	1.2550	.58506
.06	.9975	.9982	.9993	.9982	.2514	9.6659	.06570	.56	.8082	.8589	.9410	.8285	.1774	1.2403	.59507
.07	.9966	.9976	.9990	.9975	.3418	8.2915	.07664	.57	.8022	.8544	.9390	.8216	.1825	1.2263	.60505
.08	.9955	.9968	.9987	.9958	.4460	7.2616	.08758	.58	.7962	.8498	.9370	.8146	.1875	1.2130	.61501
.09	.9944	.9960	.9984	.9959	.5638	6.4613	.09851	.59	.7901	.8451	.9349	.8074	.1925	1.2003	.62492
.10	.9930	.9950	.9980	.9950	.6951	5.8218	.10944	.60	.7840	.8405	.9328	.8000	.1976	1.1882	.63481
.11	.9916	.9940	.9976	.9939	.8399	5.2992	.12035	.61	.7778	.8357	.9307	.7924	.2026	1.1767	.64466
.12	.9900	.9928	.9971	.9928	.9979	4.8643	.13126	.62	.7716	.8310	.9286	.7846	.2076	1.1657	.65448
.13	.9883	.9916	.9966	.9915	1.169	4.4969	.14217	.63	.7654	.8262	.9265	.7766	.2127	1.1552	.66427
.14	.9864	.9903	.9961	.9902	1.353	4.1824	.15306	.64	.7591	.8213	.9243	.7684	.2177	1.1452	.67402
.15	.9844	.9888	.9955	.9887	1.550	3.9103	.16395	.65	.7528	.8164	.9221	.7599	.2227	1.1356	.68374
.16	.9823	.9873	.9949	.9871	1.760	3.6727	.17482	.66	.7465	.8115	.9199	.7513	.2276	1.1265	.69342
.17	.9800	.9857	.9943	.9854	1.983	3.4635	.18569	.67	.7401	.8066	.9176	.7424	.2326	1.1179	.70307
.18	.9776	.9840	.9936	.9837	2.217	3.2779	.19654	.68	.7338	.8016	.9153	.7332	.2375	1.1097	.71264
.19	.9751	.9822	.9928	.9818	2.464	3.1123	.20739	.69	.7274	.7966	.9131	.7238	.2424	1.1018	.72225
.20	.9725	.9803	.9921	.9798	2.721	2.9635	.21822	.70	.7209	.7916	.9107	.7141	.2473	1.0944	.73179
.21	.9697	.9783	.9913	.9777	2.994	2.8293	.22904	.71	.7145	.7865	.9084	.7042	.2521	1.0873	.74129
.22	.9668	.9762	.9904	.9755	3.276	2.7076	.23984	.72	.7080	.7814	.9061	.6940	.2569	1.0806	.75076
.23	.9638	.9740	.9895	.9732	3.569	2.5968	.25063	.73	.7016	.7763	.9037	.6834	.2617	1.0742	.76019
.24	.9607	.9718	.9886	.9708	3.874	2.4956	.26141	.74	.6951	.7712	.9013	.6726	.2664	1.0681	.76958
.25	.9575	.9694	.9877	.9682	4.189	2.4027	.27217	.75	.6886	.7660	.8989	.6614	.2711	1.0624	.77894
.26	.9541	.9670	.9867	.9656	4.515	2.3173	.28291	.76	.6821	.7609	.8964	.6499	.2758	1.0570	.78825
.27	.9506	.9645	.9856	.9629	4.851	2.2385	.29364	.77	.6756	.7557	.8940	.6380	.2804	1.0519	.79751
.28	.9470	.9619	.9846	.9600	5.197	2.1656	.30435	.78	.6691	.7505	.8915	.6258	.2849	1.0471	.80677
.29	.9433	.9592	.9835	.9570	5.553	2.0979	.31504	.79	.6625	.7452	.8890	.6131	.2894	1.0425	.81597
.30	.9395	.9564	.9823	.9539	5.919	2.0351	.32572	.80	.6560	.7400	.8865	.6000	.2939	1.0382	.82511
.31	.9355	.9535	.9811	.9507	6.293	1.9765	.33637	.81	.6495	.7347	.8840	.5864	.2983	1.0342	.83425
.32	.9315	.9506	.9799	.9474	6.677	1.9219	.34701	.82	.6430	.7295	.8815	.5724	.3027	1.0305	.84335
.33	.9274	.9476	.9787	.9440	7.069	1.8707	.35762	.83	.6365	.7242	.8789	.5578	.3069	1.0270	.85239
.34	.9231	.9445	.9774	.9404	7.470	1.8229	.36822	.84	.6300	.7189	.8763	.5426	.3112	1.0237	.86140
.35	.9188	.9413	.9761	.9367	7.879	1.7780	.37879	.85	.6235	.7136	.8737	.5268	.3153	1.0207	.87037
.36	.9143	.9380	.9747	.9330	8.295	1.7358	.38935	.86	.6170	.7083	.8711	.5103	.3195	1.0179	.87929
.37	.9098	.9347	.9733	.9290	8.719	1.6961	.39988	.87	.6106	.7030	.8685	.4931	.3235	1.0153	.88818
.38	.9052	.9313	.9719	.9250	9.149	1.6587	.41039	.88	.6041	.6977	.8659	.4750	.3275	1.0129	.89703
.39	.9004	.9278	.9705	.9208	9.587	1.6234	.42087	.89	.5977	.6924	.8632	.4560	.3314	1.0108	.90583
.40	.8956	.9243	.9690	.9165	10.03	1.5901	.43133	.90	.5913	.6870	.8606	.4359	.3352	1.0089	.91460
.41	.8907	.9207	.9675	.9121	10.48	1.5587	.44177	.91	.5849	.6817	.8579	.4146	.3390	1.0071	.92332
.42	.8857	.9170	.9659	.9075	10.94	1.5289	.45218	.92	.5785	.6764	.8552	.3919	.3427	1.0056	.93201
.43	.8807	.9132	.9643	.9028	11.40	1.5007	.46257	.93	.5721	.6711	.8525	.3676	.3464	1.0043	.94065
.44	.8755	.9094	.9627	.8980	11.87	1.4740	.47293	.94	.5658	.6658	.8498	.3412	.3500	1.0031	.94925
.45	.8703	.9055	.9611	.8930	12.34	1.4487	.48326	.95	.5595	.6604	.8471	.3122	.3534	1.0022	.95781
.46	.8650	.9016	.9594	.8879	12.81	1.4246	.49357	.96	.5532	.6551	.8444	.2800	.3569	1.0014	.96633
.47	.8596	.8976	.9577	.8827	13.29	1.4018	.50385	.97	.5469	.6498	.8416	.2431	.3602	1.0008	.97481
.48	.8541	.8935	.9560	.8773	13.76	1.3801	.51410	.98	.5407	.6445	.8389	.1990	.3635	1.0003	.98325
.49	.8486	.8894	.9542	.8717	14.26	1.3595	.52433	.99	.5345	.6392	.8361	.1411	.3667	1.0001	.99165
1.00	.5283	.6339	.8333	0	0.3693	1.000	1.00000	0	.5283	.6339	.8333	.0000	.3693	1.000	1.00000

TABLE II.—SUPERSONIC FLOW

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A_*}$	$\frac{V}{a_*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_2}{p_1}$	$\frac{p_1}{p_2}$
1.00	0.5283	0.6339	0.8333	0	0.3693	1.000	1.00000	0	90.00	1.000	1.000	1.000	1.000	0.5283
1.01	.5221	.6287	.8306	.1418	.3728	1.000	1.00831	.04473	81.93	.9901	1.023	1.017	1.007	.5221
1.02	.5160	.6234	.8278	.2010	.3758	1.000	1.01658	.1257	78.64	.9805	1.047	1.033	1.013	.5160
1.03	.5099	.6181	.8250	.2468	.3787	1.001	1.02481	.2294	76.14	.9712	1.071	1.050	1.020	.5100
1.04	.5039	.6129	.8222	.2857	.3815	1.001	1.03300	.3510	74.06	.9620	1.095	1.067	1.026	.5039
1.05	.4979	.6077	.8193	.3202	.3842	1.002	1.04114	.4874	72.25	.9531	1.120	1.084	1.033	.4980
1.06	.4919	.6021	.8165	.3516	.3869	1.003	1.04925	.6367	70.63	.9444	1.144	1.101	1.039	.4920
1.07	.4860	.5972	.8137	.3807	.3895	1.004	1.05731	.7973	69.16	.9360	1.169	1.118	1.046	.4861
1.08	.4800	.5920	.8108	.4079	.3919	1.005	1.06533	.9680	67.81	.9277	1.194	1.135	1.052	.4803
1.09	.4742	.5869	.8080	.4337	.3944	1.006	1.07331	1.148	66.55	.9196	1.219	1.152	1.059	.4746
1.10	.4684	.5817	.8052	.4583	.3967	1.008	1.08124	1.336	65.36	.9118	1.245	1.169	1.065	.4689
1.11	.4626	.5766	.8023	.4818	.3990	1.010	1.08913	1.532	64.28	.9041	1.271	1.186	1.071	.4632
1.12	.4568	.5714	.7994	.5044	.4011	1.011	1.09699	1.735	63.23	.8966	1.297	1.203	1.078	.4576
1.13	.4511	.5663	.7966	.5262	.4032	1.013	1.10479	1.944	62.25	.8892	1.323	1.221	1.084	.4521
1.14	.4455	.5612	.7937	.5474	.4052	1.015	1.11256	2.160	61.31	.8820	1.350	1.238	1.090	.4467
1.15	.4398	.5562	.7908	.5679	.4072	1.017	1.12029	2.381	60.41	.8750	1.376	1.255	1.097	.4413
1.16	.4343	.5511	.7879	.5879	.4090	1.020	1.12797	2.607	59.55	.8682	1.403	1.272	1.103	.4360
1.17	.4287	.5461	.7849	.6074	.4108	1.022	1.13561	2.839	58.73	.8615	1.430	1.290	1.109	.4307
1.18	.4232	.5411	.7822	.6264	.4125	1.025	1.14321	3.074	57.94	.8549	1.458	1.307	1.115	.4255
1.19	.4176	.5361	.7793	.6451	.4141	1.026	1.15077	3.314	57.18	.8485	1.485	1.324	1.122	.4204
1.20	.4124	.5311	.7764	.6633	.4157	1.030	1.15828	3.558	56.44	.8422	1.513	1.342	1.128	.4154
1.21	.4070	.5262	.7735	.6812	.4171	1.033	1.16575	3.806	55.74	.8360	1.541	1.359	1.134	.4104
1.22	.4017	.5213	.7706	.6989	.4185	1.037	1.17319	4.057	55.05	.8300	1.570	1.376	1.141	.4055
1.23	.3964	.5164	.7677	.7162	.4198	1.040	1.18057	4.312	54.39	.8241	1.598	1.394	1.147	.4006
1.24	.3912	.5115	.7648	.7332	.4211	1.043	1.18792	4.569	53.75	.8183	1.627	1.411	1.153	.3958

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma=7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A_*}$	$\frac{V}{a_*}$	ν	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
1.25	.3861	.5067	.7619	.7500	.4223	1.047	1.19523	4.830	53.13	.8126	1.656	1.429	1.159	.9871	.3911
1.26	.3809	.5019	.7590	.7666	.4233	1.050	1.20249	5.093	52.53	.8071	1.686	1.446	1.166	.9857	.3865
1.27	.3759	.4971	.7561	.7829	.4244	1.054	1.20972	5.359	51.94	.8016	1.715	1.463	1.172	.9842	.3819
1.28	.3708	.4923	.7532	.7990	.4253	1.058	1.21690	5.627	51.38	.7963	1.745	1.481	1.178	.9827	.3774
1.29	.3658	.4876	.7503	.8149	.4262	1.062	1.22404	5.898	50.82	.7911	1.775	1.498	1.185	.9811	.3729
1.30	.3609	.4829	.7474	.8307	.4270	1.066	1.23114	6.170	50.28	.7860	1.805	1.516	1.191	.9794	.3685
1.31	.3560	.4782	.7445	.8462	.4277	1.071	1.23819	6.445	49.76	.7809	1.835	1.533	1.197	.9776	.3642
1.32	.3512	.4736	.7416	.8616	.4283	1.075	1.24521	6.721	49.25	.7760	1.866	1.551	1.204	.9758	.3599
1.33	.3464	.4690	.7387	.8769	.4289	1.080	1.25218	7.000	48.75	.7712	1.897	1.568	1.210	.9738	.3557
1.34	.3417	.4644	.7358	.8920	.4294	1.084	1.25912	7.280	48.27	.7664	1.928	1.585	1.216	.9718	.3516
1.35	.3370	.4598	.7329	.9069	.4299	1.089	1.26601	7.561	47.79	.7618	1.960	1.603	1.223	.9697	.3475
1.36	.3323	.4553	.7300	.9217	.4303	1.094	1.27286	7.844	47.33	.7572	1.991	1.620	1.229	.9676	.3435
1.37	.3277	.4508	.7271	.9364	.4306	1.099	1.27968	8.128	46.88	.7527	2.023	1.638	1.235	.9653	.3395
1.38	.3232	.4463	.7242	.9510	.4308	1.104	1.28645	8.413	46.44	.7483	2.055	1.655	1.242	.9630	.3356
1.39	.3187	.4418	.7213	.9655	.4310	1.109	1.29318	8.699	46.01	.7440	2.087	1.672	1.248	.9607	.3317
1.40	.3142	.4374	.7184	.9798	.4311	1.115	1.29987	8.987	45.58	.7397	2.120	1.690	1.255	.9582	.3280
1.41	.3098	.4330	.7155	.9940	.4312	1.120	1.30652	9.276	45.17	.7355	2.153	1.707	1.261	.9557	.3242
1.42	.3055	.4287	.7126	1.008	.4312	1.126	1.31313	9.565	44.77	.7314	2.186	1.724	1.268	.9531	.3205
1.43	.3012	.4244	.7097	1.022	.4311	1.132	1.31970	9.855	44.37	.7274	2.219	1.742	1.274	.9504	.3169
1.44	.2969	.4201	.7069	1.036	.4310	1.138	1.32623	10.146	43.98	.7235	2.253	1.759	1.281	.9476	.3133
1.45	.2927	.4158	.7040	1.050	.4308	1.144	1.33272	10.438	43.60	.7196	2.286	1.776	1.287	.9448	.3098
1.46	.2886	.4116	.7011	1.064	.4306	1.150	1.33917	10.731	43.23	.7157	2.320	1.793	1.294	.9420	.3063
1.47	.2845	.4074	.6982	1.077	.4303	1.156	1.34558	11.023	42.86	.7120	2.354	1.811	1.300	.9390	.3029
1.48	.2804	.4032	.6954	1.091	.4299	1.163	1.35195	11.317	42.51	.7083	2.389	1.828	1.307	.9360	.2996
1.49	.2764	.3991	.6925	1.105	.4295	1.169	1.35828	11.611	42.16	.7047	2.423	1.845	1.314	.9329	.2962
1.50	.2724	.3950	.6897	1.118	.4290	1.176	1.36458	11.905	41.81	.7011	2.458	1.862	1.320	.9298	.2930
1.51	.2685	.3909	.6868	1.131	.4285	1.183	1.37083	12.200	41.47	.6976	2.493	1.879	1.327	.9266	.2898
1.52	.2646	.3869	.6840	1.145	.4279	1.190	1.37705	12.496	41.14	.6941	2.529	1.896	1.334	.9233	.2866
1.53	.2608	.3829	.6811	1.158	.4273	1.197	1.38322	12.790	40.81	.6907	2.564	1.913	1.340	.9200	.2835
1.54	.2570	.3789	.6783	1.171	.4266	1.204	1.38936	13.086	40.49	.6874	2.600	1.930	1.347	.9166	.2804
1.55	.2533	.3750	.6754	1.184	.4259	1.212	1.39546	13.381	40.18	.6841	2.636	1.947	1.354	.9132	.2773
1.56	.2496	.3710	.6726	1.197	.4252	1.219	1.40152	13.677	39.87	.6809	2.673	1.964	1.361	.9097	.2744
1.57	.2459	.3672	.6698	1.210	.4245	1.227	1.40755	13.973	39.56	.6777	2.709	1.981	1.367	.9061	.2714
1.58	.2423	.3633	.6670	1.223	.4238	1.234	1.41353	14.269	39.27	.6746	2.746	1.998	1.374	.9025	.2685
1.59	.2388	.3595	.6642	1.236	.4230	1.242	1.41948	14.564	38.97	.6715	2.783	2.015	1.381	.8989	.2656
1.60	.2353	.3557	.6614	1.249	.4216	1.250	1.42539	14.861	38.68	.6684	2.820	2.032	1.388	.8952	.2628
1.61	.2318	.3520	.6586	1.262	.4206	1.258	1.43127	15.156	38.40	.6655	2.857	2.049	1.395	.8915	.2600
1.62	.2284	.3483	.6558	1.275	.4196	1.267	1.43710	15.452	38.12	.6625	2.895	2.065	1.402	.8877	.2573
1.63	.2250	.3446	.6530	1.287	.4185	1.275	1.44290	15.747	37.84	.6596	2.933	2.082	1.409	.8838	.2546
1.64	.2217	.3409	.6502	1.300	.4174	1.284	1.44866	16.043	37.57	.6568	2.971	2.099	1.416	.8799	.2519
1.65	.2184	.3373	.6475	1.312	.4162	1.292	1.45439	16.338	37.31	.6540	3.010	2.115	1.423	.8760	.2493
1.66	.2151	.3337	.6447	1.325	.4150	1.301	1.46008	16.633	37.04	.6512	3.048	2.132	1.430	.8720	.2467
1.67	.2119	.3302	.6419	1.337	.4138	1.310	1.46573	16.928	36.78	.6485	3.087	2.148	1.437	.8680	.2442
1.68	.2088	.3266	.6392	1.350	.4125	1.319	1.47135	17.222	36.53	.6458	3.126	2.165	1.444	.8640	.2417
1.69	.2057	.3232	.6364	1.362	.4112	1.328	1.47693	17.516	36.28	.6431	3.165	2.181	1.451	.8598	.2392
1.70	.2026	.3197	.6337	1.375	.4098	1.338	1.48247	17.810	36.03	.6405	3.205	2.198	1.458	.8557	.2368
1.71	.2006	.3163	.6310	1.387	.4085	1.347	1.48798	18.103	35.79	.6380	3.245	2.214	1.466	.8516	.2344
1.72	.1986	.3129	.6283	1.399	.4071	1.357	1.49345	18.397	35.55	.6355	3.285	2.230	1.473	.8474	.2320
1.73	.1966	.3095	.6256	1.412	.4056	1.367	1.49889	18.689	35.31	.6330	3.325	2.247	1.480	.8431	.2296
1.74	.1907	.3062	.6229	1.424	.4041	1.376	1.50429	18.981	35.08	.6305	3.366	2.263	1.487	.8389	.2273
1.75	.1878	.3029	.6202	1.436	.4026	1.386	1.50966	19.273	34.85	.6281	3.406	2.279	1.495	.8346	.2251
1.76	.1850	.2996	.6175	1.448	.4011	1.397	1.51499	19.565	34.62	.6257	3.447	2.295	1.502	.8302	.2228
1.77	.1822	.2964	.6148	1.460	.3996	1.407	1.52029	19.855	34.40	.6234	3.488	2.311	1.509	.8259	.2206
1.78	.1794	.2931	.6121	1.473	.3980	1.418	1.52555	20.146	34.18	.6210	3.530	2.327	1.517	.8215	.2184
1.79	.1767	.2900	.6095	1.485	.3964	1.428	1.53078	20.436	33.96	.6188	3.571	2.343	1.524	.8171	.2163
1.80	.1740	.2868	.6068	1.497	.3947	1.439	1.53598	20.725	33.75	.6165	3.613	2.359	1.532	.8127	.2142
1.81	.1714	.2837	.6041	1.509	.3931	1.450	1.54114	21.014	33.54	.6143	3.655	2.375	1.539	.8082	.2121
1.82	.1688	.2806	.6015	1.521	.3914	1.461	1.54626	21.302	33.33	.6121	3.698	2.391	1.547	.8038	.2100
1.83	.1662	.2776	.5989	1.533	.3897	1.472	1.55133	21.590	33.12	.6099	3.740	2.407	1.554	.7993	.2080
1.84	.1637	.2745	.5963	1.545	.3879	1.484	1.55642	21.877	32.92	.6078	3.783	2.422	1.562	.7948	.2060
1.85	.1612	.2715	.5936	1.556	.3862	1.495	1.56145	22.163	32.72	.6057	3.826	2.438	1.569	.7902	.2040
1.86	.1587	.2686	.5910	1.568	.3844	1.507	1.56644	22.449	32.52	.6036	3.870	2.454	1.577	.7857	.2020
1.87	.1563	.2656	.5884	1.580	.3826	1.519	1.57140	22.735	32.33	.6016	3.913	2.469	1.585	.7811	.2001
1.88	.1539	.2627	.5859	1.592	.3808	1.531	1.57633	23.019	32.13	.5996	3.957	2.485	1.592	.7765	.1982
1.89	.1516	.2598	.5833	1.604	.3790	1.543	1.58123	23.303	31.94	.5976	4.001	2.500	1.600	.7720	.1963
1.90	.1492	.2570	.5807	1.616	.3771	1.555	1.58609	23.586	31.76	.5956	4.045	2.516	1.608	.7674	.1945
1.91	.1470	.2542	.5782	1.627	.3753	1.568	1.59092	23.869	31.57	.5937	4.089	2.531	1.616	.7627	.1927
1.92	.1447	.2514	.5756	1.639	.3734	1.580	1.59572	24.151	31.39	.5918	4.134	2.546	1.624	.7581	.1909
1.93	.1425	.2486	.5731	1.651	.3715	1.593	1.60049	24.432	31.21	.5899	4.179	2.562	1.631	.7535	.1891
1.94	.1403	.2459	.5705	1.662	.3696	1.606	1.60523	24.712	31.03	.5880	4.224	2.577	1.639	.7488	.1873
1.95	.1381	.2432	.5680	1.674	.3677	1.619	1.60993	24.992	30.85	.5862	4.270	2.592	1.647	.7442	.1856
1.96	.1360	.2405	.5655	1.686	.3657	1.633	1.61460	25.271	30.68	.5844	4.315	2.607	1.655	.7395	.1839
1.97	.1339	.2378	.5630	1.697	.3638	1.646	1.61925	25.549	30.51	.5826	4.361	2.622	1.663	.7349	.1822
1.98	.1318	.2352	.5605	1.709	.3618	1.660	1.62386	25.827	30.33	.5808	4.407	2.637	1.671	.7302	.1806
1.99	.1298	.2326	.5580	1.720	.3598	1.674	1.62844	26.104	30.17	.5791	4.453	2.652	1.679		

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A^*}$	$\frac{V}{a^*}$	ν	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
2.15	.1011	.1946	.5196	1.903	.3272	1.919	1.69774	30.425	27.72	.5540	5.226	2.882	1.813	.6511	.1553
2.16	.9956	.1925	.5173	1.915	.3252	1.935	1.70183	30.649	27.58	.5525	5.277	2.896	1.822	.6464	.1540
2.17	.9802	.1903	.5150	1.926	.3231	1.953	1.70589	30.851	27.44	.5511	5.327	2.910	1.831	.6419	.1527
2.18	.9649	.1882	.5127	1.937	.3210	1.970	1.70992	31.212	27.30	.5498	5.378	2.924	1.839	.6373	.1514
2.19	.9500	.1861	.5104	1.948	.3189	1.987	1.71393	31.473	27.17	.5484	5.429	2.938	1.848	.6327	.1502
2.20	.9352	.1841	.5081	1.960	.3169	2.005	1.71791	31.732	27.04	.5471	5.480	2.951	1.857	.6281	.1489
2.21	.9207	.1820	.5059	1.971	.3148	2.023	1.72187	31.991	26.90	.5457	5.531	2.965	1.866	.6236	.1476
2.22	.9064	.1800	.5036	1.982	.3127	2.041	1.72579	32.250	26.77	.5444	5.583	2.978	1.875	.6191	.1464
2.23	.8923	.1780	.5014	1.993	.3106	2.059	1.72970	32.507	26.64	.5431	5.636	2.992	1.883	.6145	.1452
2.24	.8785	.1760	.4991	2.004	.3085	2.078	1.73357	32.763	26.51	.5418	5.687	3.005	1.892	.6100	.1440
2.25	.8648	.1740	.4969	2.016	.3065	2.096	1.73742	33.018	26.39	.5406	5.740	3.019	1.901	.6055	.1428
2.26	.8514	.1721	.4947	2.027	.3044	2.115	1.74125	33.273	26.26	.5393	5.792	3.032	1.910	.6011	.1417
2.27	.8382	.1702	.4925	2.038	.3023	2.134	1.74504	33.527	26.14	.5381	5.845	3.045	1.919	.5966	.1405
2.28	.8251	.1683	.4903	2.049	.3003	2.153	1.74882	33.780	26.01	.5368	5.898	3.058	1.929	.5921	.1394
2.29	.8123	.1664	.4881	2.060	.2982	2.173	1.75257	34.032	25.89	.5356	5.951	3.071	1.938	.5877	.1382
2.30	.7997	.1646	.4859	2.071	.2961	2.193	1.75629	34.283	25.77	.5344	6.005	3.085	1.947	.5833	.1371
2.31	.7873	.1628	.4837	2.082	.2941	2.213	1.75999	34.533	25.65	.5332	6.059	3.098	1.956	.5789	.1360
2.32	.7751	.1609	.4816	2.093	.2920	2.233	1.76366	34.783	25.53	.5321	6.113	3.110	1.965	.5745	.1349
2.33	.7631	.1592	.4794	2.104	.2900	2.254	1.76731	35.031	25.42	.5309	6.167	3.123	1.974	.5702	.1338
2.34	.7512	.1574	.4773	2.116	.2879	2.274	1.77093	35.279	25.30	.5297	6.222	3.136	1.984	.5658	.1328
2.35	.7396	.1556	.4752	2.127	.2859	2.295	1.77453	35.526	25.18	.5286	6.276	3.149	1.993	.5615	.1317
2.36	.7281	.1539	.4731	2.138	.2839	2.316	1.77811	35.771	25.07	.5275	6.331	3.162	2.002	.5572	.1307
2.37	.7168	.1522	.4709	2.149	.2818	2.338	1.78166	36.017	24.96	.5264	6.386	3.174	2.012	.5529	.1297
2.38	.7057	.1505	.4688	2.160	.2798	2.359	1.78519	36.261	24.85	.5253	6.442	3.187	2.021	.5486	.1286
2.39	.6948	.1488	.4668	2.171	.2778	2.381	1.78869	36.504	24.73	.5242	6.497	3.199	2.031	.5444	.1276
2.40	.6840	.1472	.4647	2.182	.2758	2.403	1.79218	36.746	24.62	.5231	6.553	3.212	2.040	.5401	.1266
2.41	.6734	.1456	.4626	2.193	.2738	2.425	1.79563	36.988	24.52	.5221	6.609	3.224	2.050	.5359	.1257
2.42	.6630	.1439	.4606	2.204	.2718	2.448	1.79907	37.229	24.41	.5210	6.666	3.237	2.059	.5317	.1247
2.43	.6527	.1424	.4585	2.215	.2698	2.471	1.80248	37.469	24.30	.5200	6.722	3.249	2.069	.5276	.1237
2.44	.6426	.1408	.4565	2.226	.2678	2.494	1.80587	37.708	24.19	.5189	6.779	3.261	2.079	.5234	.1228
2.45	.6327	.1392	.4544	2.237	.2658	2.517	1.80924	37.946	24.09	.5179	6.836	3.273	2.088	.5193	.1218
2.46	.6229	.1377	.4524	2.248	.2639	2.540	1.81258	38.183	23.99	.5169	6.894	3.285	2.098	.5152	.1209
2.47	.6133	.1362	.4504	2.259	.2619	2.564	1.81591	38.420	23.88	.5159	6.951	3.298	2.108	.5111	.1200
2.48	.6038	.1346	.4484	2.269	.2599	2.588	1.81921	38.655	23.78	.5149	7.009	3.310	2.118	.5071	.1191
2.49	.5945	.1332	.4464	2.280	.2580	2.612	1.82249	38.890	23.68	.5140	7.067	3.321	2.128	.5030	.1182
2.50	.5853	.1317	.4444	2.291	.2561	2.637	1.82574	39.124	23.58	.5130	7.125	3.333	2.138	.4990	.1173
2.51	.5762	.1302	.4425	2.302	.2541	2.661	1.82898	39.357	23.48	.5120	7.183	3.345	2.147	.4950	.1164
2.52	.5674	.1288	.4405	2.313	.2522	2.686	1.83219	39.589	23.38	.5111	7.242	3.357	2.157	.4911	.1155
2.53	.5586	.1274	.4386	2.324	.2503	2.712	1.83538	39.820	23.28	.5102	7.301	3.369	2.167	.4871	.1147
2.54	.5500	.1260	.4366	2.335	.2484	2.737	1.83855	40.050	23.18	.5092	7.360	3.380	2.177	.4832	.1138
2.55	.5415	.1246	.4347	2.346	.2465	2.763	1.84170	40.280	23.09	.5083	7.420	3.392	2.187	.4793	.1130
2.56	.5332	.1232	.4328	2.357	.2446	2.789	1.84483	40.509	22.99	.5074	7.479	3.403	2.198	.4754	.1122
2.57	.5250	.1218	.4309	2.367	.2427	2.815	1.84794	40.736	22.91	.5065	7.539	3.415	2.208	.4715	.1113
2.58	.5169	.1205	.4289	2.378	.2409	2.842	1.85103	40.963	22.81	.5056	7.599	3.426	2.218	.4677	.1105
2.59	.5090	.1192	.4271	2.389	.2390	2.869	1.85410	41.189	22.71	.5047	7.659	3.438	2.228	.4639	.1097
2.60	.5012	.1179	.4252	2.400	.2371	2.896	1.85714	41.415	22.62	.5039	7.720	3.449	2.238	.4601	.1089
2.61	.4935	.1166	.4233	2.411	.2353	2.923	1.86017	41.639	22.53	.5030	7.781	3.460	2.249	.4564	.1081
2.62	.4859	.1153	.4214	2.422	.2335	2.951	1.86318	41.863	22.44	.5022	7.842	3.471	2.259	.4526	.1074
2.63	.4784	.1140	.4196	2.432	.2317	2.979	1.86616	42.086	22.35	.5013	7.903	3.483	2.269	.4489	.1066
2.64	.4711	.1128	.4177	2.443	.2298	3.007	1.86913	42.307	22.26	.5005	7.965	3.494	2.280	.4452	.1058
2.65	.4639	.1115	.4159	2.454	.2280	3.036	1.87208	42.529	22.17	.4996	8.026	3.505	2.290	.4416	.1051
2.66	.4568	.1103	.4141	2.465	.2262	3.065	1.87501	42.749	22.08	.4988	8.088	3.516	2.301	.4379	.1043
2.67	.4498	.1091	.4122	2.476	.2245	3.094	1.87792	42.968	22.00	.4980	8.150	3.527	2.311	.4343	.1036
2.68	.4429	.1079	.4104	2.486	.2227	3.123	1.88081	43.187	21.91	.4972	8.213	3.537	2.322	.4307	.1028
2.69	.4362	.1067	.4086	2.497	.2209	3.153	1.88368	43.405	21.82	.4964	8.275	3.548	2.332	.4271	.1021
2.70	.4295	.1056	.4068	2.508	.2192	3.183	1.88653	43.621	21.74	.4956	8.338	3.559	2.343	.4236	.1014
2.71	.4229	.1044	.4051	2.519	.2174	3.213	1.88936	43.835	21.65	.4949	8.401	3.570	2.354	.4201	.1007
2.72	.4165	.1033	.4033	2.530	.2157	3.244	1.89218	44.043	21.57	.4941	8.465	3.580	2.364	.4166	.9998
2.73	.4102	.1022	.4015	2.540	.2140	3.275	1.89497	44.257	21.49	.4933	8.528	3.591	2.375	.4131	.9929
2.74	.4039	.1010	.3998	2.551	.2123	3.306	1.89773	44.461	21.41	.4926	8.592	3.601	2.386	.4097	.9860
2.75	.3978	.9994	.3980	2.562	.2106	3.338	1.90051	44.664	21.32	.4918	8.656	3.612	2.397	.4062	.9792
2.76	.3917	.9985	.3963	2.572	.2089	3.370	1.90325	44.866	21.24	.4911	8.721	3.622	2.407	.4028	.9724
2.77	.3858	.9978	.3945	2.583	.2072	3.402	1.90598	45.067	21.16	.4903	8.785	3.633	2.418	.3994	.9656
2.78	.3799	.9971	.3928	2.594	.2055	3.434	1.90868	45.267	21.08	.4896	8.850	3.643	2.429	.3961	.9589
2.79	.3742	.9966	.3911	2.605	.2039	3.467	1.91137	45.467	21.00	.4889	8.915	3.653	2.440	.3928	.9526
2.80	.3685	.9961	.3894	2.615	.2022	3.500	1.91404	45.666	20.92	.4882	8.980	3.664	2.451	.3895	.9461
2.81	.3629	.9956	.3877	2.626	.2006	3.534	1.91669	45.864	20.85	.4875	9.045	3.674	2.462	.3862	.9397
2.82	.3574	.9951	.3860	2.637	.1990	3.567	1.91933	46.061	20.77	.4868	9.111	3.684	2.473	.3829	.9334
2.83	.3520	.9946	.3844	2.647	.1973	3.601	1.92195	46.258	20.69	.4861	9.177	3.694	2.484	.3797	.9271
2.84	.3467	.9941	.3827	2.658	.1957	3.636	1.92455	46.453	20.62	.4854	9.243	3.704	2.496	.3765	.9209
2.85	.3415	.9936	.3810	2.669	.1941	3.671	1.92714	46.648	20.54	.4847	9.310	3.714	2.507	.3733	.9147
2.86	.3363	.9931	.3793	2.679	.1926	3.706	1.92970	46.842	20.47	.4840	9.376	3.724	2.518	.3701	.9086
2.87	.3312	.9926	.3777	2.690	.1910	3.741	1.93225	47.035	20.39	.4833	9.443	3.734	2.529	.3670	.9026
2.88	.3263	.9921	.3761	2.701	.1894	3.777	1.93479	47.228	20.32	.4827	9.510	3.743	2.540	.3639	.8966
2.89	.3213	.9916	.3745	2.711	.1879	3.813	1.93731	47.420	20.24						

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A_*}$	$\frac{V}{a_*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
3.05	.2526	.7226	.3496	2.881	.1645	4.441	1.97547	50.713	19.14	.4723	10.69	3.902	2.738	.3145
3.06	.2489	.7149	.3481	2.892	.1631	4.483	1.97772	50.902	19.07	.4717	10.76	3.911	2.750	.3118
3.07	.2452	.7074	.3466	2.903	.1618	4.526	1.97997	51.090	19.01	.4712	10.83	3.920	2.762	.3091
3.08	.2416	.6999	.3452	2.913	.1604	4.570	1.98219	51.277	18.95	.4706	10.90	3.929	2.774	.3065
3.09	.2380	.6925	.3437	2.924	.1591	4.613	1.98441	51.464	18.88	.4701	10.97	3.938	2.786	.3038
3.10	.2345	.6852	.3422	2.934	.1577	4.657	1.98661	51.650	18.82	.4695	11.05	3.947	2.799	.3012
3.11	.2310	.6779	.3406	2.945	.1564	4.702	1.98879	51.835	18.76	.4689	11.12	3.955	2.811	.2986
3.12	.2276	.6708	.3393	2.955	.1551	4.747	1.99097	52.020	18.69	.4683	11.19	3.964	2.823	.2960
3.13	.2243	.6637	.3379	2.966	.1538	4.792	1.99313	52.203	18.63	.4679	11.26	3.973	2.835	.2935
3.14	.2210	.6568	.3365	2.977	.1525	4.838	1.99527	52.386	18.57	.4674	11.34	3.981	2.848	.2910
3.15	.2177	.6499	.3351	2.987	.1512	4.884	1.99740	52.569	18.51	.4669	11.41	3.990	2.860	.2885
3.16	.2146	.6430	.3337	2.998	.1500	4.930	1.99952	52.751	18.45	.4664	11.48	3.998	2.872	.2860
3.17	.2114	.6363	.3323	3.008	.1487	4.977	2.00162	52.931	18.39	.4659	11.56	4.006	2.885	.2835
3.18	.2083	.6296	.3309	3.019	.1475	5.025	2.00372	53.112	18.33	.4654	11.63	4.015	2.897	.2811
3.19	.2053	.6231	.3295	3.029	.1462	5.073	2.00579	53.292	18.27	.4648	11.71	4.023	2.909	.2786
3.20	.2023	.6165	.3281	3.040	.1450	5.121	2.00786	53.470	18.21	.4643	11.78	4.031	2.922	.2762
3.21	.1993	.6101	.3267	3.050	.1438	5.170	2.00991	53.648	18.15	.4639	11.85	4.040	2.935	.2738
3.22	.1964	.6037	.3253	3.061	.1426	5.219	2.01195	53.826	18.09	.4634	11.93	4.048	2.947	.2715
3.23	.1936	.5975	.3240	3.071	.1414	5.268	2.01398	54.003	18.03	.4629	12.01	4.056	2.960	.2691
3.24	.1908	.5912	.3226	3.082	.1402	5.319	2.01599	54.179	17.98	.4624	12.08	4.064	2.972	.2668
3.25	.1880	.5851	.3213	3.092	.1390	5.369	2.01799	54.355	17.92	.4619	12.16	4.072	2.985	.2645
3.26	.1853	.5790	.3199	3.103	.1378	5.420	2.01998	54.529	17.86	.4614	12.23	4.080	2.998	.2622
3.27	.1826	.5730	.3186	3.113	.1367	5.472	2.02196	54.703	17.81	.4610	12.31	4.088	3.011	.2600
3.28	.1799	.5671	.3173	3.124	.1355	5.523	2.02392	54.877	17.75	.4605	12.38	4.096	3.023	.2577
3.29	.1773	.5612	.3160	3.134	.1344	5.576	2.02587	55.050	17.70	.4600	12.46	4.104	3.036	.2555
3.30	.1748	.5554	.3147	3.145	.1332	5.629	2.02781	55.222	17.64	.4596	12.54	4.112	3.049	.2533
3.31	.1722	.5497	.3134	3.155	.1321	5.682	2.02974	55.393	17.58	.4591	12.62	4.120	3.062	.2511
3.32	.1698	.5440	.3121	3.166	.1310	5.736	2.03165	55.564	17.53	.4587	12.69	4.128	3.075	.2489
3.33	.1673	.5384	.3108	3.176	.1299	5.790	2.03356	55.734	17.48	.4582	12.77	4.135	3.088	.2468
3.34	.1649	.5329	.3095	3.187	.1288	5.845	2.03545	55.904	17.42	.4578	12.85	4.143	3.101	.2446
3.35	.1625	.5274	.3082	3.197	.1277	5.900	2.03733	56.073	17.37	.4573	12.93	4.151	3.114	.2425
3.36	.1602	.5220	.3069	3.208	.1266	5.956	2.03920	56.241	17.31	.4569	13.00	4.158	3.127	.2404
3.37	.1579	.5166	.3057	3.218	.1255	6.012	2.04106	56.409	17.26	.4565	13.08	4.166	3.141	.2383
3.38	.1557	.5113	.3044	3.229	.1245	6.069	2.04290	56.576	17.21	.4560	13.16	4.173	3.154	.2363
3.39	.1534	.5061	.3032	3.239	.1234	6.126	2.04474	56.742	17.16	.4556	13.24	4.181	3.167	.2342
3.40	.1512	.5009	.3019	3.250	.1224	6.184	2.04656	56.907	17.10	.4552	13.32	4.188	3.180	.2322
3.41	.1491	.4958	.3007	3.260	.1214	6.242	2.04837	57.073	17.05	.4548	13.40	4.196	3.194	.2302
3.42	.1470	.4908	.2995	3.271	.1203	6.301	2.05017	57.237	17.00	.4544	13.48	4.203	3.207	.2282
3.43	.1449	.4858	.2982	3.281	.1193	6.360	2.05196	57.401	16.95	.4540	13.56	4.211	3.220	.2263
3.44	.1428	.4808	.2970	3.291	.1183	6.420	2.05374	57.564	16.90	.4535	13.64	4.218	3.234	.2243
3.45	.1408	.4759	.2958	3.302	.1173	6.480	2.05551	57.726	16.85	.4531	13.72	4.225	3.247	.2224
3.46	.1388	.4711	.2946	3.312	.1163	6.541	2.05727	57.888	16.80	.4527	13.80	4.232	3.261	.2205
3.47	.1368	.4663	.2934	3.323	.1153	6.602	2.05901	58.050	16.75	.4523	13.88	4.240	3.274	.2186
3.48	.1349	.4616	.2922	3.333	.1144	6.664	2.06075	58.210	16.70	.4519	13.96	4.247	3.288	.2167
3.49	.1330	.4569	.2910	3.344	.1134	6.727	2.06247	58.370	16.65	.4515	14.04	4.254	3.301	.2148
3.50	.1311	.4523	.2899	3.354	.1124	6.790	2.06419	58.530	16.60	.4512	14.13	4.261	3.315	.2129
3.51	.1293	.4478	.2887	3.365	.1115	6.853	2.06589	58.689	16.55	.4508	14.21	4.268	3.329	.2111
3.52	.1274	.4433	.2875	3.375	.1105	6.917	2.06759	58.847	16.51	.4504	14.29	4.275	3.343	.2093
3.53	.1256	.4388	.2864	3.385	.1096	6.982	2.06927	59.004	16.46	.4500	14.37	4.282	3.356	.2075
3.54	.1239	.4344	.2852	3.396	.1087	7.047	2.07094	59.162	16.41	.4496	14.45	4.289	3.370	.2057
3.55	.1221	.4300	.2841	3.406	.1078	7.113	2.07261	59.318	16.36	.4492	14.54	4.296	3.384	.2039
3.56	.1204	.4257	.2829	3.417	.1069	7.179	2.07426	59.474	16.31	.4489	14.62	4.303	3.398	.2022
3.57	.1188	.4214	.2818	3.427	.1059	7.246	2.07590	59.629	16.27	.4485	14.70	4.309	3.412	.2004
3.58	.1171	.4172	.2806	3.437	.1051	7.313	2.07754	59.784	16.22	.4481	14.79	4.316	3.426	.1987
3.59	.1155	.4131	.2795	3.448	.1042	7.382	2.07916	59.938	16.17	.4478	14.87	4.323	3.440	.1970
3.60	.1138	.4089	.2784	3.458	.1033	7.450	2.08077	60.091	16.13	.4474	14.95	4.330	3.454	.1953
3.61	.1123	.4049	.2773	3.469	.1024	7.519	2.08238	60.244	16.08	.4471	15.04	4.336	3.468	.1936
3.62	.1107	.4008	.2762	3.479	.1016	7.589	2.08397	60.397	16.04	.4467	15.12	4.343	3.482	.1920
3.63	.1092	.3968	.2751	3.490	.1007	7.659	2.08556	60.549	15.99	.4463	15.21	4.350	3.496	.1903
3.64	.1076	.3929	.2740	3.500	.9984	7.730	2.08713	60.700	15.95	.4460	15.29	4.356	3.510	.1887
3.65	.1062	.3890	.2729	3.510	.9900	7.802	2.08870	60.851	15.90	.4456	15.38	4.363	3.525	.1871
3.66	.1047	.3852	.2718	3.521	.9817	7.874	2.09026	61.000	15.86	.4453	15.46	4.369	3.539	.1855
3.67	.1032	.3813	.2707	3.531	.9734	7.947	2.09180	61.150	15.81	.4450	15.55	4.376	3.553	.1839
3.68	.1018	.3776	.2697	3.542	.9652	8.020	2.09334	61.299	15.77	.4446	15.63	4.382	3.568	.1823
3.69	.1004	.3739	.2686	3.552	.9570	8.094	2.09487	61.447	15.72	.4443	15.72	4.388	3.582	.1807
3.70	.9903	.3702	.2675	3.562	.9490	8.169	2.09639	61.595	15.68	.4439	15.81	4.395	3.596	.1792
3.71	.9767	.3665	.2665	3.573	.9410	8.244	2.09790	61.743	15.64	.4436	15.89	4.401	3.611	.1777
3.72	.9633	.3629	.2654	3.583	.9331	8.320	2.09941	61.889	15.59	.4433	15.98	4.408	3.625	.1761
3.73	.9500	.3594	.2644	3.593	.9253	8.397	2.10090	62.036	15.55	.4430	16.07	4.414	3.640	.1746
3.74	.9370	.3558	.2633	3.604	.9175	8.474	2.10238	62.181	15.51	.4426	16.15	4.420	3.654	.1731
3.75	.9242	.3524	.2623	3.614	.9099	8.552	2.10386	62.326	15.47	.4423	16.24	4.426	3.669	.1717
3.76	.9116	.3489	.2613	3.625	.9021	8.630	2.10533	62.471	15.42	.4420	16.33	4.432	3.684	.1702
3.77	.8991	.3455	.2602	3.635	.8945	8.709	2.10679	62.615	15.38	.4417	16.42	4.439	3.698	.1687
3.78	.8869	.3421	.2592	3.645	.8870	8.789	2.10824	62.758	15.34	.4414	16.50	4.445	3.713	.1673
3.79	.8748	.3388	.2582	3.656	.8796	8.870	2.10968	62.901	15.30	.4410	16.59	4.451	3.728	.1659
3.80	.8629	.3355	.2572	3.666	.8722	8.951	2.11111	63.044	15.26	.4407	16.68	4.457	3.743	.1645
3.81	.8512	.3322	.2562	3.676	.8649	9.032	2.11254	63.186	15.22	.4404	16.77	4.463	3.758	.1631
3.82	.8396	.3290	.2552	3.687	.8577	9.115	2.11395	63.327	15.18	.4401	16.86	4.469	3.772	.1617
3.83	.8283	.3258	.2542	3.697	.8505	9.198	2.11536	63.468	15.14	.4398	16.95	4.475	3.787	.1603
3.84	.8171	.												

EQUATIONS, TABLES, AND CHARTS FOR COMPRESSIBLE FLOW

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	θ	$\frac{q}{p_1}$	$\frac{A}{A^*}$	$\frac{V}{a^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
3.95	.7042	.2902	.2427	3.821	.7691	10.25	2.13163	65.118	14.67	.4363	18.04	4.544	3.969	.1448
3.96	.6945	.2874	.2418	3.852	.7627	10.34	2.13294	65.253	14.63	.4360	18.13	4.549	3.985	.1435
3.97	.6855	.2846	.2408	3.882	.7563	10.44	2.13424	65.386	14.59	.4358	18.22	4.555	4.000	.1423
3.98	.6764	.2819	.2399	3.912	.7500	10.53	2.13553	65.520	14.55	.4355	18.31	4.560	4.016	.1411
3.99	.6675	.2793	.2390	3.943	.7438	10.62	2.13681	65.652	14.52	.4352	18.41	4.566	4.031	.1399
4.00	.6586	.2766	.2381	3.973	.7376	10.72	2.13809	65.785	14.48	.4350	18.50	4.571	4.047	.1388
4.01	.6499	.2740	.2372	4.003	.7315	10.81	2.13936	65.917	14.44	.4347	18.59	4.577	4.062	.1376
4.02	.6413	.2714	.2363	4.033	.7255	10.91	2.14062	66.048	14.40	.4344	18.69	4.582	4.078	.1364
4.03	.6328	.2688	.2354	4.063	.7194	11.01	2.14188	66.179	14.37	.4342	18.78	4.588	4.094	.1353
4.04	.6245	.2663	.2345	4.093	.7135	11.11	2.14312	66.309	14.33	.4339	18.88	4.593	4.110	.1342
4.05	.6163	.2638	.2336	4.123	.7076	11.21	2.14436	66.439	14.30	.4336	18.97	4.598	4.125	.1330
4.06	.6082	.2613	.2327	4.153	.7017	11.31	2.14560	66.569	14.26	.4334	19.06	4.604	4.141	.1319
4.07	.6002	.2589	.2319	4.183	.6959	11.41	2.14682	66.698	14.22	.4331	19.16	4.609	4.157	.1308
4.08	.5923	.2564	.2310	4.213	.6902	11.51	2.14804	66.826	14.19	.4329	19.25	4.614	4.173	.1297
4.09	.5845	.2540	.2301	4.243	.6845	11.61	2.14926	66.954	14.15	.4326	19.35	4.619	4.189	.1286
4.10	.5769	.2516	.2293	4.273	.6788	11.71	2.15046	67.082	14.12	.4324	19.45	4.624	4.205	.1276
4.11	.5694	.2493	.2284	4.303	.6732	11.82	2.15166	67.209	14.08	.4321	19.54	4.630	4.221	.1265
4.12	.5619	.2470	.2275	4.333	.6677	11.92	2.15285	67.336	14.05	.4319	19.64	4.635	4.237	.1254
4.13	.5546	.2447	.2267	4.363	.6622	12.03	2.15404	67.462	14.01	.4316	19.73	4.640	4.253	.1244
4.14	.5474	.2424	.2258	4.393	.6568	12.14	2.15522	67.588	13.98	.4314	19.83	4.645	4.269	.1234
4.15	.5403	.2401	.2250	4.423	.6514	12.24	2.15639	67.713	13.94	.4311	19.93	4.650	4.285	.1223
4.16	.5333	.2379	.2242	4.453	.6460	12.35	2.15756	67.838	13.91	.4309	20.02	4.655	4.301	.1213
4.17	.5264	.2357	.2233	4.483	.6407	12.46	2.15871	67.963	13.88	.4306	20.12	4.660	4.318	.1203
4.18	.5195	.2335	.2225	4.513	.6354	12.57	2.15987	68.087	13.84	.4304	20.22	4.665	4.334	.1193
4.19	.5128	.2313	.2217	4.543	.6302	12.68	2.16101	68.210	13.81	.4302	20.32	4.670	4.350	.1183
4.20	.5062	.2292	.2208	4.573	.6251	12.79	2.16215	68.333	13.77	.4299	20.41	4.675	4.367	.1173
4.21	.4997	.2271	.2200	4.603	.6200	12.90	2.16329	68.456	13.74	.4297	20.51	4.680	4.383	.1164
4.22	.4932	.2250	.2192	4.633	.6149	13.02	2.16442	68.578	13.71	.4295	20.61	4.685	4.399	.1154
4.23	.4869	.2229	.2184	4.663	.6098	13.13	2.16554	68.700	13.67	.4292	20.71	4.690	4.416	.1144
4.24	.4806	.2209	.2176	4.693	.6049	13.25	2.16665	68.821	13.64	.4290	20.81	4.694	4.432	.1135
4.25	.4745	.2189	.2168	4.723	.5999	13.36	2.16776	68.942	13.61	.4288	20.91	4.699	4.449	.1126
4.26	.4684	.2169	.2160	4.753	.5950	13.48	2.16886	69.063	13.58	.4286	21.01	4.704	4.466	.1116
4.27	.4624	.2149	.2152	4.783	.5902	13.60	2.16996	69.183	13.54	.4283	21.11	4.709	4.482	.1107
4.28	.4565	.2129	.2144	4.813	.5854	13.72	2.17105	69.302	13.51	.4281	21.20	4.713	4.499	.1098
4.29	.4507	.2110	.2136	4.843	.5806	13.83	2.17214	69.422	13.48	.4279	21.30	4.718	4.516	.1089
4.30	.4449	.2090	.2129	4.873	.5759	13.95	2.17321	69.541	13.45	.4277	21.41	4.723	4.532	.1080
4.31	.4393	.2071	.2121	4.903	.5712	14.08	2.17429	69.659	13.42	.4275	21.51	4.728	4.549	.1071
4.32	.4337	.2052	.2113	4.933	.5666	14.20	2.17535	69.777	13.38	.4272	21.61	4.732	4.566	.1062
4.33	.4282	.2034	.2105	4.963	.5620	14.32	2.17642	69.895	13.35	.4270	21.71	4.737	4.583	.1054
4.34	.4228	.2015	.2098	4.993	.5574	14.45	2.17747	70.012	13.32	.4268	21.81	4.741	4.600	.1045
4.35	.4174	.2000	.2090	5.023	.5529	14.57	2.17852	70.128	13.29	.4266	21.91	4.746	4.617	.1036
4.36	.4121	.1979	.2083	5.053	.5484	14.70	2.17956	70.245	13.26	.4264	22.01	4.751	4.633	.1028
4.37	.4069	.1961	.2075	5.083	.5440	14.82	2.18060	70.361	13.23	.4262	22.11	4.755	4.651	.1020
4.38	.4018	.1944	.2067	5.113	.5396	14.95	2.18163	70.476	13.20	.4260	22.22	4.760	4.668	.1011
4.39	.3968	.1926	.2060	5.143	.5352	15.08	2.18266	70.591	13.17	.4258	22.32	4.764	4.685	.1003
4.40	.3918	.1909	.2053	5.173	.5309	15.21	2.18368	70.706	13.14	.4255	22.42	4.768	4.702	.9948
4.41	.3868	.1892	.2045	5.203	.5266	15.34	2.18470	70.820	13.11	.4253	22.52	4.773	4.719	.9907
4.42	.3820	.1875	.2038	5.233	.5224	15.47	2.18571	70.934	13.08	.4251	22.63	4.777	4.736	.9867
4.43	.3772	.1858	.2030	5.263	.5182	15.61	2.18671	71.048	13.05	.4249	22.73	4.782	4.753	.9827
4.44	.3725	.1841	.2023	5.293	.5140	15.74	2.18771	71.161	13.02	.4247	22.83	4.786	4.771	.9787
4.45	.3678	.1825	.2016	5.323	.5099	15.87	2.18870	71.274	12.99	.4245	22.94	4.790	4.788	.9748
4.46	.3633	.1808	.2009	5.353	.5058	16.01	2.18969	71.386	12.96	.4243	23.04	4.795	4.805	.9709
4.47	.3587	.1792	.2002	5.383	.5017	16.15	2.19068	71.498	12.93	.4241	23.14	4.799	4.823	.9670
4.48	.3543	.1776	.1994	5.413	.4977	16.28	2.19165	71.610	12.90	.4239	23.25	4.803	4.840	.9631
4.49	.3499	.1761	.1987	5.443	.4937	16.42	2.19262	71.721	12.87	.4237	23.35	4.808	4.858	.9592
4.50	.3455	.1745	.1980	5.473	.4898	16.56	2.19360	71.832	12.84	.4236	23.46	4.812	4.875	.9553
4.51	.3412	.1729	.1973	5.503	.4859	16.70	2.19456	71.942	12.81	.4234	23.56	4.816	4.893	.9514
4.52	.3370	.1714	.1966	5.533	.4820	16.84	2.19552	72.052	12.78	.4232	23.67	4.820	4.910	.9475
4.53	.3329	.1699	.1959	5.563	.4781	16.99	2.19647	72.162	12.75	.4230	23.77	4.824	4.928	.9436
4.54	.3288	.1684	.1952	5.593	.4743	17.13	2.19742	72.271	12.73	.4228	23.88	4.829	4.946	.9397
4.55	.3247	.1669	.1945	5.623	.4706	17.28	2.19836	72.380	12.70	.4226	23.99	4.833	4.963	.9358
4.56	.3207	.1654	.1938	5.653	.4668	17.42	2.19930	72.489	12.67	.4224	24.09	4.837	4.981	.9319
4.57	.3168	.1640	.1932	5.683	.4631	17.57	2.20023	72.597	12.64	.4222	24.20	4.841	4.999	.9280
4.58	.3129	.1625	.1925	5.713	.4594	17.72	2.20116	72.705	12.61	.4220	24.31	4.845	5.017	.9241
4.59	.3090	.1611	.1918	5.743	.4558	17.87	2.20203	72.812	12.58	.4219	24.41	4.849	5.034	.9202
4.60	.3053	.1597	.1911	5.773	.4522	18.02	2.20300	72.919	12.56	.4217	24.52	4.853	5.052	.9163
4.61	.3015	.1583	.1905	5.803	.4486	18.17	2.20391	73.026	12.53	.4215	24.63	4.857	5.070	.9124
4.62	.2978	.1569	.1898	5.833	.4450	18.32	2.20482	73.132	12.50	.4213	24.74	4.861	5.088	.9085
4.63	.2942	.1556	.1891	5.863	.4415	18.48	2.20572	73.238	12.47	.4211	24.84	4.865	5.106	.9046
4.64	.2906	.1542	.1885	5.893	.4380	18.63	2.20662	73.344	12.45	.4210	24.95	4.869	5.124	.9007
4.65	.2871	.1529	.1878	5.923	.4345	18.79	2.20751	73.449	12.42	.4208	25.06	4.873	5.143	.8968
4.66	.2836	.1515	.1872	5.953	.4311	18.94	2.20840	73.554	12.39	.4206	25.17	4.877	5.160	.8929
4.67	.2802	.1502	.1865	5.983	.4277	19.10	2.20929	73.659	12.37	.4204	25.28	4.881	5.179	.8890
4.68	.2768	.1489	.1859	6.013	.4243	19.26	2.21017	73.763	12.34	.4203	25.39	4.885	5.197	.8851
4.69	.2734	.1476	.1852	6.043	.4210	19.42	2.21104	73.867	12.31	.4201	25.50	4.889	5.215	.8812
4.70	.2701	.1464	.1846	6.073	.4177	19.58	2.21191	73.970	12.28	.4199	25.61	4.893	5.233	.8773
4.71	.2669	.1451	.1839	6.103	.4144	19.75	2.21278	74.073	12.26	.4197	25.71	4.896	5.252	.8734
4.72	.2637	.1438	.1833	6.133	.4112	19.91	2.21364	74.176	12.23	.4196	25.82	4.900	5.270	.8695
4.73	.2605	.1426	.1827	6.163	.4079	20.07	2.21450	74.279	12.21	.4194	25.94	4.904	5.289	.8656
4.74	.2573													

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{1}{A^*}$	$\frac{1}{a^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_{t1}}{p_{t2}}$	
4.85	.2255	-.1287	-.1753	4.746	.3714	-.22.15	2.224455	75.482	11.90	.4175	27.28	4.948	5.512	.6936	-.3252
4.86	.2229	-.1276	-.1747	4.756	.3695	-.22.33	2.225257	75.580	11.87	.4173	27.39	4.952	5.531	.6882	-.3239
4.87	.2202	-.1265	-.1741	4.766	.3677	-.22.51	2.226055	75.678	11.85	.4172	27.50	4.955	5.550	.6828	-.3226
4.88	.2177	-.1254	-.1735	4.776	.3658	-.22.70	2.226848	75.775	11.83	.4170	27.62	4.959	5.569	.6775	-.3213
4.89	.2151	-.1244	-.1729	4.787	.3600	-.22.88	2.227638	75.872	11.80	.4169	27.73	4.962	5.588	.6722	-.3200
4.90	.2126	-.1233	-.1724	4.797	.3573	-.23.07	2.228424	75.969	11.78	.4167	27.85	4.966	5.607	.6670	-.3187
4.91	.2101	-.1223	-.1718	4.807	.3545	-.23.25	2.229206	76.066	11.75	.4165	27.96	4.969	5.626	.6618	-.3174
4.92	.2076	-.1213	-.1712	4.817	.3518	-.23.44	2.229984	76.162	11.73	.4164	28.07	4.973	5.646	.6567	-.3161
4.93	.2052	-.1202	-.1706	4.828	.3491	-.23.63	2.230758	76.258	11.70	.4163	28.19	4.976	5.665	.6516	-.3149
4.94	.2028	-.1192	-.1700	4.838	.3464	-.23.82	2.231528	76.353	11.68	.4161	28.30	4.980	5.684	.6465	-.3136
4.95	.2004	-.1182	-.1695	4.848	.3437	-.24.02	2.232294	76.449	11.66	.4160	28.42	4.983	5.703	.6415	-.3124
4.96	.1981	-.1173	-.1689	4.858	.3411	-.24.21	2.233056	76.544	11.63	.4158	28.54	4.987	5.723	.6364	-.3111
4.97	.1957	-.1163	-.1683	4.868	.3385	-.24.41	2.233815	76.638	11.61	.4157	28.65	4.990	5.742	.6317	-.3099
4.98	.1935	-.1153	-.1678	4.879	.3359	-.24.60	2.234570	76.732	11.58	.4155	28.77	4.993	5.761	.6268	-.3087
4.99	.1912	-.1144	-.1672	4.889	.3333	-.24.80	2.235321	76.826	11.56	.4154	28.88	4.997	5.781	.6220	-.3075
5.00	.1890	-.1134	-.1667	4.899	.3308	-.25.00	2.236068	76.920	11.54	.4152	29.00	5.000	5.800	.6172	-.3062
5.01	.1868	-.1125	-.1661	4.909	.3282	-.25.20	2.236811	77.013	11.51	.4151	29.12	5.003	5.820	.6124	-.3051
5.02	.1847	-.1115	-.1656	4.919	.3257	-.25.40	2.237551	77.106	11.49	.4149	29.23	5.007	5.839	.6077	-.3039
5.03	.1825	-.1106	-.1650	4.930	.3233	-.25.61	2.238287	77.199	11.47	.4148	29.35	5.010	5.859	.6030	-.3027
5.04	.1804	-.1097	-.1645	4.940	.3208	-.25.81	2.239020	77.291	11.44	.4147	29.47	5.013	5.878	.5981	-.3015
5.05	.1783	-.1088	-.1639	4.950	.3184	-.26.02	2.239749	77.385	11.42	.4145	29.59	5.016	5.898	.5938	-.3003
5.06	.1763	-.1079	-.1634	4.960	.3159	-.26.22	2.240474	77.477	11.40	.4144	29.70	5.020	5.918	.5893	-.2991
5.07	.1742	-.1070	-.1628	4.970	.3135	-.26.43	2.241195	77.568	11.38	.4142	29.82	5.023	5.937	.5848	-.2980
5.08	.1722	-.1061	-.1623	4.981	.3112	-.26.64	2.241914	77.660	11.35	.4141	29.94	5.026	5.957	.5803	-.2968
5.09	.1703	-.1053	-.1618	4.991	.3088	-.26.86	2.242628	77.751	11.33	.4140	30.06	5.029	5.977	.5759	-.2957
5.10	.1683	-.1044	-.1612	5.001	.3065	-.27.07	2.243339	77.841	11.31	.4138	30.18	5.033	5.997	.5715	-.2945
5.11	.1664	-.1035	-.1607	5.011	.3042	-.27.28	2.244047	77.931	11.29	.4137	30.30	5.036	6.016	.5672	-.2934
5.12	.1645	-.1027	-.1602	5.021	.3019	-.27.50	2.244751	78.021	11.26	.4136	30.42	5.039	6.036	.5628	-.2923
5.13	.1626	-.1019	-.1597	5.032	.2996	-.27.72	2.245451	78.111	11.24	.4134	30.54	5.042	6.056	.5586	-.2911
5.14	.1608	-.1010	-.1591	5.042	.2973	-.27.94	2.246148	78.201	11.22	.4133	30.66	5.045	6.076	.5543	-.2900
5.15	.1589	-.1002	-.1586	5.052	.2951	-.28.16	2.246842	78.290	11.20	.4132	30.78	5.048	6.096	.5501	-.2889
5.16	.1571	-.9939	-.1581	5.062	.2929	-.28.38	2.247532	78.379	11.18	.4130	30.90	5.051	6.117	.5460	-.2878
5.17	.1553	-.9858	-.1576	5.072	.2907	-.28.60	2.248219	78.468	11.15	.4129	31.02	5.054	6.137	.5418	-.2867
5.18	.1536	-.9778	-.1571	5.083	.2885	-.28.83	2.248903	78.556	11.13	.4128	31.14	5.058	6.157	.5377	-.2856
5.19	.1518	-.9699	-.1566	5.093	.2863	-.29.06	2.249583	78.645	11.11	.4126	31.26	5.061	6.177	.5337	-.2845
5.20	.1501	-.9620	-.1561	5.103	.2842	-.29.28	2.250260	78.733	11.09	.4125	31.38	5.064	6.197	.5297	-.2834
5.21	.1484	-.9543	-.1555	5.113	.2821	-.29.51	2.250934	78.820	11.07	.4124	31.50	5.067	6.217	.5257	-.2823
5.22	.1468	-.9466	-.1550	5.123	.2799	-.29.74	2.251604	78.908	11.04	.4123	31.62	5.070	6.238	.5217	-.2811
5.23	.1451	-.9389	-.1545	5.134	.2778	-.29.96	2.252271	78.995	11.02	.4121	31.75	5.073	6.258	.5178	-.2800
5.24	.1435	-.9314	-.1540	5.144	.2758	-.30.21	2.252935	79.081	11.00	.4120	31.87	5.076	6.278	.5139	-.2790
5.25	.1419	-.9239	-.1536	5.154	.2737	-.30.45	2.253596	79.167	10.98	.4119	31.99	5.079	6.299	.5100	-.2782
5.26	.1403	-.9165	-.1531	5.164	.2717	-.30.68	2.254254	79.254	10.96	.4118	32.11	5.082	6.319	.5062	-.2771
5.27	.1387	-.9092	-.1526	5.174	.2697	-.30.92	2.254908	79.340	10.94	.4116	32.24	5.085	6.340	.5024	-.2761
5.28	.1372	-.9019	-.1521	5.184	.2677	-.31.16	2.255559	79.426	10.92	.4115	32.36	5.088	6.360	.4987	-.2750
5.29	.1356	-.8947	-.1516	5.195	.2657	-.31.41	2.256207	79.511	10.90	.4114	32.48	5.090	6.381	.4950	-.2740
5.30	.1341	-.8875	-.1511	5.205	.2637	-.31.65	2.256852	79.597	10.88	.4113	32.61	5.093	6.401	.4913	-.2730
5.31	.1326	-.8805	-.1506	5.215	.2617	-.31.89	2.257494	79.681	10.86	.4112	32.73	5.096	6.422	.4876	-.2720
5.32	.1311	-.8734	-.1501	5.225	.2598	-.32.14	2.258133	79.765	10.83	.4110	32.85	5.099	6.443	.4840	-.2710
5.33	.1297	-.8665	-.1497	5.235	.2579	-.32.39	2.258769	79.850	10.81	.4109	32.98	5.102	6.464	.4804	-.2700
5.34	.1282	-.8596	-.1492	5.246	.2560	-.32.64	2.259401	79.934	10.79	.4108	33.10	5.105	6.484	.4768	-.2690
5.35	.1268	-.8528	-.1487	5.256	.2541	-.32.89	2.260031	80.018	10.77	.4107	33.23	5.108	6.505	.4733	-.2680
5.36	.1254	-.8461	-.1482	5.266	.2522	-.33.14	2.260658	80.101	10.75	.4106	33.35	5.111	6.526	.4697	-.2670
5.37	.1240	-.8394	-.1478	5.276	.2504	-.33.40	2.261281	80.185	10.73	.4104	33.48	5.113	6.547	.4663	-.2660
5.38	.1227	-.8327	-.1473	5.286	.2485	-.33.66	2.261902	80.268	10.71	.4103	33.60	5.116	6.568	.4628	-.2650
5.39	.1213	-.8262	-.1468	5.296	.2467	-.33.91	2.262520	80.351	10.69	.4102	33.73	5.119	6.589	.4594	-.2641
5.40	.1200	-.8197	-.1464	5.307	.2449	-.34.17	2.263135	80.434	10.67	.4101	33.85	5.122	6.610	.4560	-.2631
5.41	.1187	-.8132	-.1459	5.317	.2431	-.34.44	2.263747	80.517	10.65	.4100	33.98	5.125	6.631	.4526	-.2621
5.42	.1174	-.8068	-.1454	5.327	.2413	-.34.70	2.264356	80.599	10.63	.4099	34.11	5.127	6.652	.4493	-.2612
5.43	.1161	-.8005	-.1450	5.337	.2395	-.34.97	2.264962	80.680	10.61	.4098	34.23	5.130	6.673	.4460	-.2602
5.44	.1148	-.7942	-.1445	5.347	.2378	-.35.23	2.265566	80.760	10.59	.4096	34.36	5.133	6.694	.4427	-.2593
5.45	.1135	-.7880	-.1441	5.357	.2361	-.35.50	2.266166	80.842	10.57	.4095	34.49	5.136	6.715	.4395	-.2583
5.46	.1123	-.7818	-.1436	5.368	.2344	-.35.77	2.266764	80.923	10.55	.4094	34.61	5.138	6.737	.4362	-.2574
5.47	.1111	-.7757	-.1432	5.378	.2326	-.36.04	2.267359	81.004	10.53	.4093	34.74	5.141	6.758	.4330	-.2565
5.48	.1099	-.7697	-.1427	5.389	.2309	-.36.32	2.267951	81.084	10.51	.4092	34.87	5.144	6.779	.4299	-.2556
5.49	.1087	-.7637	-.1423	5.399	.2293	-.36.59	2.268540	81.165	10.50	.4091	35.00	5.146	6.800	.4267	-.2546
5.50	.1075	-.7578	-.1418	5.408	.2276	-.36.87	2.269127	81.245	10.48	.4090	35.13	5.149	6.822	.4236	-.2537
5.51	.1063	-.7519	-.1414	5.418	.2260	-.37.15	2.269711	81.324	10.46	.4089	35.25	5.152	6.843	.4205	-.2528
5.52	.1052	-.7460	-.1410	5.429	.2243	-.37.43	2.270292	81.404	10.44	.4088	35.38	5.154	6.865	.4175	-.2519
5.53	.1040	-.7403	-.1405	5.439	.2227	-.37.71	2.270870	81.484	10.42	.4086	35.51	5.157	6.886	.4144	-.2510
5.54	.1029	-.7345	-.1401	5.449	.2211	-.38.00	2.271446	81.563	10.40	.4085	35.64	5.159	6.908	.4114	-.2501
5.55	.1018	-.7289	-.1397	5.459	.2195	-.38.28	2.272019	81.641	10.38	.4084	35.77	5.162	6.929	.4084	-.2492
5.56	.1007	-.7232	-.1392	5.469	.2179	-.38.57	2.272589	81.720	10.36	.4083	35.90	5.165	6.951	.4054	-.2483
5.57	.9961	-.7177	-.1388	5.479	.2163	-.38.86									

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A^*}$	$\frac{V}{a^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$	
5.75	.8216	.6254	.1314	5.662	.1902	44.40	2.282942	83.169	10.02	.4064	38.41	5.212	7.369	.3536	.2324
5.76	.8130	.6207	.1310	5.673	.1888	44.72	2.283462	83.243	9.996	.4063	38.54	5.214	7.392	.3510	.2316
5.77	.8044	.6161	.1306	5.683	.1875	45.05	2.283980	83.317	9.980	.4062	38.66	5.217	7.414	.3486	.2308
5.78	.7960	.6114	.1302	5.693	.1862	45.38	2.284496	83.391	9.963	.4061	38.81	5.219	7.436	.3461	.2300
5.79	.7876	.6069	.1298	5.703	.1848	45.72	2.285009	83.463	9.946	.4060	38.94	5.221	7.459	.3436	.2292
5.80	.7794	.6023	.1294	5.713	.1835	46.05	2.285520	83.537	9.928	.4059	39.06	5.224	7.481	.3412	.2284
5.81	.7713	.5978	.1290	5.723	.1823	46.39	2.286029	83.609	9.911	.4058	39.22	5.226	7.504	.3388	.2277
5.82	.7632	.5934	.1286	5.733	.1810	46.72	2.286535	83.683	9.894	.4058	39.35	5.228	7.527	.3364	.2269
5.83	.7553	.5889	.1282	5.744	.1797	47.07	2.287040	83.755	9.877	.4057	39.49	5.231	7.549	.3340	.2261
5.84	.7474	.5846	.1279	5.754	.1784	47.41	2.287542	83.827	9.860	.4056	39.62	5.233	7.572	.3317	.2254
5.85	.7396	.5802	.1275	5.764	.1772	47.75	2.288041	83.899	9.842	.4055	39.76	5.235	7.595	.3293	.2246
5.86	.7320	.5759	.1271	5.774	.1760	48.10	2.288539	83.971	9.826	.4054	39.90	5.237	7.618	.3270	.2238
5.87	.7244	.5716	.1267	5.784	.1747	48.45	2.289034	84.042	9.809	.4053	40.03	5.240	7.640	.3247	.2231
5.88	.7169	.5674	.1263	5.794	.1735	48.80	2.289527	84.114	9.792	.4052	40.17	5.242	7.663	.3225	.2223
5.89	.7095	.5632	.1260	5.804	.1723	49.15	2.290018	84.185	9.775	.4051	40.31	5.244	7.686	.3202	.2216
5.90	.7021	.5590	.1256	5.815	.1711	49.51	2.290507	84.257	9.758	.4050	40.45	5.246	7.709	.3180	.2208
5.91	.6949	.5549	.1252	5.825	.1699	49.86	2.290993	84.327	9.742	.4049	40.58	5.249	7.732	.3157	.2201
5.92	.6877	.5508	.1249	5.835	.1687	50.22	2.291477	84.398	9.725	.4049	40.72	5.251	7.755	.3135	.2194
5.93	.6807	.5468	.1245	5.845	.1676	50.59	2.291960	84.468	9.708	.4048	40.86	5.253	7.778	.3113	.2186
5.94	.6737	.5428	.1241	5.855	.1664	50.95	2.292440	84.539	9.692	.4047	41.00	5.255	7.801	.3092	.2179
5.95	.6668	.5388	.1238	5.865	.1652	51.32	2.292918	84.609	9.675	.4046	41.14	5.257	7.824	.3070	.2172
5.96	.6599	.5348	.1234	5.876	.1641	51.68	2.293394	84.679	9.659	.4045	41.28	5.260	7.847	.3049	.2165
5.97	.6532	.5309	.1230	5.886	.1630	52.05	2.293867	84.748	9.643	.4044	41.41	5.262	7.871	.3028	.2157
5.98	.6465	.5270	.1227	5.896	.1618	52.43	2.294339	84.817	9.626	.4043	41.55	5.264	7.894	.3007	.2150
5.99	.6399	.5232	.1223	5.906	.1607	52.80	2.294809	84.887	9.610	.4042	41.69	5.266	7.917	.2986	.2143
6.00	.6334	.5194	.1220	5.916	.1596	53.18	2.295276	84.955	9.594	.4042	41.83	5.268	7.941	.2965	.2136
6.01	.6269	.5156	.1216	5.926	.1585	53.56	2.295742	85.025	9.578	.4041	41.97	5.270	7.964	.2945	.2129
6.02	.6205	.5118	.1212	5.936	.1574	53.94	2.296205	85.093	9.562	.4040	42.11	5.273	7.987	.2924	.2122
6.03	.6142	.5081	.1209	5.947	.1563	54.32	2.296667	85.162	9.546	.4039	42.25	5.275	8.011	.2904	.2115
6.04	.6080	.5044	.1205	5.957	.1553	54.71	2.297126	85.230	9.530	.4038	42.40	5.277	8.034	.2884	.2108
6.05	.6018	.5008	.1202	5.967	.1542	55.10	2.297583	85.297	9.514	.4037	42.54	5.279	8.058	.2864	.2101
6.06	.5957	.4971	.1198	5.977	.1531	55.49	2.298039	85.366	9.498	.4037	42.68	5.281	8.081	.2844	.2094
6.07	.5897	.4935	.1195	5.987	.1521	55.88	2.298492	85.433	9.482	.4036	42.82	5.283	8.105	.2825	.2088
6.08	.5838	.4900	.1191	5.997	.1511	56.28	2.298944	85.500	9.467	.4035	42.96	5.285	8.129	.2806	.2081
6.09	.5779	.4864	.1188	6.007	.1500	56.68	2.299393	85.568	9.451	.4034	43.10	5.287	8.152	.2786	.2074
6.10	.5721	.4829	.1185	6.017	.1490	57.08	2.299841	85.635	9.435	.4033	43.25	5.289	8.176	.2767	.2067
6.11	.5663	.4795	.1181	6.028	.1480	57.48	2.300286	85.702	9.420	.4033	43.39	5.291	8.200	.2748	.2061
6.12	.5606	.4760	.1178	6.038	.1470	57.88	2.300730	85.768	9.404	.4032	43.53	5.293	8.223	.2730	.2054
6.13	.5550	.4726	.1174	6.048	.1460	58.29	2.301172	85.834	9.389	.4031	43.67	5.295	8.247	.2711	.2047
6.14	.5494	.4692	.1171	6.058	.1450	58.70	2.301612	85.901	9.373	.4030	43.82	5.297	8.271	.2692	.2041
6.15	.5439	.4658	.1168	6.068	.1440	59.11	2.302050	85.967	9.358	.4029	43.96	5.299	8.295	.2674	.2034
6.16	.5385	.4625	.1164	6.078	.1430	59.53	2.302486	86.033	9.343	.4029	44.10	5.301	8.319	.2656	.2028
6.17	.5331	.4592	.1161	6.088	.1421	59.94	2.302920	86.099	9.327	.4028	44.25	5.303	8.343	.2638	.2021
6.18	.5278	.4559	.1158	6.099	.1411	60.36	2.303353	86.164	9.312	.4027	44.39	5.305	8.367	.2620	.2015
6.19	.5225	.4527	.1154	6.109	.1402	60.79	2.303783	86.229	9.297	.4026	44.54	5.307	8.391	.2602	.2008
6.20	.5173	.4495	.1151	6.119	.1392	61.21	2.304212	86.295	9.282	.4025	44.68	5.309	8.415	.2584	.2002
6.21	.5122	.4463	.1148	6.129	.1383	61.64	2.304639	86.360	9.267	.4025	44.82	5.311	8.439	.2567	.1995
6.22	.5071	.4431	.1144	6.139	.1373	62.07	2.305064	86.424	9.252	.4024	44.97	5.313	8.464	.2550	.1989
6.23	.5021	.4400	.1141	6.149	.1364	62.50	2.305487	86.490	9.237	.4023	45.12	5.315	8.488	.2532	.1983
6.24	.4971	.4369	.1138	6.159	.1355	62.93	2.305908	86.554	9.222	.4022	45.26	5.317	8.512	.2515	.1977
6.25	.4922	.4338	.1135	6.169	.1346	63.37	2.306328	86.618	9.207	.4022	45.41	5.319	8.536	.2498	.1970
6.26	.4874	.4307	.1132	6.180	.1337	63.81	2.306746	86.683	9.192	.4021	45.55	5.321	8.561	.2482	.1964
6.27	.4825	.4277	.1128	6.190	.1328	64.25	2.307162	86.746	9.177	.4020	45.70	5.323	8.585	.2465	.1958
6.28	.4778	.4246	.1125	6.200	.1319	64.69	2.307576	86.810	9.163	.4019	45.84	5.325	8.610	.2448	.1952
6.29	.4731	.4217	.1122	6.210	.1310	65.14	2.307989	86.874	9.148	.4019	45.99	5.327	8.634	.2432	.1945
6.30	.4684	.4187	.1119	6.220	.1302	65.59	2.308400	86.937	9.133	.4018	46.14	5.329	8.658	.2416	.1939
6.31	.4638	.4158	.1116	6.230	.1293	66.04	2.308809	87.000	9.119	.4017	46.29	5.331	8.683	.2399	.1933
6.32	.4593	.4128	.1113	6.240	.1284	66.50	2.309216	87.063	9.104	.4016	46.43	5.332	8.708	.2383	.1927
6.33	.4548	.4100	.1109	6.251	.1276	66.95	2.309622	87.126	9.090	.4016	46.58	5.334	8.732	.2367	.1921
6.34	.4504	.4071	.1106	6.261	.1267	67.41	2.310026	87.189	9.075	.4015	46.73	5.336	8.757	.2352	.1915
6.35	.4460	.4042	.1103	6.271	.1259	67.88	2.310428	87.251	9.061	.4014	46.88	5.338	8.781	.2336	.1909
6.36	.4416	.4014	.1100	6.281	.1250	68.34	2.310828	87.313	9.046	.4014	47.02	5.340	8.806	.2320	.1903
6.37	.4373	.3986	.1097	6.291	.1242	68.81	2.311227	87.376	9.032	.4013	47.17	5.342	8.831	.2305	.1897
6.38	.4331	.3958	.1094	6.301	.1234	69.28	2.311625	87.438	9.018	.4012	47.32	5.344	8.856	.2290	.1891
6.39	.4288	.3931	.1091	6.311	.1226	69.75	2.312020	87.499	9.004	.4011	47.47	5.345	8.881	.2274	.1886
6.40	.4247	.3904	.1088	6.321	.1218	70.23	2.312414	87.561	8.989	.4011	47.62	5.347	8.905	.2259	.1880
6.41	.4206	.3877	.1085	6.332	.1210	70.71	2.312806	87.623	8.975	.4010	47.77	5.349	8.930	.2244	.1874
6.42	.4165	.3850	.1082	6.342	.1202	71.19	2.313197	87.684	8.961	.4009	47.92	5.351	8.955	.2230	.1868
6.43	.4125	.3823	.1079	6.352	.1194	71.67	2.313586	87.745	8.947	.4009	48.07	5.353	8.980	.2215	.1862
6.44	.4085	.3797	.1076	6.362	.1186	72.16	2.313973	87.806	8.933	.4008	48.22	5.354	9.005	.2200	.1857
6.45	.4045	.3771	.1073	6.372	.1178	72.65	2.314359	87.867	8.919	.4007	48.37	5.356	9.031	.2186	.1851
6.46	.4006	.3745	.1070	6.382	.1170	73.14	2.314743	87.927	8.905	.4007	48.52	5.358	9.056	.2171	.1845
6.47	.3968	.3719	.1067	6.392	.1163	73.63	2.315126	87.988	8.891	.4006	48.67	5.360	9.081	.2157	.1840
6.48	.3930	.3693	.1064	6.402	.1155	74.13	2.315507	88.048	8.877	.4005	48.82	5.362	9.106	.2143	.1834
6.49	.3892	.3668	.1061												

TABLE II.—SUPERSONIC FLOW—Continued

$\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A^*}$	$\frac{V}{a^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$	
6.65	.3341 -	.3289 -	.1016	6.574	.1034 -	83.03	2.321750	89.049	8.649	.3994	51.43	5.391	9.540	.1915 -	.1742 -
6.66	.3309 -	.3267 -	.1013	6.584	.1028 -	83.58	2.322104	89.106	8.636	.3993	51.58	5.392	9.566	.1905 -	.1737 -
6.67	.3278 -	.3245 -	.1010	6.595	.1021 -	84.13	2.322456	89.164	8.623	.3993	51.74	5.394	9.592	.1893 -	.1732 -
6.68	.3247 -	.3223 -	.1008	6.605	.1014 -	84.68	2.322807	89.221	8.610	.3992	51.89	5.395	9.618	.1881 -	.1727 -
6.69	.3217 -	.3201 -	.1005	6.615	.1006 -	85.24	2.323157	89.278	8.597	.3992	52.05	5.397	9.644	.1869 -	.1721 -
6.70	.3187 -	.3180 -	.1002	6.625	.1001 -	85.80	2.323505	89.335	8.584	.3991	52.21	5.399	9.670	.1857 -	.1716 -
6.71	.3157 -	.3158 -	.9995 -	6.635	.9950 -	86.37	2.323852	89.391	8.571	.3990	52.36	5.407	9.695	.1845 -	.1711 -
6.72	.3127 -	.3137 -	.9998 -	6.645	.9886 -	86.94	2.324198	89.448	8.558	.3990	52.52	5.402	9.722	.1833 -	.1706 -
6.73	.3096 -	.3116 -	.9992 -	6.655	.9823 -	87.51	2.324542	89.504	8.545	.3989	52.68	5.403	9.748	.1821 -	.1701 -
6.74	.3069 -	.3096 -	.9915 -	6.665	.9761 -	88.08	2.324884	89.561	8.532	.3988	52.83	5.405	9.775	.1810 -	.1696 -
6.75	.3041 -	.3075 -	.9889 -	6.676	.9699 -	88.66	2.325226	89.617	8.520	.3986	52.99	5.407	9.801	.1798 -	.1691 -
6.76	.3013 -	.3055 -	.9862 -	6.686	.9637 -	89.24	2.325566	89.673	8.507	.3987	53.15	5.408	9.827	.1786 -	.1686 -
6.77	.2985 -	.3034 -	.9836 -	6.696	.9576 -	89.82	2.325904	89.729	8.494	.3987	53.31	5.410	9.853	.1775 -	.1681 -
6.78	.2957 -	.3014 -	.9810 -	6.706	.9515 -	90.41	2.326242	89.784	8.482	.3986	53.46	5.411	9.880	.1764 -	.1677 -
6.79	.2930 -	.2994 -	.9784 -	6.716	.9454 -	91.00	2.326578	89.840	8.469	.3986	53.62	5.413	9.906	.1753 -	.1671 -
6.80	.2902 -	.2974 -	.9758 -	6.726	.9395 -	91.59	2.326912	89.895	8.457	.3985	53.78	5.415	9.933	.1741 -	.1667 -
6.81	.2876 -	.2955 -	.9732 -	6.736	.9335 -	92.19	2.327245	89.950	8.444	.3984	53.94	5.416	9.959	.1730 -	.1662 -
6.82	.2849 -	.2935 -	.9706 -	6.746	.9276 -	92.79	2.327577	90.005	8.432	.3984	54.10	5.418	9.986	.1719 -	.1657 -
6.83	.2823 -	.2916 -	.9681 -	6.756	.9218 -	93.39	2.327908	90.060	8.419	.3983	54.26	5.419	10.01	.1709 -	.1652 -
6.84	.2797 -	.2897 -	.9655 -	6.767	.9160 -	94.00	2.328237	90.116	8.407	.3983	54.42	5.421	10.04	.1698 -	.1647 -
6.85	.2771 -	.2878 -	.9630 -	6.777	.9102 -	94.61	2.328565	90.170	8.394	.3982	54.58	5.422	10.07	.1687 -	.1643 -
6.86	.2746 -	.2859 -	.9604 -	6.787	.9045 -	95.22	2.328892	90.225	8.382	.3981	54.74	5.424	10.09	.1676 -	.1638 -
6.87	.2720 -	.2840 -	.9579 -	6.797	.8988 -	95.83	2.329217	90.279	8.370	.3981	54.90	5.425	10.12	.1666 -	.1633 -
6.88	.2696 -	.2821 -	.9554 -	6.807	.8931 -	96.45	2.329541	90.333	8.357	.3980	55.06	5.427	10.15	.1655 -	.1628 -
6.89	.2671 -	.2803 -	.9529 -	6.817	.8875 -	97.08	2.329864	90.387	8.345	.3980	55.22	5.428	10.17	.1645 -	.1624 -
6.90	.2646 -	.2785 -	.9504 -	6.827	.8820 -	97.70	2.330186	90.441	8.333	.3979	55.38	5.430	10.20	.1634 -	.1619 -
6.91	.2622 -	.2766 -	.9479 -	6.837	.8764 -	98.33	2.330506	90.495	8.321	.3979	55.54	5.431	10.23	.1624 -	.1614 -
6.92	.2598 -	.2748 -	.9454 -	6.847	.8710 -	98.96	2.330825	90.549	8.309	.3978	55.70	5.433	10.25	.1614 -	.1610 -
6.93	.2575 -	.2730 -	.9430 -	6.857	.8655 -	99.60	2.331143	90.602	8.297	.3977	55.86	5.434	10.28	.1604 -	.1605 -
6.94	.2551 -	.2713 -	.9405 -	6.868	.8601 -	100.2	2.331500	90.655	8.285	.3977	56.02	5.436	10.31	.1594 -	.1601 -
6.95	.2528 -	.2695 -	.9380 -	6.878	.8548 -	100.9	2.331775	90.709	8.273	.3976	56.19	5.437	10.33	.1584 -	.1596 -
6.96	.2505 -	.2677 -	.9356 -	6.888	.8495 -	101.5	2.332049	90.762	8.261	.3976	56.35	5.439	10.36	.1574 -	.1592 -
6.97	.2482 -	.2660 -	.9332 -	6.898	.8442 -	102.2	2.332320	90.815	8.249	.3975	56.51	5.440	10.39	.1564 -	.1587 -
6.98	.2460 -	.2643 -	.9307 -	6.908	.8389 -	102.8	2.332594	90.867	8.237	.3975	56.67	5.442	10.42	.1554 -	.1582 -
6.99	.2438 -	.2626 -	.9283 -	6.918	.8337 -	103.5	2.332862	90.920	8.225	.3974	56.84	5.443	10.44	.1545 -	.1578 -
7.00	.2416 -	.2609 -	.9259 -	6.928	.8286 -	104.1	2.333133	90.973	8.213	.3974	57.00	5.444	10.47	.1535 -	.1574 -
7.01	.2394 -	.2592 -	.9235 -	6.938	.8234 -	104.8	2.333404	91.026	8.201	.3973	57.16	5.446	10.50	.1526 -	.1569 -
7.02	.2372 -	.2575 -	.9211 -	6.948	.8183 -	105.5	2.333674	91.079	8.190	.3973	57.33	5.447	10.52	.1516 -	.1565 -
7.03	.2351 -	.2559 -	.9188 -	6.959	.8133 -	106.1	2.333945	91.132	8.178	.3972	57.49	5.449	10.55	.1507 -	.1560 -
7.04	.2330 -	.2542 -	.9164 -	6.969	.8082 -	106.8	2.334215	91.182	8.166	.3971	57.66	5.450	10.58	.1497 -	.1556 -
7.05	.2309 -	.2526 -	.9140 -	6.979	.8032 -	107.5	2.334486	91.234	8.155	.3971	57.82	5.452	10.61	.1488 -	.1551 -
7.06	.2288 -	.2510 -	.9117 -	6.989	.7983 -	108.2	2.334756	91.286	8.143	.3970	57.98	5.453	10.63	.1479 -	.1547 -
7.07	.2267 -	.2494 -	.9093 -	6.999	.7934 -	108.9	2.335025	91.337	8.131	.3970	58.15	5.454	10.66	.1470 -	.1543 -
7.08	.2247 -	.2478 -	.9070 -	7.009	.7885 -	109.5	2.335295	91.389	8.120	.3969	58.31	5.456	10.69	.1461 -	.1538 -
7.09	.2227 -	.2462 -	.9047 -	7.019	.7837 -	110.2	2.335563	91.440	8.108	.3969	58.48	5.457	10.72	.1452 -	.1534 -
7.10	.2207 -	.2446 -	.9024 -	7.029	.7789 -	110.9	2.335831	91.492	8.097	.3968	58.65	5.459	10.74	.1443 -	.1530 -
7.11	.2187 -	.2430 -	.9001 -	7.039	.7741 -	111.6	2.336098	91.543	8.085	.3968	58.81	5.460	10.77	.1434 -	.1525 -
7.12	.2168 -	.2415 -	.8978 -	7.049	.7693 -	112.3	2.336362	91.594	8.074	.3967	58.98	5.461	10.80	.1425 -	.1521 -
7.13	.2149 -	.2400 -	.8955 -	7.060	.7646 -	113.0	2.336626	91.645	8.062	.3967	59.14	5.463	10.83	.1416 -	.1517 -
7.14	.2130 -	.2384 -	.8932 -	7.070	.7600 -	113.7	2.336889	91.695	8.051	.3966	59.31	5.464	10.85	.1408 -	.1513 -
7.15	.2111 -	.2369 -	.8909 -	7.080	.7553 -	114.5	2.337151	91.746	8.040	.3966	59.48	5.465	10.88	.1399 -	.1509 -
7.16	.2092 -	.2354 -	.8886 -	7.090	.7507 -	115.2	2.337412	91.796	8.028	.3965	59.64	5.467	10.91	.1390 -	.1504 -
7.17	.2073 -	.2339 -	.8864 -	7.100	.7461 -	115.9	2.337674	91.847	8.017	.3965	59.81	5.468	10.94	.1382 -	.1500 -
7.18	.2055 -	.2324 -	.8841 -	7.110	.7416 -	116.6	2.337936	91.897	8.006	.3964	59.98	5.470	10.97	.1374 -	.1496 -
7.19	.2037 -	.2310 -	.8819 -	7.120	.7371 -	117.3	2.338198	91.947	7.995	.3964	60.15	5.471	10.99	.1365 -	.1492 -
7.20	.2019 -	.2295 -	.8797 -	7.130	.7326 -	118.1	2.338459	91.997	7.984	.3963	60.31	5.472	11.02	.1357 -	.1488 -
7.21	.2001 -	.2281 -	.8774 -	7.140	.7281 -	118.8	2.338719	92.047	7.972	.3963	60.48	5.474	11.05	.1349 -	.1484 -
7.22	.1983 -	.2266 -	.8752 -	7.150	.7237 -	119.5	2.338978	92.097	7.961	.3962	60.65	5.475	11.08	.1340 -	.1480 -
7.23	.1966 -	.2252 -	.8730 -	7.161	.7194 -	120.3	2.339236	92.146	7.950	.3962	60.82	5.476	11.11	.1332 -	.1476 -
7.24	.1949 -	.2238 -	.8708 -	7.171	.7150 -	121.0	2.339494	92.196	7.939	.3961	60.99	5.478	11.13	.1324 -	.1472 -
7.25	.1932 -	.2224 -	.8686 -	7.181	.7107 -	121.8	2.339751	92.245	7.928	.3961	61.16	5.479	11.16	.1316 -	.1468 -
7.26	.1915 -	.2210 -	.8664 -	7.191	.7064 -	122.5	2.339999	92.294	7.917	.3960	61.33	5.480	11.19	.1308 -	.1464 -
7.27	.1898 -	.2196 -	.8643 -	7.201	.7021 -	123.3	2.340248	92.343	7.906	.3960	61.50	5.481	11.22	.1300 -	.1460 -
7.28	.1881 -	.2182 -	.8621 -	7.211	.6979 -	124.1	2.340496	92.392	7.895	.3959	61.66	5.483	11.25	.1292 -	.1456 -
7.29	.1865 -	.2169 -	.8599 -	7.221	.6937 -	124.8	2.340743	92.441	7.884	.3959	61.83	5.484	11.28	.1285 -	.1452 -
7.30	.1848 -	.2155 -	.8578 -	7.231	.6896 -	125.6	2.340989	92.490	7.874	.3958	62.01	5.485	11.30	.1277 -	.1448 -
7.31	.1832 -	.2142 -	.8556 -	7.241	.6854 -	126.4	2.341233	92.538	7.863	.3958	62.18	5.487	11.33	.1269 -	.1444 -
7.32	.1816 -	.2128 -	.8535 -	7.251	.6813 -	127.2	2.341477	92.587	7.852	.3957	62.35	5.488	11.36	.1262 -	.1440 -
7.33	.1801 -	.2115 -	.8514 -	7.261	.6772 -	127.9	2.341720	92.635	7.841	.3957	62.52	5.489	11.39	.1254 -	.1436 -
7.34	.1785 -	.2102 -	.8492 -	7.272	.6731 -	128.7	2.341962	92.684	7.830	.3956	62.69	5.490	11.42	.1246 -	.1432 -
7.35	.1769 -	.2089 -	.8471 -	7.282	.6691 -	129.5	2.342204	92.732	7.820	.3956	62.86	5.492	11.45	.1239 -	.1428 -
7.36	.1754 -	.2076 -	.8450 -	7.292	.6651 -	130.3	2.342445	92.780	7.809	.3955	63.03	5.493	11.48	.1232 -	.142

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A^*}$	$\frac{V}{a^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
7.55	.1489	-.1847	-.8064	7.483	.5942	146.2	2.348648	93.670	7.611	.3947	66.34	5.516	12.03	.1100
7.56	.1477	-.1836	-.8045	7.494	.5908	147.0	2.348899	93.716	7.601	.3946	66.51	5.517	12.06	.1093
7.57	.1464	-.1824	-.8025	7.504	.5873	147.9	2.349148	93.762	7.591	.3946	66.69	5.518	12.09	.1087
7.58	.1452	-.1813	-.8006	7.514	.5839	148.8	2.349397	93.807	7.581	.3946	66.87	5.520	12.11	.1081
7.59	.1439	-.1802	-.7986	7.524	.5805	149.7	2.349644	93.853	7.571	.3945	67.04	5.521	12.14	.1074
7.60	.1427	-.1792	-.7967	7.534	.5771	150.6	2.349891	93.898	7.561	.3945	67.22	5.522	12.17	.1068
7.61	.1415	-.1781	-.7948	7.544	.5737	151.5	2.350137	93.943	7.551	.3944	67.40	5.523	12.20	.1062
7.62	.1403	-.1770	-.7928	7.554	.5704	152.4	2.350382	93.988	7.541	.3944	67.58	5.524	12.23	.1056
7.63	.1391	-.1759	-.7909	7.564	.5671	153.3	2.350626	94.033	7.531	.3943	67.75	5.525	12.26	.1049
7.64	.1380	-.1749	-.7890	7.574	.5638	154.2	2.350869	94.078	7.521	.3943	67.93	5.527	12.29	.1043
7.65	.1368	-.1738	-.7871	7.584	.5605	155.1	2.351112	94.123	7.511	.3943	68.11	5.528	12.32	.1037
7.66	.1357	-.1728	-.7852	7.594	.5572	156.0	2.351353	94.168	7.501	.3942	68.29	5.529	12.35	.1031
7.67	.1345	-.1717	-.7833	7.605	.5540	157.0	2.351594	94.212	7.491	.3942	68.47	5.530	12.38	.1025
7.68	.1334	-.1707	-.7815	7.615	.5508	157.9	2.351834	94.257	7.482	.3941	68.65	5.531	12.41	.1019
7.69	.1323	-.1697	-.7796	7.625	.5476	158.8	2.352072	94.301	7.472	.3941	68.83	5.532	12.44	.1013
7.70	.1312	-.1687	-.7777	7.635	.5445	159.8	2.352310	94.345	7.462	.3941	69.01	5.533	12.47	.1008
7.71	.1301	-.1677	-.7759	7.645	.5413	160.7	2.352548	94.389	7.452	.3940	69.18	5.534	12.50	.1002
7.72	.1290	-.1667	-.7740	7.655	.5382	161.7	2.352784	94.433	7.443	.3940	69.36	5.536	12.53	.9959
7.73	.1279	-.1657	-.7722	7.665	.5351	162.6	2.353019	94.477	7.433	.3939	69.55	5.537	12.56	.9902
7.74	.1269	-.1647	-.7703	7.675	.5320	163.6	2.353254	94.521	7.423	.3939	69.73	5.538	12.59	.9845
7.75	.1258	-.1637	-.7685	7.685	.5290	164.5	2.353488	94.565	7.414	.3939	69.91	5.539	12.62	.9788
7.76	.1248	-.1627	-.7667	7.695	.5259	165.5	2.353721	94.608	7.404	.3938	70.09	5.540	12.65	.9732
7.77	.1237	-.1618	-.7648	7.705	.5229	166.5	2.353953	94.652	7.395	.3938	70.27	5.541	12.68	.9676
7.78	.1227	-.1608	-.7630	7.715	.5199	167.4	2.354184	94.695	7.385	.3937	70.45	5.542	12.71	.9620
7.79	.1217	-.1599	-.7612	7.726	.5170	168.4	2.354415	94.739	7.375	.3937	70.63	5.543	12.74	.9565
7.80	.1207	-.1589	-.7594	7.736	.5140	169.4	2.354644	94.782	7.366	.3937	70.81	5.544	12.77	.9510
7.81	.1197	-.1580	-.7576	7.746	.5111	170.4	2.354873	94.825	7.356	.3936	71.00	5.545	12.80	.9456
7.82	.1187	-.1571	-.7558	7.756	.5082	171.4	2.355101	94.868	7.347	.3936	71.18	5.547	12.83	.9402
7.83	.1177	-.1561	-.7540	7.766	.5053	172.4	2.355328	94.911	7.338	.3935	71.36	5.548	12.86	.9348
7.84	.1168	-.1552	-.7523	7.776	.5024	173.4	2.355555	94.954	7.328	.3935	71.54	5.549	12.89	.9295
7.85	.1158	-.1543	-.7505	7.786	.4995	174.4	2.355780	94.996	7.319	.3935	71.73	5.550	12.92	.9242
7.86	.1149	-.1534	-.7487	7.796	.4967	175.4	2.356005	95.039	7.309	.3934	71.91	5.551	12.95	.9189
7.87	.1139	-.1525	-.7470	7.806	.4939	176.4	2.356229	95.082	7.300	.3934	72.09	5.552	12.98	.9137
7.88	.1130	-.1516	-.7452	7.816	.4911	177.5	2.356453	95.124	7.291	.3933	72.28	5.553	13.02	.9085
7.89	.1121	-.1507	-.7435	7.826	.4883	178.5	2.356675	95.166	7.281	.3933	72.46	5.554	13.05	.9033
7.90	.1111	-.1498	-.7417	7.836	.4855	179.5	2.356897	95.208	7.272	.3933	72.65	5.555	13.08	.8982
7.91	.1102	-.1489	-.7400	7.847	.4828	180.5	2.357119	95.251	7.263	.3932	72.83	5.556	13.11	.8931
7.92	.1093	-.1481	-.7383	7.857	.4801	181.6	2.357338	95.293	7.254	.3932	73.01	5.557	13.14	.8880
7.93	.1084	-.1472	-.7365	7.867	.4774	182.6	2.357557	95.334	7.245	.3932	73.20	5.558	13.17	.8830
7.94	.1076	-.1464	-.7348	7.877	.4747	183.7	2.357776	95.376	7.235	.3931	73.38	5.559	13.20	.8780
7.95	.1067	-.1455	-.7331	7.887	.4720	184.7	2.357994	95.418	7.226	.3931	73.57	5.560	13.23	.8731
7.96	.1058	-.1447	-.7314	7.897	.4693	185.8	2.358211	95.460	7.217	.3930	73.76	5.561	13.26	.8682
7.97	.1050	-.1438	-.7297	7.907	.4667	186.9	2.358427	95.501	7.208	.3930	73.94	5.562	13.29	.8633
7.98	.1041	-.1430	-.7280	7.917	.4641	188.0	2.358642	95.542	7.199	.3930	74.13	5.563	13.33	.8584
7.99	.1033	-.1422	-.7263	7.927	.4615	189.0	2.358857	95.584	7.190	.3929	74.31	5.564	13.36	.8536
8.00	.1024	-.1414	-.7246	7.937	.4589	190.1	2.359071	95.625	7.181	.3929	74.50	5.565	13.39	.8488
8.01	.1016	-.1405	-.7230	7.947	.4563	191.2	2.359285	95.666	7.172	.3929	74.69	5.566	13.42	.8440
8.02	.1008	-.1397	-.7213	7.957	.4538	192.3	2.359497	95.707	7.163	.3928	74.87	5.567	13.45	.8393
8.03	.9997	-.1389	-.7196	7.967	.4512	193.4	2.359709	95.748	7.154	.3928	75.06	5.568	13.48	.8346
8.04	.9916	-.1381	-.7180	7.978	.4487	194.5	2.359920	95.789	7.145	.3927	75.25	5.569	13.51	.8299
8.05	.9837	-.1373	-.7163	7.988	.4462	195.6	2.360130	95.830	7.136	.3927	75.44	5.570	13.54	.8253
8.06	.9758	-.1365	-.7147	7.998	.4437	196.7	2.360340	95.871	7.127	.3927	75.62	5.571	13.57	.8207
8.07	.9679	-.1358	-.7130	8.008	.4413	197.8	2.360549	95.912	7.118	.3926	75.81	5.572	13.61	.8161
8.08	.9602	-.1350	-.7114	8.018	.4388	199.0	2.360757	95.953	7.109	.3926	76.00	5.573	13.64	.8115
8.09	.9525	-.1342	-.7097	8.028	.4364	200.1	2.360965	95.992	7.100	.3926	76.19	5.574	13.67	.8070
8.10	.9449	-.1334	-.7081	8.038	.4339	201.2	2.361172	96.032	7.092	.3925	76.38	5.575	13.70	.8025
8.11	.9373	-.1327	-.7065	8.048	.4315	202.4	2.361378	96.073	7.083	.3925	76.57	5.576	13.73	.7981
8.12	.9298	-.1319	-.7049	8.058	.4292	203.5	2.361583	96.112	7.074	.3925	76.76	5.577	13.76	.7937
8.13	.9224	-.1312	-.7033	8.068	.4268	204.6	2.361788	96.153	7.065	.3924	76.95	5.578	13.80	.7893
8.14	.9150	-.1304	-.7017	8.078	.4244	205.8	2.361992	96.193	7.057	.3924	77.14	5.579	13.83	.7849
8.15	.9078	-.1297	-.7001	8.088	.4221	207.0	2.362195	96.233	7.048	.3924	77.33	5.580	13.86	.7805
8.16	.9005	-.1289	-.6985	8.098	.4197	208.1	2.362397	96.272	7.039	.3923	77.52	5.581	13.89	.7762
8.17	.8934	-.1282	-.6969	8.109	.4174	209.3	2.362599	96.312	7.031	.3923	77.71	5.582	13.92	.7719
8.18	.8863	-.1275	-.6953	8.119	.4151	210.5	2.362800	96.352	7.022	.3923	77.90	5.583	13.95	.7677
8.19	.8793	-.1267	-.6937	8.129	.4129	211.7	2.363001	96.391	7.013	.3922	78.09	5.584	13.99	.7634
8.20	.8723	-.1260	-.6921	8.139	.4106	212.8	2.363201	96.430	7.005	.3922	78.28	5.585	14.02	.7592
8.21	.8654	-.1253	-.6906	8.149	.4083	214.0	2.363400	96.470	6.996	.3921	78.47	5.586	14.05	.7551
8.22	.8586	-.1246	-.6890	8.159	.4061	215.2	2.363598	96.509	6.988	.3921	78.66	5.587	14.08	.7509
8.23	.8518	-.1239	-.6874	8.169	.4039	216.4	2.363796	96.548	6.979	.3921	78.86	5.588	14.11	.7468
8.24	.8451	-.1232	-.6859	8.179	.4017	217.7	2.363993	96.587	6.971	.3920	79.05	5.588	14.15	.7427
8.25	.8384	-.1225	-.6843	8.189	.3995	218.9	2.364190	96.626	6.962	.3920	79.24	5.589	14.18	.7386
8.26	.8318	-.1218	-.6828	8.199	.3973	220.1	2.364385	96.665	6.954	.3920	79.43	5.590	14.21	.7346
8.27	.8253	-.1211	-.6813	8.209	.3951	221.3	2.364581	96.704	6.945	.3919	79.63	5.591	14.24	.7306
8.28	.8188	-.1205	-.6797	8.219	.3930	222.5	2.364775	96.742	6.937	.3919	79.82	5.592	14.27	.7266
8.29	.8124	-.1198	-.6782	8.229	.3908	223.8	2.364969	96.781	6.928	.3919	80.01	5.593	14.31	.7226
8.30	.8060	-.1191	-.6767	8.240	.3887	225.0	2.365162	96.820	6.920	.3918	80.21	5.594	14.34	.7187
8.31	.7997	-.1184	-.6752	8.250	.3866	226.3	2.365354	96.858	6.912	.3918	80.40	5.595	14.37	.7147
8.32	.7935	-.1178	-.6737	8.260	.3845	227.5	2.365546	96.896						

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	θ	$\frac{q}{p_1}$	$\frac{A}{A^*}$	$\frac{V}{a^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
8.45	.7170	.1096	.6544	8.791	.3584	244.4	2.367983	97.388	.3914	83.14	5.607	14.83	.6625	.1082
8.46	.7115	.1090	.6530	8.401	.3565	245.7	2.368166	97.424	.3913	83.33	5.608	14.86	.6599	.1080
8.47	.7060	.1084	.6515	8.411	.3545	247.0	2.368348	97.462	.3913	83.53	5.609	14.89	.6554	.1077
8.48	.7006	.1078	.6501	8.421	.3526	248.4	2.368530	97.499	.3913	83.73	5.610	14.93	.6519	.1075
8.49	.6952	.1072	.6487	8.431	.3508	249.7	2.368712	97.536	.3912	83.93	5.611	14.96	.6484	.1072
8.50	.6898	.1066	.6472	8.441	.3489	251.1	2.368892	97.573	.3912	84.13	5.612	14.99	.6449	.1070
8.51	.6846	.1060	.6458	8.451	.3470	252.5	2.369072	97.609	.3912	84.32	5.613	15.02	.6415	.1067
8.52	.6793	.1054	.6444	8.461	.3452	253.8	2.369252	97.646	.3911	84.52	5.613	15.06	.6380	.1065
8.53	.6741	.1048	.6430	8.471	.3433	255.2	2.369431	97.683	.3911	84.72	5.614	15.09	.6346	.1062
8.54	.6690	.1043	.6416	8.481	.3415	256.6	2.369609	97.719	.3911	84.92	5.615	15.12	.6313	.1060
8.55	.6638	.1037	.6402	8.491	.3397	258.0	2.369787	97.756	.3911	85.12	5.616	15.16	.6279	.1057
8.56	.6588	.1031	.6388	8.501	.3379	259.4	2.369964	97.792	.3910	85.32	5.617	15.19	.6246	.1055
8.57	.6538	.1026	.6374	8.511	.3361	260.8	2.370140	97.828	.3910	85.52	5.618	15.22	.6212	.1052
8.58	.6488	.1020	.6360	8.522	.3343	262.2	2.370316	97.865	.3910	85.72	5.618	15.26	.6179	.1050
8.59	.6438	.1015	.6346	8.532	.3326	263.6	2.370492	97.901	.3909	85.92	5.619	15.29	.6147	.1048
8.60	.6390	.1009	.6332	8.542	.3308	265.0	2.370667	97.937	.3909	86.12	5.620	15.32	.6114	.1045
8.61	.6341	.1004	.6319	8.552	.3291	266.4	2.370841	97.973	.3909	86.32	5.621	15.36	.6082	.1043
8.62	.6293	.9981	.6305	8.562	.3273	267.9	2.371015	98.009	.3909	86.52	5.622	15.39	.6050	.1040
8.63	.6245	.9927	.6291	8.572	.3256	269.3	2.371188	98.045	.3908	86.72	5.623	15.42	.6018	.1038
8.64	.6198	.9873	.6277	8.582	.3239	270.8	2.371360	98.081	.3908	86.92	5.623	15.46	.5986	.1035
8.65	.6151	.9820	.6264	8.592	.3222	272.2	2.371532	98.116	.3908	87.13	5.624	15.49	.5954	.1033
8.66	.6105	.9767	.6250	8.602	.3205	273.7	2.371704	98.152	.3907	87.33	5.625	15.53	.5923	.1031
8.67	.6059	.9714	.6237	8.612	.3188	275.1	2.371875	98.187	.3907	87.53	5.626	15.56	.5892	.1029
8.68	.6013	.9662	.6223	8.622	.3171	276.6	2.372045	98.223	.3907	87.73	5.627	15.59	.5861	.1026
8.69	.5968	.9610	.6210	8.632	.3155	278.1	2.372215	98.258	.3906	87.94	5.627	15.63	.5830	.1024
8.70	.5923	.9558	.6197	8.642	.3138	279.6	2.372384	98.293	.3906	88.14	5.628	15.66	.5799	.1021
8.71	.5878	.9507	.6183	8.652	.3122	281.1	2.372553	98.329	.3906	88.34	5.629	15.69	.5769	.1019
8.72	.5834	.9456	.6170	8.662	.3105	282.6	2.372721	98.364	.3906	88.54	5.630	15.73	.5739	.1017
8.73	.5790	.9405	.6157	8.673	.3089	284.1	2.372899	98.399	.3905	88.75	5.631	15.76	.5709	.1014
8.74	.5747	.9355	.6143	8.683	.3073	285.6	2.373056	98.434	.3905	88.95	5.631	15.80	.5679	.1012
8.75	.5704	.9305	.6130	8.693	.3057	287.1	2.373222	98.469	.3905	89.16	5.632	15.83	.5649	.1010
8.76	.5661	.9255	.6117	8.703	.3041	288.6	2.373398	98.504	.3904	89.36	5.633	15.86	.5620	.1007
8.77	.5619	.9205	.6104	8.713	.3025	290.1	2.373554	98.539	.3904	89.57	5.634	15.90	.5590	.1005
8.78	.5577	.9156	.6091	8.723	.3010	291.7	2.373719	98.574	.3904	89.77	5.635	15.93	.5561	.1003
8.79	.5536	.9106	.6078	8.733	.2994	293.2	2.373883	98.608	.3904	89.97	5.635	15.97	.5532	.1001
8.80	.5494	.9059	.6065	8.743	.2978	294.8	2.374047	98.642	.3903	90.18	5.636	16.00	.5504	.9998
8.81	.5453	.9011	.6052	8.753	.2963	296.3	2.374210	98.677	.3903	90.39	5.637	16.04	.5475	.9996
8.82	.5413	.8963	.6039	8.763	.2948	297.9	2.374373	98.711	.3903	90.59	5.638	16.07	.5447	.9993
8.83	.5373	.8915	.6026	8.773	.2932	299.5	2.374535	98.745	.3903	90.80	5.638	16.10	.5418	.9991
8.84	.5333	.8868	.6014	8.783	.2917	301.0	2.374697	98.780	.3902	91.00	5.639	16.14	.5390	.9989
8.85	.5293	.8821	.6001	8.793	.2902	302.6	2.374859	98.814	.3902	91.21	5.640	16.17	.5362	.9987
8.86	.5254	.8774	.5988	8.803	.2887	304.2	2.375019	98.848	.3902	91.42	5.641	16.21	.5335	.9984
8.87	.5215	.8728	.5975	8.813	.2872	305.8	2.375180	98.882	.3901	91.62	5.641	16.24	.5307	.9982
8.88	.5177	.8682	.5963	8.824	.2857	307.4	2.375339	98.916	.3901	91.83	5.642	16.28	.5280	.9980
8.89	.5139	.8636	.5950	8.834	.2843	309.0	2.375499	98.950	.3901	92.04	5.643	16.31	.5253	.9978
8.90	.5101	.8590	.5938	8.844	.2828	310.6	2.375657	98.984	.3901	92.25	5.644	16.35	.5226	.9976
8.91	.5063	.8545	.5925	8.854	.2814	312.3	2.375816	99.018	.3900	92.45	5.645	16.38	.5199	.9974
8.92	.5026	.8501	.5913	8.864	.2799	313.9	2.375973	99.051	.3900	92.66	5.645	16.41	.5172	.9972
8.93	.4989	.8456	.5900	8.874	.2785	315.5	2.376131	99.085	.3900	92.87	5.646	16.45	.5145	.9970
8.94	.4952	.8411	.5888	8.884	.2771	317.2	2.376287	99.119	.3900	93.08	5.647	16.48	.5119	.9968
8.95	.4916	.8367	.5875	8.894	.2756	318.8	2.376444	99.152	.3899	93.29	5.647	16.52	.5093	.9966
8.96	.4880	.8323	.5863	8.904	.2742	320.5	2.376599	99.186	.3899	93.50	5.648	16.55	.5067	.9964
8.97	.4844	.8280	.5851	8.914	.2728	322.1	2.376755	99.219	.3899	93.70	5.649	16.59	.5041	.9962
8.98	.4809	.8236	.5839	8.924	.2714	323.8	2.376909	99.252	.3899	93.91	5.650	16.62	.5015	.9960
8.99	.4773	.8193	.5826	8.934	.2701	325.5	2.377064	99.286	.3898	94.12	5.650	16.66	.4989	.9958
9.00	.4739	.8150	.5814	8.944	.2687	327.2	2.377217	99.319	.3898	94.33	5.651	16.69	.4964	.9956
9.01	.4704	.8108	.5802	8.954	.2673	328.9	2.377371	99.352	.3898	94.54	5.652	16.73	.4939	.9954
9.02	.4670	.8066	.5790	8.964	.2660	330.6	2.377524	99.384	.3897	94.75	5.653	16.76	.4913	.9952
9.03	.4636	.8024	.5778	8.974	.2646	332.3	2.377676	99.417	.3897	94.96	5.654	16.80	.4888	.9950
9.04	.4602	.7982	.5766	8.985	.2633	334.0	2.377828	99.451	.3897	95.18	5.654	16.83	.4864	.9948
9.05	.4569	.7940	.5754	8.995	.2619	335.7	2.377979	99.483	.3897	95.39	5.655	16.87	.4839	.9946
9.06	.4535	.7899	.5742	9.005	.2606	337.5	2.378130	99.516	.3896	95.60	5.656	16.90	.4814	.9944
9.07	.4503	.7858	.5730	9.015	.2593	339.2	2.378281	99.549	.3896	95.81	5.656	16.94	.4790	.9942
9.08	.4470	.7818	.5718	9.025	.2580	340.9	2.378431	99.581	.3896	96.02	5.657	16.97	.4766	.9940
9.09	.4438	.7777	.5706	9.035	.2567	342.7	2.378580	99.614	.3896	96.23	5.658	17.01	.4742	.9938
9.10	.4405	.7737	.5694	9.045	.2554	344.5	2.378729	99.646	.3895	96.45	5.658	17.05	.4718	.9936
9.11	.4374	.7697	.5682	9.055	.2541	346.2	2.378878	99.679	.3895	96.66	5.659	17.08	.4694	.9934
9.12	.4342	.7657	.5671	9.065	.2528	348.0	2.379026	99.711	.3895	96.87	5.660	17.12	.4670	.9932
9.13	.4311	.7618	.5659	9.075	.2515	349.8	2.379174	99.743	.3895	97.08	5.660	17.15	.4646	.9930
9.14	.4280	.7578	.5647	9.085	.2503	351.6	2.379321	99.775	.3894	97.30	5.661	17.19	.4623	.9928
9.15	.4249	.7539	.5636	9.095	.2490	353.4	2.379468	99.807	.3894	97.51	5.662	17.22	.4600	.9926
9.16	.4218	.7501	.5624	9.105	.2478	355.2	2.379614	99.840	.3894	97.72	5.663	17.26	.4577	.9924
9.17	.4188	.7462	.5612	9.115	.2465	357.0	2.379760	99.872	.3894	97.94	5.663	17.29	.4554	.9922
9.18	.4158	.7424	.5601	9.125	.2453	358.8	2.379905	99.904	.3893	98.15	5.664	17.33	.4531	.9920
9.19	.4128	.7386	.5589	9.135	.2441	360.6	2.380050	99.936	.3893	98.37	5.665	17.37	.4508	.9918
9.20	.4099	.7348	.5578	9.145	.2428	362.5	2.380195	99.967	.3893	98.58	5.665	17.40	.4486	.9916
9.21	.4069	.7310	.5566	9.156	.2416	364.3	2.380339	99.999	.3893	98.79	5.666	17.44	.4463	.9914
9.22	.4040	.7273	.5555	9.166	.2404	366.2	2.380483	100.031	.3892	99.01	5.667	17.47	.4441	.9912
9.23	.4011	.7236	.5544	9.176	.2392	368.0	2.380626	100.062	.3892	99.23	5.667	17.51	.4419	.9910
9.24	.3983</													

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{1}{A^*}$	$\frac{V}{a^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_2}{p_{t1}}$	
9.35	.3683	.6507	.5410	9.205	2254	391.9	2.382311	100.436	6.140	.3889	101.8	5.675	17.94	.4102	.8849
9.36	.3657	.6574	.5399	9.206	2243	392.9	2.382448	100.467	6.131	.3889	102.0	5.676	17.98	.4112	.8828
9.37	.3631	.6640	.5388	9.207	2232	393.8	2.382585	100.498	6.122	.3889	102.3	5.677	18.01	.4121	.8809
9.38	.3605	.6705	.5377	9.207	2221	394.8	2.382722	100.529	6.113	.3889	102.5	5.677	18.05	.4131	.8791
9.39	.3580	.6771	.5366	9.208	2210	395.8	2.382859	100.559	6.104	.3888	102.7	5.678	18.09	.4141	.8773
9.40	.3555	.6838	.5355	9.208	2199	400.8	2.382995	100.590	6.107	.3888	102.9	5.679	18.12	.4151	.8754
9.41	.3530	.6904	.5344	9.209	2188	402.8	2.383130	100.620	6.100	.3888	103.1	5.679	18.16	.4161	.8736
9.42	.3505	.6971	.5333	9.209	2177	404.8	2.383265	100.651	6.094	.3888	103.4	5.680	18.20	.4171	.8718
9.43	.3481	.7038	.5322	9.210	2167	406.8	2.383400	100.681	6.087	.3888	103.6	5.681	18.23	.4181	.8699
9.44	.3456	.7105	.5311	9.210	2156	408.8	2.383534	100.711	6.081	.3887	103.8	5.681	18.27	.4192	.8681
9.45	.3432	.7173	.5300	9.209	2146	410.9	2.383668	100.742	6.074	.3887	104.0	5.682	18.31	.4202	.8662
9.46	.3408	.7240	.5289	9.209	2135	412.9	2.383802	100.772	6.068	.3887	104.2	5.683	18.34	.4212	.8644
9.47	.3384	.7307	.5278	9.210	2125	414.9	2.383935	100.802	6.062	.3887	104.5	5.683	18.38	.4222	.8626
9.48	.3361	.7374	.5267	9.210	2114	417.0	2.384068	100.832	6.055	.3886	104.7	5.684	18.42	.4232	.8607
9.49	.3337	.7441	.5256	9.210	2104	419.1	2.384200	100.862	6.049	.3886	104.9	5.684	18.45	.4242	.8589
9.50	.3314	.7508	.5245	9.209	2094	421.1	2.384332	100.892	6.042	.3886	105.1	5.685	18.49	.4252	.8572
9.51	.3291	.7575	.5234	9.209	2084	423.2	2.384464	100.922	6.036	.3886	105.3	5.686	18.53	.4262	.8554
9.52	.3268	.7642	.5223	9.209	2073	425.3	2.384595	100.952	6.030	.3885	105.6	5.686	18.57	.4272	.8536
9.53	.3245	.7709	.5212	9.209	2063	427.4	2.384726	100.982	6.023	.3885	105.8	5.687	18.60	.4282	.8518
9.54	.3223	.7776	.5201	9.208	2053	429.5	2.384856	101.011	6.017	.3885	106.0	5.688	18.64	.4292	.8500
9.55	.3201	.7843	.5190	9.208	2043	431.6	2.384986	101.041	6.011	.3885	106.2	5.688	18.68	.4302	.8483
9.56	.3179	.7910	.5179	9.208	2033	433.7	2.385116	101.071	6.004	.3885	106.5	5.689	18.71	.4312	.8465
9.57	.3157	.7977	.5168	9.208	2023	435.8	2.385245	101.100	5.998	.3884	106.7	5.689	18.75	.4322	.8447
9.58	.3135	.8044	.5157	9.208	2013	437.9	2.385374	101.129	5.992	.3884	106.9	5.690	18.79	.4332	.8430
9.59	.3113	.8111	.5146	9.208	2003	440.0	2.385502	101.159	5.985	.3884	107.1	5.691	18.83	.4342	.8412
9.60	.3092	.8178	.5135	9.207	1993	442.1	2.385630	101.188	5.979	.3884	107.4	5.691	18.86	.4352	.8394
9.61	.3070	.8245	.5124	9.207	1983	444.2	2.385758	101.217	5.973	.3884	107.6	5.692	18.90	.4362	.8376
9.62	.3049	.8312	.5113	9.207	1973	446.3	2.385886	101.247	5.967	.3883	107.8	5.692	18.94	.4372	.8358
9.63	.3028	.8379	.5102	9.207	1963	448.4	2.386012	101.276	5.960	.3883	108.0	5.693	18.98	.4382	.8340
9.64	.3007	.8446	.5091	9.207	1953	450.5	2.386139	101.305	5.954	.3883	108.3	5.694	19.01	.4392	.8322
9.65	.2986	.8513	.5080	9.206	1943	452.6	2.386265	101.334	5.948	.3883	108.5	5.694	19.05	.4402	.8304
9.66	.2965	.8580	.5069	9.206	1933	454.7	2.386391	101.363	5.942	.3883	108.7	5.695	19.09	.4412	.8286
9.67	.2944	.8647	.5058	9.206	1923	456.8	2.386516	101.392	5.936	.3882	108.9	5.695	19.13	.4422	.8268
9.68	.2923	.8714	.5047	9.206	1913	458.9	2.386641	101.421	5.930	.3882	109.2	5.696	19.16	.4432	.8250
9.69	.2902	.8781	.5036	9.205	1903	461.0	2.386766	101.450	5.923	.3882	109.4	5.697	19.20	.4442	.8232
9.70	.2881	.8848	.5025	9.205	1893	463.1	2.386890	101.479	5.917	.3882	109.6	5.697	19.24	.4452	.8214
9.71	.2860	.8915	.5014	9.205	1883	465.2	2.387014	101.507	5.911	.3882	109.8	5.698	19.28	.4462	.8196
9.72	.2840	.8982	.5003	9.205	1873	467.3	2.387138	101.536	5.905	.3881	110.1	5.698	19.31	.4472	.8178
9.73	.2820	.9049	.4992	9.205	1863	469.4	2.387261	101.564	5.899	.3881	110.3	5.699	19.35	.4482	.8160
9.74	.2800	.9116	.4981	9.205	1853	471.5	2.387384	101.593	5.893	.3881	110.5	5.700	19.39	.4492	.8142
9.75	.2780	.9183	.4970	9.204	1843	473.6	2.387507	101.621	5.887	.3881	110.7	5.700	19.43	.4502	.8124
9.76	.2760	.9250	.4959	9.204	1833	475.7	2.387629	101.650	5.881	.3880	111.0	5.701	19.47	.4512	.8106
9.77	.2740	.9317	.4948	9.204	1823	477.8	2.387751	101.678	5.875	.3880	111.2	5.701	19.50	.4522	.8088
9.78	.2720	.9384	.4937	9.204	1813	479.9	2.387872	101.707	5.869	.3880	111.4	5.702	19.54	.4532	.8070
9.79	.2700	.9451	.4926	9.204	1803	482.0	2.387993	101.735	5.863	.3880	111.7	5.703	19.58	.4542	.8052
9.80	.2680	.9518	.4915	9.203	1793	484.1	2.388114	101.763	5.857	.3880	111.9	5.703	19.62	.4552	.8034
9.81	.2660	.9585	.4904	9.203	1783	486.2	2.388234	101.791	5.851	.3879	112.1	5.704	19.66	.4562	.8016
9.82	.2640	.9652	.4893	9.203	1773	488.3	2.388354	101.820	5.845	.3879	112.3	5.704	19.69	.4572	.8000
9.83	.2620	.9719	.4882	9.203	1763	490.4	2.388474	101.848	5.839	.3879	112.6	5.705	19.73	.4582	.7982
9.84	.2600	.9786	.4871	9.203	1753	492.5	2.388593	101.876	5.833	.3879	112.8	5.705	19.77	.4592	.7964
9.85	.2580	.9853	.4860	9.202	1743	494.6	2.388712	101.904	5.827	.3879	113.0	5.706	19.81	.4602	.7946
9.86	.2560	.9920	.4849	9.202	1733	496.7	2.388831	101.932	5.821	.3878	113.3	5.707	19.85	.4612	.7928
9.87	.2540	.9987	.4838	9.202	1723	500.8	2.388950	101.960	5.815	.3878	113.5	5.707	19.89	.4622	.7910
9.88	.2520	.1000	.4827	9.202	1713	502.9	2.389069	101.987	5.809	.3878	113.7	5.708	19.93	.4632	.7892
9.89	.2500	.1000	.4816	9.202	1703	505.0	2.389188	102.015	5.803	.3878	113.9	5.708	19.97	.4642	.7874
9.90	.2480	.1000	.4805	9.201	1693	507.1	2.389307	102.043	5.797	.3878	114.2	5.709	20.00	.4652	.7856
9.91	.2460	.1000	.4794	9.201	1683	509.2	2.389426	102.070	5.792	.3877	114.4	5.709	20.04	.4662	.7838
9.92	.2440	.1000	.4783	9.201	1673	511.3	2.389545	102.098	5.786	.3877	114.6	5.710	20.08	.4672	.7820
9.93	.2420	.1000	.4772	9.201	1663	513.4	2.389664	102.126	5.780	.3877	114.9	5.711	20.12	.4682	.7802
9.94	.2400	.1000	.4761	9.201	1653	515.5	2.389783	102.153	5.774	.3877	115.1	5.711	20.15	.4692	.7784
9.95	.2380	.1000	.4750	9.200	1643	517.6	2.389902	102.180	5.768	.3877	115.3	5.712	20.19	.4702	.7766
9.96	.2360	.1000	.4739	9.200	1633	519.7	2.389999	102.208	5.762	.3877	115.6	5.712	20.23	.4712	.7748
9.97	.2340	.1000	.4728	9.200	1623	521.8	2.390114	102.235	5.756	.3876	115.8	5.713	20.27	.4722	.7730
9.98	.2320	.1000	.4717	9.200	1613	523.9	2.390229	102.262	5.750	.3876	116.0	5.713	20.31	.4732	.7712
9.99	.2300	.1000	.4706	9.200	1603	526.0	2.390343	102.290	5.744	.3876	116.3	5.714	20.35	.4742	.7694
10.00	.2280	.1000	.4695	9.200	1593	528.1	2.390457	102.317	5.738	.3876	116.5	5.714	20.39	.4752	.7676
10.02	.2255	.1000	.4684	9.200	1583	530.2	2.390604	102.344	5.732	.3875	116.8	5.715	20.43	.4762	.7658
10.04	.2230	.1000	.4673	9.200	1573	532.3	2.390750	102.371	5.726	.3875	117.0	5.715	20.47	.4772	.7640
10.06	.2205	.1000	.4662	9.200	1563	534.4	2.390896	102.398	5.720	.3875	117.3	5.716	20.51	.4782	.7622
10.08	.2180	.1000	.4651	9.200	1553	536.5	2.391042	102.425	5.714	.3875	117.5	5.716	20.55	.4792	.7604
10.10	.2155	.1000	.4640	9.200	1543	538.6	2.391188	102.452	5.708	.3874	117.8	5.717	20.59	.4802	.7586
10.12	.2130	.1000	.4629	9.200	1533	540.7	2.391334	102.479	5.702	.3874	118.0	5.717	20.63	.4812	.7568
10.14	.2105	.1000	.4618	9.200	1523	542.8	2.391479	102.506	5.696	.3874	118.3	5.718	20.67	.4822	.7550
10.16	.2080	.1000	.4607	9.200	1513	544.9	2.391625	102.533	5.690	.3874	11				

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{1}{1-\lambda}$	$\frac{V}{a_1}$	ν	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
10.50	.1701	.3921	.4338	10.45	.1313	.675.0	2.395766	103.61	5.465	.3867	128.5	5.740	22.38	.2422	.7022
10.52	.1679	.3885	.4323	10.47	.1301	.681.1	2.395964	103.66	5.455	.3867	129.0	5.741	22.46	.2400	.6996
10.54	.1655	.3850	.4307	10.49	.1289	.687.3	2.396160	103.71	5.444	.3866	129.4	5.742	22.54	.2379	.6968
10.56	.1637	.3815	.4291	10.51	.1278	.693.5	2.396355	103.76	5.434	.3866	129.9	5.743	22.63	.2358	.6942
10.58	.1616	.3780	.4276	10.53	.1267	.699.7	2.396550	103.81	5.424	.3866	130.4	5.744	22.71	.2337	.6917
10.60	.1596	.3747	.4260	10.55	.1255	.706.0	2.396743	103.86	5.413	.3865	130.9	5.744	22.79	.2317	.6891
10.62	.1576	.3713	.4245	10.57	.1244	.712.3	2.396935	103.90	5.403	.3865	131.4	5.745	22.87	.2296	.6866
10.64	.1556	.3680	.4230	10.59	.1233	.718.7	2.397126	103.96	5.393	.3865	131.9	5.746	22.96	.2276	.6839
10.66	.1537	.3647	.4215	10.61	.1223	.725.2	2.397316	104.01	5.383	.3864	132.4	5.747	23.04	.2256	.6814
10.68	.1518	.3614	.4200	10.63	.1212	.731.6	2.397505	104.05	5.373	.3864	132.9	5.748	23.12	.2236	.6789
10.70	.1499	.3582	.4185	10.65	.1201	.738.2	2.397693	104.10	5.363	.3864	133.4	5.749	23.21	.2216	.6763
10.72	.1480	.3550	.4170	10.67	.1191	.744.8	2.397880	104.14	5.353	.3863	133.9	5.750	23.29	.2197	.6737
10.74	.1462	.3518	.4155	10.69	.1180	.751.4	2.398066	104.19	5.343	.3863	134.4	5.751	23.37	.2178	.6712
10.76	.1444	.3487	.4140	10.71	.1170	.758.1	2.398251	104.24	5.333	.3863	134.9	5.752	23.46	.2159	.6688
10.78	.1426	.3456	.4125	10.73	.1160	.764.8	2.398435	104.29	5.323	.3862	135.4	5.753	23.54	.2140	.6663
10.80	.1408	.3426	.4111	10.75	.1150	.771.5	2.398618	104.33	5.313	.3862	135.9	5.753	23.62	.2121	.6638
10.82	.1391	.3395	.4096	10.77	.1140	.778.4	2.398801	104.38	5.303	.3862	136.4	5.754	23.71	.2103	.6614
10.84	.1374	.3365	.4081	10.79	.1130	.785.2	2.398982	104.43	5.293	.3862	136.9	5.755	23.79	.2085	.6589
10.86	.1357	.3336	.4067	10.81	.1120	.792.1	2.399162	104.48	5.283	.3861	137.4	5.756	23.88	.2067	.6565
10.88	.1340	.3306	.4053	10.83	.1110	.799.1	2.399341	104.52	5.274	.3861	137.9	5.757	23.96	.2048	.6542
10.90	.1324	.3277	.4038	10.85	.1101	.806.1	2.399519	104.57	5.264	.3861	138.5	5.758	24.05	.2031	.6518
10.92	.1307	.3249	.4024	10.87	.1091	.813.1	2.399697	104.61	5.254	.3860	139.0	5.759	24.13	.2013	.6494
10.94	.1291	.3220	.4010	10.89	.1082	.820.3	2.399873	104.66	5.245	.3860	139.5	5.759	24.21	.2006	.6469
10.96	.1276	.3192	.3996	10.91	.1073	.827.4	2.400049	104.71	5.235	.3860	140.0	5.760	24.30	.2007	.6447
10.98	.1260	.3165	.3982	10.93	.1064	.834.6	2.400223	104.75	5.225	.3860	140.5	5.761	24.39	.2002	.6424
11.00	.1245	.3137	.3968	10.95	.1054	.841.9	2.400397	104.80	5.216	.3859	141.0	5.762	24.47	.2005	.6400
11.02	.1230	.3109	.3954	10.97	.1045	.849.2	2.400570	104.85	5.206	.3859	141.5	5.763	24.56	.2007	.6376
11.04	.1215	.3083	.3941	11.00	.1036	.856.6	2.400741	104.89	5.197	.3859	142.0	5.764	24.64	.2012	.6354
11.06	.1200	.3056	.3927	11.02	.1028	.864.0	2.400912	104.93	5.188	.3858	142.5	5.764	24.73	.2016	.6330
11.08	.1186	.3030	.3913	11.04	.1019	.871.5	2.401082	104.98	5.178	.3858	143.1	5.765	24.81	.2020	.6308
11.10	.1171	.3003	.3900	11.06	.1010	.879.0	2.401252	105.02	5.169	.3858	143.6	5.766	24.90	.2024	.6286
11.12	.1157	.2978	.3886	11.08	.1002	.886.6	2.401420	105.06	5.159	.3858	144.1	5.767	24.99	.2029	.6263
11.14	.1143	.2952	.3873	11.10	.0993	.894.2	2.401587	105.11	5.150	.3857	144.6	5.768	25.08	.2033	.6241
11.16	.1130	.2927	.3860	11.12	.0984	.901.9	2.401754	105.16	5.141	.3857	145.1	5.768	25.16	.2038	.6218
11.18	.1116	.2902	.3846	11.14	.0975	.909.6	2.401919	105.20	5.132	.3857	145.7	5.769	25.25	.2042	.6197
11.20	.1103	.2877	.3833	11.16	.0968	.917.4	2.402084	105.24	5.123	.3856	146.2	5.770	25.33	.2047	.6174
11.22	.1090	.2852	.3820	11.18	.0960	.925.2	2.402248	105.28	5.113	.3856	146.7	5.771	25.42	.2051	.6152
11.24	.1077	.2828	.3807	11.20	.0952	.933.1	2.402412	105.33	5.104	.3856	147.2	5.772	25.51	.2056	.6131
11.26	.1064	.2804	.3794	11.22	.0944	.941.1	2.402574	105.37	5.095	.3856	147.8	5.772	25.60	.2060	.6109
11.28	.1051	.2780	.3781	11.24	.0936	.949.1	2.402735	105.42	5.086	.3855	148.3	5.773	25.69	.2065	.6087
11.30	.1039	.2756	.3768	11.26	.0928	.957.1	2.402896	105.46	5.077	.3855	148.8	5.774	25.77	.2070	.6066
11.32	.1026	.2733	.3755	11.28	.0920	.965.3	2.403056	105.50	5.068	.3855	149.3	5.775	25.86	.2075	.6044
11.34	.1014	.2710	.3743	11.30	.0913	.973.5	2.403215	105.55	5.059	.3855	149.9	5.775	25.95	.2080	.6023
11.36	.1002	.2687	.3730	11.32	.0905	.981.6	2.403373	105.59	5.050	.3854	150.4	5.776	26.04	.2085	.6002
11.38	.9905	.2664	.3717	11.34	.0897	.989.9	2.403531	105.63	5.041	.3854	150.9	5.777	26.12	.2090	.5981
11.40	.9788	.2642	.3705	11.36	.0890	.998.3	2.403687	105.67	5.032	.3854	151.5	5.778	26.21	.2095	.5959
11.42	.9673	.2620	.3692	11.38	.0883	.1007	2.403843	105.71	5.024	.3854	152.0	5.779	26.30	.2100	.5939
11.44	.9559	.2598	.3680	11.40	.0875	.1015	2.403998	105.75	5.015	.3853	152.5	5.779	26.39	.2105	.5918
11.46	.9447	.2576	.3668	11.42	.0868	.1024	2.404152	105.80	5.006	.3853	153.1	5.780	26.48	.2110	.5897
11.48	.9337	.2554	.3655	11.44	.0861	.1032	2.404306	105.84	4.997	.3853	153.6	5.781	26.57	.2115	.5877
11.50	.9228	.2533	.3643	11.46	.0854	.1041	2.404459	105.88	4.989	.3853	154.1	5.781	26.66	.2120	.5858
11.52	.9120	.2512	.3631	11.48	.0847	.1050	2.404610	105.92	4.980	.3852	154.7	5.782	26.75	.2125	.5836
11.54	.9014	.2491	.3619	11.50	.0840	.1058	2.404762	105.97	4.971	.3852	155.2	5.783	26.84	.2130	.5816
11.56	.8909	.2470	.3607	11.52	.0833	.1067	2.404912	106.01	4.963	.3852	155.7	5.784	26.93	.2135	.5797
11.58	.8806	.2450	.3595	11.54	.0826	.1076	2.405062	106.05	4.954	.3852	156.3	5.784	27.02	.2140	.5776
11.60	.8704	.2430	.3583	11.56	.0819	.1085	2.405211	106.09	4.945	.3851	156.8	5.785	27.11	.2145	.5757
11.62	.8604	.2409	.3571	11.58	.0812	.1094	2.405359	106.13	4.937	.3851	157.4	5.786	27.20	.2150	.5737
11.64	.8505	.2390	.3559	11.60	.0806	.1103	2.405506	106.17	4.928	.3851	157.9	5.787	27.29	.2155	.5717
11.66	.8406	.2370	.3547	11.62	.0800	.1112	2.405653	106.21	4.920	.3851	158.5	5.787	27.38	.2160	.5698
11.68	.8310	.2350	.3536	11.64	.0793	.1121	2.405799	106.25	4.912	.3850	159.0	5.788	27.47	.2165	.5678
11.70	.8215	.2331	.3524	11.66	.0787	.1130	2.405944	106.29	4.903	.3850	159.5	5.789	27.56	.2170	.5659
11.72	.8120	.2312	.3512	11.68	.0780	.1140	2.406089	106.33	4.895	.3850	160.1	5.789	27.65	.2175	.5639
11.74	.8027	.2293	.3501	11.70	.0774	.1149	2.406233	106.37	4.886	.3850	160.6	5.790	27.74	.2180	.5620
11.76	.7935	.2274	.3489	11.72	.0768	.1158	2.406376	106.41	4.878	.3849	161.2	5.791	27.84	.2185	.5601
11.78	.7845	.2256	.3478	11.74	.0762	.1168	2.406518	106.45	4.870	.3849	161.7	5.791	27.93	.2190	.5583
11.80	.7755	.2237	.3466	11.76	.0755	.1177	2.406660	106.49	4.861	.3849	162.3	5.792	28.02	.2195	.5564
11.82	.7667	.2219	.3455	11.78	.0749	.1187	2.406801	106.53	4.853	.3849	162.8	5.793	28.11	.2200	.5544
11.84	.7580	.2201	.3444	11.80	.0743	.1197	2.406942	106.57	4.845	.3848	163.4	5.793	28.20	.2205	.5526
11.86	.7494	.2183	.3433	11.82	.0737	.1206	2.407081	106.61	4.837	.3848	163.9	5.794	28.30	.2210	.5508
11.88	.7409	.2165	.3422	11.84	.0732	.1216	2.407220	106.65	4.829	.3848	164.5	5.795	28.39	.2215	.5489
11.90	.7325	.2148	.3410	11.86	.0726	.1226	2.407359	106.69	4.820	.3848	165.1	5.795	28.48	.2220	.5471
11.92	.7243	.2131	.3399	11.88	.0720	.1236	2.407496	106.73	4.812	.3848	165.6	5.796	28.57	.2225	.5453
11.94	.7161	.2113	.3388	11.90	.0714	.1246	2.407633	106.76	4.804	.3847	166.2	5.797	28.67	.2230	.5435
11.96	.7080	.2096	.3377	11.92	.0708	.1256	2.407770	106.81	4.796	.3847	166.7	5.797	28.76		

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A^*}$	$\frac{V}{a^*}$	ν	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
12.30	.5857	.1831	.3199	12.26	.6202	1437	2.409989	107.44	4.663	.3843	176.3	5.808	30.36	.1144	.5122
12.32	.5792	.1816	.3189	12.28	.6154	1448	2.410115	107.48	4.656	.3843	176.9	5.809	30.46	.1135	.5105
12.34	.5729	.1802	.3179	12.30	.6107	1460	2.410239	107.51	4.648	.3843	177.5	5.809	30.55	.1126	.5088
12.36	.5667	.1788	.3169	12.32	.6060	1471	2.410363	107.55	4.641	.3843	178.1	5.810	30.65	.1117	.5072
12.38	.5605	.1774	.3159	12.34	.6013	1482	2.410486	107.59	4.633	.3843	178.6	5.810	30.75	.1109	.5056
12.40	.5544	.1760	.3149	12.36	.5967	1494	2.410609	107.62	4.626	.3842	179.2	5.811	30.84	.1100	.5039
12.42	.5484	.1747	.3140	12.38	.5921	1506	2.410731	107.66	4.618	.3842	179.8	5.812	30.94	.1092	.5023
12.44	.5424	.1733	.3130	12.40	.5876	1517	2.410853	107.69	4.611	.3842	180.4	5.812	31.04	.1083	.5007
12.46	.5365	.1720	.3120	12.42	.5831	1529	2.410974	107.73	4.603	.3842	181.0	5.813	31.13	.1075	.4991
12.48	.5307	.1706	.3110	12.44	.5786	1541	2.411094	107.77	4.596	.3842	181.5	5.813	31.23	.1067	.4975
12.50	.5250	.1693	.3101	12.46	.5742	1553	2.411214	107.80	4.589	.3841	182.1	5.814	31.33	.1059	.4960
12.52	.5193	.1680	.3091	12.48	.5698	1565	2.411333	107.84	4.581	.3841	182.7	5.815	31.42	.1051	.4944
12.54	.5137	.1667	.3082	12.50	.5655	1577	2.411452	107.87	4.574	.3841	183.3	5.815	31.52	.1043	.4927
12.56	.5082	.1654	.3072	12.52	.5612	1589	2.411571	107.90	4.567	.3841	183.9	5.816	31.62	.1035	.4912
12.58	.5028	.1642	.3063	12.54	.5570	1601	2.411688	107.94	4.559	.3841	184.5	5.816	31.72	.1027	.4897
12.60	.4973	.1629	.3053	12.56	.5527	1614	2.411805	107.98	4.552	.3840	185.1	5.817	31.81	.1019	.4881
12.62	.4920	.1617	.3044	12.58	.5486	1626	2.411922	108.01	4.545	.3840	185.6	5.817	31.91	.1011	.4865
12.64	.4868	.1604	.3035	12.60	.5444	1639	2.412038	108.05	4.538	.3840	186.2	5.818	32.01	.1004	.4850
12.66	.4816	.1592	.3025	12.62	.5403	1651	2.412154	108.08	4.530	.3840	186.8	5.819	32.11	.9961	.4835
12.68	.4764	.1580	.3016	12.64	.5362	1664	2.412269	108.12	4.523	.3840	187.4	5.819	32.21	.9885	.4820
12.70	.4714	.1568	.3007	12.66	.5322	1676	2.412383	108.15	4.516	.3839	188.0	5.820	32.31	.9810	.4805
12.72	.4663	.1556	.2998	12.68	.5282	1689	2.412497	108.18	4.509	.3839	188.6	5.820	32.41	.9737	.4790
12.74	.4614	.1544	.2989	12.70	.5242	1702	2.412611	108.22	4.502	.3839	189.2	5.821	32.50	.9664	.4775
12.76	.4565	.1532	.2979	12.72	.5203	1715	2.412723	108.25	4.495	.3839	189.8	5.821	32.60	.9591	.4760
12.78	.4517	.1521	.2970	12.74	.5164	1728	2.412836	108.29	4.488	.3839	190.4	5.822	32.70	.9520	.4745
12.80	.4469	.1509	.2961	12.76	.5126	1741	2.412948	108.32	4.481	.3839	191.0	5.822	32.80	.9448	.4730
12.82	.4422	.1498	.2952	12.78	.5087	1754	2.413059	108.35	4.474	.3838	191.6	5.823	32.90	.9378	.4715
12.84	.4376	.1487	.2944	12.80	.5050	1767	2.413170	108.39	4.467	.3838	192.2	5.823	33.00	.9308	.4701
12.86	.4329	.1475	.2935	12.82	.5012	1781	2.413280	108.42	4.460	.3838	192.8	5.824	33.10	.9239	.4686
12.88	.4284	.1464	.2926	12.84	.4975	1794	2.413390	108.45	4.453	.3838	193.4	5.825	33.20	.9170	.4672
12.90	.4239	.1453	.2917	12.86	.4938	1807	2.413500	108.49	4.446	.3838	194.0	5.825	33.30	.9102	.4657
12.92	.4195	.1442	.2908	12.88	.4901	1821	2.413609	108.52	4.439	.3837	194.6	5.826	33.40	.9035	.4643
12.94	.4151	.1432	.2900	12.90	.4865	1835	2.413717	108.55	4.432	.3837	195.2	5.826	33.50	.8968	.4629
12.96	.4107	.1421	.2891	12.92	.4829	1848	2.413825	108.59	4.425	.3837	195.8	5.827	33.60	.8902	.4614
12.98	.4065	.1410	.2882	12.94	.4794	1862	2.413932	108.62	4.419	.3837	196.4	5.827	33.70	.8836	.4600
13.00	.4023	.1400	.2874	12.96	.4759	1876	2.414039	108.65	4.412	.3837	197.0	5.828	33.81	.8771	.4586
13.02	.3981	.1389	.2865	12.98	.4723	1890	2.414146	108.69	4.405	.3837	197.6	5.828	33.91	.8706	.4572
13.04	.3939	.1379	.2857	13.00	.4689	1904	2.414252	108.72	4.398	.3836	198.2	5.829	34.01	.8642	.4559
13.06	.3898	.1369	.2848	13.02	.4655	1918	2.414357	108.75	4.391	.3836	198.8	5.829	34.11	.8580	.4544
13.08	.3858	.1359	.2840	13.04	.4620	1933	2.414462	108.78	4.385	.3836	199.4	5.830	34.21	.8517	.4530
13.10	.3818	.1349	.2831	13.06	.4586	1947	2.414567	108.82	4.378	.3836	200.1	5.830	34.31	.8453	.4517
13.12	.3779	.1339	.2823	13.08	.4553	1961	2.414671	108.85	4.371	.3836	200.7	5.831	34.42	.8392	.4503
13.14	.3740	.1329	.2814	13.10	.4520	1976	2.414775	108.88	4.365	.3836	201.3	5.831	34.52	.8331	.4489
13.16	.3701	.1319	.2806	13.12	.4487	1990	2.414878	108.91	4.358	.3835	201.9	5.832	34.62	.8271	.4475
13.18	.3663	.1309	.2798	13.14	.4454	2005	2.414981	108.94	4.351	.3835	202.5	5.832	34.72	.8210	.4462
13.20	.3626	.1300	.2790	13.16	.4422	2020	2.415083	108.97	4.345	.3835	203.1	5.833	34.82	.8151	.4448
13.22	.3589	.1290	.2781	13.18	.4390	2034	2.415185	109.01	4.338	.3835	203.7	5.833	34.93	.8091	.4435
13.24	.3552	.1281	.2773	13.20	.4358	2049	2.415286	109.04	4.332	.3835	204.4	5.834	35.03	.8032	.4422
13.26	.3516	.1271	.2765	13.22	.4327	2064	2.415387	109.07	4.325	.3835	205.0	5.834	35.13	.7974	.4409
13.28	.3480	.1262	.2757	13.24	.4296	2079	2.415488	109.10	4.319	.3834	205.6	5.835	35.24	.7918	.4395
13.30	.3444	.1253	.2749	13.26	.4264	2095	2.415588	109.13	4.312	.3834	206.2	5.835	35.34	.7860	.4382
13.32	.3409	.1244	.2741	13.28	.4234	2110	2.415687	109.16	4.306	.3834	206.8	5.836	35.44	.7802	.4369
13.34	.3374	.1235	.2733	13.30	.4203	2125	2.415788	109.20	4.299	.3834	207.5	5.836	35.55	.7747	.4356
13.36	.3340	.1226	.2725	13.32	.4173	2141	2.415885	109.23	4.293	.3834	208.1	5.837	35.65	.7691	.4342
13.38	.3306	.1217	.2717	13.34	.4143	2156	2.415983	109.26	4.286	.3834	208.7	5.837	35.76	.7636	.4330
13.40	.3273	.1208	.2709	13.36	.4113	2172	2.416081	109.29	4.280	.3833	209.3	5.838	35.86	.7582	.4316
13.42	.3240	.1199	.2701	13.38	.4084	2188	2.416179	109.32	4.273	.3833	210.0	5.838	35.96	.7527	.4304
13.44	.3207	.1191	.2694	13.40	.4055	2204	2.416276	109.35	4.267	.3833	210.6	5.838	36.07	.7474	.4291
13.46	.3175	.1182	.2686	13.42	.4026	2219	2.416373	109.38	4.261	.3833	211.2	5.839	36.17	.7420	.4278
13.48	.3143	.1174	.2678	13.44	.4000	2236	2.416469	109.41	4.254	.3833	211.8	5.839	36.28	.7367	.4265
13.50	.3111	.1165	.2670	13.46	.3969	2252	2.416565	109.44	4.248	.3833	212.5	5.840	36.38	.7315	.4253
13.52	.3080	.1157	.2663	13.48	.3941	2268	2.416660	109.47	4.242	.3832	213.1	5.840	36.49	.7263	.4241
13.54	.3049	.1149	.2655	13.50	.3913	2284	2.416754	109.51	4.235	.3832	213.7	5.841	36.59	.7212	.4228
13.56	.3019	.1140	.2647	13.52	.3885	2300	2.416849	109.54	4.229	.3832	214.4	5.841	36.70	.7161	.4216
13.58	.2988	.1132	.2640	13.54	.3858	2317	2.416944	109.57	4.223	.3832	215.0	5.842	36.80	.7109	.4204
13.60	.2958	.1124	.2632	13.56	.3830	2334	2.417037	109.59	4.217	.3832	215.6	5.842	36.91	.7059	.4191
13.62	.2929	.1116	.2625	13.58	.3803	2350	2.417131	109.62	4.211	.3832	216.3	5.843	37.02	.7009	.4179
13.64	.2900	.1108	.2617	13.60	.3777	2367	2.417224	109.65	4.204	.3832	216.9	5.843	37.12	.6960	.4166
13.66	.2871	.1100	.2610	13.62	.3750	2384	2.417317	109.69	4.198	.3831	217.5	5.843	37.23	.6911	.4155
13.68	.2842	.1092	.2602	13.64	.3724	2401	2.417409	109.72	4.192	.3831	218.2	5.844	37.33	.6862	.4142
13.70	.2814	.1085	.2595	13.66	.3697	2418	2.417500	109.75	4.186	.3831	218.8	5.844	37.44	.6814	.4130
13.72	.2787	.1077	.2588	13.68	.3672	2435	2.417592	109.77	4.180	.3831	219.4	5.845	37.55	.6767	.4118
13.74	.2759	.1069	.2580	13.70	.3646	2452	2.417683	109.81	4.174	.3831	220.1	5.845	37.65	.6719	.4106
13.76	.2732	.1062	.2573	13.72	.3620	2470	2.417773	109.84	4.168	.3831	220.7	5.846	37.76	.6672	.4094
13.78	.2705	.1													

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TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A_1}$	V a_1	ν	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t1}}$
14.10	.2313	.9427	.2453	14.06	.3219	.2780	2.4192569	110.32	4.067	.3828	.231.8	5.853	39.60	.5931	.3900
14.12	.2290	.9362	.2447	14.06	.3197	.2799	2.4193409	110.35	4.061	.3828	.232.4	5.853	39.71	.5890	.3889
14.14	.2268	.9297	.2440	14.10	.3175	.2815	2.4194246	110.38	4.055	.3828	.233.1	5.854	39.82	.5849	.3878
14.16	.2246	.9232	.2433	14.13	.3153	.2835	2.4195079	110.41	4.050	.3828	.233.8	5.854	39.93	.5810	.3867
14.18	.2225	.9170	.2426	14.15	.3132	.2857	2.4195909	110.44	4.044	.3828	.234.4	5.854	40.04	.5770	.3856
14.20	.2204	.9108	.2420	14.17	.3111	.2877	2.4196735	110.46	4.038	.3828	.235.1	5.855	40.15	.5732	.3845
14.22	.2183	.9045	.2413	14.19	.3089	.2897	2.4197558	110.49	4.033	.3827	.235.7	5.855	40.26	.5693	.3834
14.24	.2162	.8983	.2406	14.21	.3068	.2916	2.4198378	110.52	4.027	.3827	.236.4	5.856	40.37	.5654	.3824
14.26	.2141	.8922	.2400	14.23	.3048	.2936	2.4199194	110.54	4.021	.3827	.237.1	5.856	40.48	.5616	.3813
14.28	.2121	.8861	.2393	14.25	.3027	.2956	2.4200007	110.57	4.016	.3827	.237.7	5.856	40.60	.5578	.3802
14.30	.2100	.8800	.2387	14.27	.3006	.2977	2.4200816	110.60	4.010	.3827	.238.4	5.857	40.71	.5540	.3791
14.32	.2080	.8740	.2380	14.29	.2986	.2997	2.4201622	110.63	4.004	.3827	.239.1	5.857	40.82	.5503	.3780
14.34	.2061	.8682	.2374	14.31	.2967	.3017	2.4202425	110.65	3.999	.3827	.239.7	5.858	40.93	.5466	.3771
14.36	.2041	.8623	.2367	14.33	.2946	.3038	2.4203225	110.68	3.993	.3827	.240.4	5.858	41.04	.5429	.3760
14.38	.2022	.8565	.2361	14.35	.2927	.3058	2.4204021	110.71	3.988	.3826	.241.1	5.858	41.15	.5393	.3750
14.40	.2003	.8506	.2355	14.37	.2907	.3079	2.4204815	110.74	3.982	.3826	.241.8	5.859	41.26	.5357	.3739
14.42	.1984	.8449	.2348	14.39	.2888	.3100	2.4205610	110.76	3.977	.3826	.242.4	5.859	41.38	.5321	.3729
14.44	.1965	.8392	.2342	14.41	.2869	.3121	2.4206391	110.79	3.971	.3826	.243.1	5.860	41.49	.5285	.3719
14.46	.1947	.8335	.2335	14.43	.2849	.3142	2.4207175	110.81	3.966	.3826	.243.8	5.860	41.60	.5250	.3708
14.48	.1929	.8280	.2329	14.45	.2830	.3163	2.4207955	110.84	3.960	.3826	.244.5	5.860	41.71	.5215	.3698
14.50	.1910	.8224	.2323	14.47	.2812	.3184	2.4208732	110.87	3.955	.3826	.245.1	5.861	41.83	.5180	.3688
14.52	.1892	.8168	.2317	14.49	.2793	.3206	2.4209505	110.90	3.949	.3825	.245.8	5.861	41.94	.5146	.3677
14.54	.1875	.8114	.2310	14.51	.2774	.3227	2.4210277	110.92	3.944	.3825	.246.5	5.861	42.05	.5111	.3668
14.56	.1857	.8059	.2304	14.53	.2756	.3249	2.4211045	110.95	3.938	.3825	.247.2	5.862	42.17	.5078	.3657
14.58	.1840	.8005	.2298	14.55	.2737	.3271	2.4211810	110.97	3.933	.3825	.247.8	5.862	42.28	.5044	.3647
14.60	.1823	.7952	.2292	14.57	.2720	.3292	2.4212572	111.00	3.927	.3825	.248.5	5.863	42.39	.5011	.3638
14.62	.1806	.7899	.2286	14.59	.2702	.3314	2.4213330	111.03	3.922	.3825	.249.2	5.863	42.51	.4978	.3628
14.64	.1789	.7847	.2280	14.61	.2684	.3336	2.4214086	111.05	3.917	.3825	.249.9	5.863	42.62	.4945	.3618
14.66	.1772	.7794	.2274	14.63	.2666	.3359	2.4214839	111.08	3.911	.3825	.250.6	5.864	42.73	.4912	.3608
14.68	.1756	.7743	.2268	14.65	.2649	.3381	2.4215588	111.10	3.906	.3825	.251.3	5.864	42.85	.4880	.3598
14.70	.1739	.7691	.2262	14.67	.2631	.3404	2.4216335	111.13	3.901	.3824	.251.9	5.864	42.96	.4847	.3588
14.72	.1723	.7640	.2256	14.69	.2614	.3426	2.4217078	111.16	3.895	.3824	.252.6	5.865	43.08	.4816	.3578
14.74	.1707	.7590	.2250	14.71	.2597	.3449	2.4217819	111.18	3.890	.3824	.253.3	5.865	43.19	.4784	.3569
14.76	.1692	.7540	.2244	14.73	.2580	.3472	2.4218557	111.21	3.885	.3824	.254.0	5.865	43.31	.4753	.3559
14.78	.1676	.7490	.2238	14.75	.2563	.3494	2.4219292	111.23	3.880	.3824	.254.7	5.866	43.42	.4722	.3550
14.80	.1660	.7440	.2232	14.77	.2546	.3518	2.4220023	111.26	3.874	.3824	.255.4	5.866	43.54	.4691	.3540
14.82	.1645	.7392	.2226	14.79	.2530	.3541	2.4220752	111.28	3.869	.3824	.256.1	5.866	43.65	.4660	.3531
14.84	.1630	.7343	.2220	14.81	.2513	.3564	2.4221479	111.31	3.864	.3824	.256.8	5.867	43.77	.4630	.3521
14.86	.1615	.7295	.2214	14.83	.2497	.3588	2.4222202	111.34	3.859	.3823	.257.5	5.867	43.88	.4600	.3512
14.88	.1600	.7247	.2208	14.85	.2480	.3611	2.4222922	111.36	3.853	.3823	.258.2	5.868	44.00	.4570	.3502
14.90	.1586	.7199	.2203	14.87	.2464	.3635	2.4223640	111.38	3.848	.3823	.258.9	5.868	44.11	.4540	.3493
14.92	.1571	.7153	.2197	14.89	.2449	.3659	2.4224355	111.41	3.843	.3823	.259.5	5.868	44.23	.4511	.3483
14.94	.1557	.7106	.2191	14.91	.2433	.3683	2.4225066	111.43	3.838	.3823	.260.2	5.869	44.35	.4481	.3474
14.96	.1543	.7059	.2185	14.93	.2417	.3707	2.4225776	111.46	3.833	.3823	.260.9	5.869	44.46	.4452	.3465
14.98	.1529	.7014	.2180	14.95	.2401	.3731	2.4226482	111.48	3.828	.3823	.261.6	5.869	44.58	.4424	.3456
15.00	.1515	.6968	.2174	14.97	.2386	.3755	2.4227186	111.51	3.823	.3823	.262.3	5.870	44.69	.4395	.3446
15.02	.1501	.6923	.2168	14.99	.2371	.3779	2.4227886	111.53	3.817	.3823	.263.0	5.870	44.81	.4367	.3437
15.04	.1487	.6878	.2163	15.01	.2355	.3804	2.4228585	111.56	3.812	.3822	.263.7	5.870	44.93	.4339	.3428
15.06	.1474	.6833	.2157	15.03	.2340	.3829	2.4229280	111.59	3.807	.3822	.264.4	5.871	45.05	.4311	.3419
15.08	.1461	.6789	.2151	15.05	.2325	.3854	2.4229973	111.61	3.802	.3822	.265.1	5.871	45.16	.4283	.3410
15.10	.1447	.6745	.2146	15.07	.2310	.3879	2.4230663	111.63	3.797	.3822	.265.9	5.871	45.28	.4256	.3401
15.12	.1434	.6702	.2140	15.09	.2296	.3904	2.4231350	111.66	3.792	.3822	.266.6	5.872	45.40	.4229	.3392
15.14	.1421	.6658	.2135	15.11	.2281	.3929	2.4232035	111.68	3.787	.3822	.267.3	5.872	45.52	.4201	.3383
15.16	.1409	.6615	.2129	15.13	.2266	.3955	2.4232717	111.71	3.782	.3822	.268.0	5.872	45.63	.4175	.3374
15.18	.1396	.6573	.2124	15.15	.2252	.3980	2.4233396	111.73	3.777	.3822	.268.7	5.873	45.75	.4148	.3365
15.20	.1383	.6531	.2118	15.17	.2237	.4005	2.4234073	111.76	3.772	.3822	.269.4	5.873	45.87	.4122	.3357
15.22	.1371	.6489	.2113	15.19	.2223	.4032	2.4234747	111.78	3.767	.3821	.270.1	5.873	45.99	.4096	.3347
15.24	.1359	.6447	.2107	15.21	.2209	.4057	2.4235419	111.80	3.762	.3821	.270.8	5.874	46.11	.4070	.3339
15.26	.1347	.6406	.2102	15.23	.2195	.4083	2.4236088	111.83	3.757	.3821	.271.5	5.874	46.22	.4044	.3330
15.28	.1335	.6365	.2097	15.25	.2181	.4110	2.4236754	111.85	3.752	.3821	.272.2	5.874	46.34	.4018	.3321
15.30	.1323	.6325	.2091	15.27	.2167	.4135	2.4237418	111.88	3.748	.3821	.272.9	5.875	46.46	.3992	.3313
15.32	.1311	.6284	.2086	15.29	.2154	.4162	2.4238079	111.90	3.743	.3821	.273.7	5.875	46.58	.3967	.3304
15.34	.1299	.6244	.2081	15.31	.2140	.4189	2.4238735	111.92	3.738	.3821	.274.4	5.875	46.70	.3942	.3295
15.36	.1288	.6204	.2075	15.33	.2127	.4215	2.4239394	111.95	3.733	.3821	.275.1	5.876	46.82	.3917	.3287
15.38	.1276	.6165	.2070	15.35	.2113	.4242	2.4240048	111.97	3.728	.3821	.275.8	5.876	46.94	.3893	.3278
15.40	.1265	.6126	.2065	15.37	.2100	.4269	2.4240699	112.00	3.723	.3820	.276.5	5.876	47.06	.3868	.3270
15.42	.1254	.6087	.2060	15.39	.2087	.4296	2.4241348	112.02	3.718	.3820	.277.2	5.876	47.18	.3844	.3262
15.44	.1243	.6049	.2054	15.41	.2074	.4323	2.4241994	112.04	3.714	.3820	.278.0	5.877	47.30	.3820	.3253
15.46	.1232	.6010	.2049	15.43	.2061	.4351	2.4242636	112.06	3.709	.3820	.278.7	5.877	47.42	.3796	.3245
15.48	.1221	.5972	.2044	15.45	.2048	.4378	2.4243280	112.09	3.704	.3820	.279.4	5.877	47.54	.3772	.3236
15.50	.1210	.5935	.2039	15.47	.2035	.4406	2.4243916	112.11	3.699	.3820	.280.1	5.878	47.66	.3748	.3228
15.52	.1199	.5897	.2034	15.49	.2022	.4434	2.4244555	112.14	3.694	.3820	.280.9	5.878	47.78	.3725	.3220
15.54	.1189	.5861	.2029	15.51	.2010	.4462	2.4245189	112.16	3.690	.3820	.281.6	5.878	47.90	.3702	.3211
15.56	.1178	.5824	.2023	15.53	.1997	.4490	2.4245821	112.18	3.685	.3820</					

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A^*}$	$\frac{V}{u^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
15.90	.1016	.5238	.1939	15.87	.1798	4990	2.4256206	112.57	3.606	.3818	294.8	5.884	50.10	.3311
15.92	.1007	.5206	.1935	15.89	.1787	5020	2.4256797	112.59	3.601	.3818	295.5	5.884	50.23	.3291
15.94	.9986	.5174	.1930	15.91	.1776	5051	2.4257385	112.61	3.597	.3818	296.3	5.884	50.35	.3271
15.96	.9899	.5142	.1925	15.93	.1765	5082	2.4257971	112.63	3.592	.3818	297.0	5.885	50.47	.3251
15.98	.9815	.5111	.1920	15.95	.1754	5113	2.4258555	112.66	3.588	.3818	297.8	5.885	50.60	.3232
16.00	.9731	.5079	.1916	15.97	.1744	5145	2.4259137	112.68	3.583	.3817	298.5	5.885	50.72	.3212
16.02	.9647	.5048	.1911	15.99	.1733	5176	2.4259717	112.70	3.579	.3817	299.3	5.885	50.85	.3192
16.04	.9565	.5017	.1906	16.01	.1723	5208	2.4260295	112.72	3.574	.3817	300.0	5.886	50.97	.3173
16.06	.9484	.4987	.1902	16.03	.1712	5239	2.4260871	112.74	3.570	.3817	300.7	5.886	51.10	.3154
16.08	.9404	.4957	.1897	16.05	.1702	5271	2.4261444	112.76	3.566	.3817	301.5	5.886	51.22	.3135
16.10	.9323	.4926	.1892	16.07	.1692	5304	2.4262015	112.79	3.561	.3817	302.3	5.887	51.35	.3116
16.12	.9244	.4895	.1888	16.09	.1681	5336	2.4262585	112.81	3.557	.3817	303.0	5.887	51.47	.3097
16.14	.9165	.4867	.1883	16.11	.1671	5369	2.4263152	112.83	3.552	.3817	303.8	5.887	51.60	.3079
16.16	.9089	.4838	.1879	16.13	.1661	5401	2.4263717	112.85	3.548	.3817	304.5	5.887	51.72	.3060
16.18	.9011	.4808	.1874	16.15	.1651	5434	2.4264280	112.87	3.543	.3817	305.3	5.888	51.85	.3042
16.20	.8936	.4779	.1870	16.17	.1642	5466	2.4264841	112.89	3.539	.3817	306.0	5.888	51.97	.3024
16.22	.8860	.4751	.1865	16.19	.1632	5499	2.4265400	112.91	3.535	.3816	306.8	5.888	52.10	.3005
16.24	.8784	.4721	.1861	16.21	.1622	5533	2.4265958	112.94	3.530	.3816	307.5	5.888	52.23	.2987
16.26	.8712	.4694	.1856	16.23	.1612	5566	2.4266513	112.96	3.526	.3816	308.3	5.889	52.35	.2969
16.28	.8638	.4665	.1852	16.25	.1603	5600	2.4267066	112.98	3.522	.3816	309.0	5.889	52.48	.2952
16.30	.8565	.4637	.1847	16.27	.1593	5634	2.4267617	113.00	3.517	.3816	309.8	5.889	52.61	.2934
16.32	.8491	.4609	.1843	16.29	.1584	5667	2.4268166	113.02	3.513	.3816	310.6	5.889	52.73	.2916
16.34	.8423	.4582	.1838	16.31	.1574	5701	2.4268713	113.04	3.509	.3816	311.3	5.890	52.86	.2899
16.36	.8352	.4554	.1834	16.33	.1565	5735	2.4269258	113.06	3.504	.3816	312.1	5.890	52.99	.2882
16.38	.8283	.4527	.1830	16.35	.1556	5770	2.4269801	113.08	3.500	.3816	312.9	5.890	53.12	.2865
16.40	.8213	.4500	.1825	16.37	.1546	5804	2.4270342	113.11	3.496	.3816	313.6	5.891	53.24	.2848
16.42	.8144	.4473	.1821	16.39	.1537	5839	2.4270881	113.13	3.492	.3816	314.4	5.891	53.37	.2831
16.44	.8077	.4447	.1816	16.41	.1528	5874	2.4271418	113.15	3.487	.3815	315.2	5.891	53.50	.2814
16.46	.8009	.4420	.1812	16.43	.1519	5910	2.4271954	113.17	3.483	.3815	315.9	5.891	53.63	.2798
16.48	.7942	.4394	.1808	16.45	.1510	5945	2.4272487	113.19	3.479	.3815	316.7	5.892	53.75	.2781
16.50	.7876	.4367	.1803	16.47	.1501	5980	2.4273019	113.21	3.475	.3815	317.5	5.892	53.88	.2765
16.52	.7811	.4341	.1799	16.49	.1492	6016	2.4273548	113.23	3.470	.3815	318.2	5.892	54.01	.2749
16.54	.7747	.4316	.1795	16.51	.1484	6051	2.4274077	113.25	3.466	.3815	319.0	5.892	54.14	.2732
16.56	.7682	.4290	.1791	16.53	.1475	6087	2.4274602	113.27	3.462	.3815	319.8	5.893	54.27	.2716
16.58	.7620	.4265	.1786	16.55	.1466	6123	2.4275126	113.29	3.458	.3815	320.6	5.893	54.40	.2700
16.60	.7556	.4240	.1782	16.57	.1457	6160	2.4275648	113.31	3.454	.3815	321.3	5.893	54.53	.2685
16.62	.7493	.4215	.1778	16.59	.1449	6196	2.4276169	113.33	3.449	.3815	322.1	5.893	54.66	.2669
16.64	.7432	.4190	.1774	16.61	.1440	6233	2.4276687	113.35	3.445	.3815	322.9	5.894	54.78	.2653
16.66	.7372	.4166	.1770	16.63	.1432	6268	2.4277204	113.37	3.441	.3815	323.7	5.894	54.91	.2638
16.68	.7311	.4141	.1765	16.65	.1424	6306	2.4277719	113.39	3.437	.3814	324.4	5.894	55.04	.2622
16.70	.7250	.4117	.1761	16.67	.1415	6343	2.4278232	113.41	3.433	.3814	325.2	5.894	55.17	.2607
16.72	.7191	.4093	.1757	16.69	.1407	6380	2.4278743	113.43	3.429	.3814	326.0	5.895	55.30	.2592
16.74	.7132	.4069	.1753	16.71	.1399	6417	2.4279252	113.45	3.425	.3814	326.8	5.895	55.43	.2577
16.76	.7074	.4045	.1749	16.73	.1391	6455	2.4279760	113.47	3.421	.3814	327.6	5.895	55.56	.2562
16.78	.7016	.4021	.1745	16.75	.1383	6493	2.4280266	113.49	3.417	.3814	328.3	5.895	55.69	.2547
16.80	.6959	.3998	.1741	16.77	.1375	6531	2.4280770	113.51	3.413	.3814	329.1	5.896	55.82	.2532
16.82	.6902	.3974	.1737	16.79	.1367	6570	2.4281272	113.53	3.408	.3814	329.9	5.896	55.95	.2517
16.84	.6846	.3951	.1733	16.81	.1359	6607	2.4281772	113.55	3.404	.3814	330.7	5.896	56.09	.2503
16.86	.6790	.3928	.1729	16.83	.1351	6647	2.4282271	113.57	3.400	.3814	331.5	5.896	56.22	.2488
16.88	.6735	.3905	.1725	16.85	.1343	6685	2.4282768	113.59	3.396	.3814	332.3	5.897	56.35	.2474
16.90	.6680	.3883	.1721	16.87	.1336	6724	2.4283264	113.61	3.392	.3814	333.1	5.897	56.48	.2460
16.92	.6626	.3860	.1717	16.89	.1328	6763	2.4283757	113.63	3.388	.3813	333.8	5.897	56.61	.2446
16.94	.6572	.3838	.1713	16.91	.1320	6802	2.4284249	113.65	3.384	.3813	334.6	5.897	56.74	.2432
16.96	.6520	.3816	.1709	16.93	.1313	6841	2.4284739	113.67	3.380	.3813	335.4	5.898	56.88	.2418
16.98	.6467	.3794	.1705	16.95	.1305	6881	2.4285228	113.69	3.376	.3813	336.2	5.898	57.01	.2404
17.00	.6415	.3772	.1701	16.97	.1298	6920	2.4285714	113.71	3.372	.3813	337.0	5.898	57.14	.2390
17.02	.6364	.3750	.1697	16.99	.1290	6960	2.4286199	113.73	3.368	.3813	337.8	5.898	57.27	.2376
17.04	.6311	.3729	.1693	17.01	.1283	7001	2.4286683	113.75	3.364	.3813	338.6	5.898	57.40	.2363
17.06	.6261	.3707	.1689	17.03	.1276	7042	2.4287164	113.77	3.360	.3813	339.4	5.899	57.54	.2349
17.08	.6211	.3686	.1685	17.05	.1268	7081	2.4287645	113.79	3.356	.3813	340.2	5.899	57.67	.2336
17.10	.6161	.3665	.1681	17.07	.1261	7122	2.4288123	113.81	3.353	.3813	341.0	5.899	57.80	.2322
17.12	.6111	.3644	.1677	17.09	.1254	7163	2.4288600	113.83	3.349	.3813	341.8	5.899	57.94	.2309
17.14	.6063	.3623	.1674	17.11	.1247	7204	2.4289075	113.85	3.345	.3813	342.6	5.900	58.07	.2296
17.16	.6014	.3602	.1670	17.13	.1240	7246	2.4289548	113.87	3.341	.3813	343.4	5.900	58.20	.2283
17.18	.5966	.3581	.1666	17.15	.1233	7287	2.4290020	113.88	3.337	.3812	344.2	5.900	58.34	.2270
17.20	.5918	.3561	.1662	17.17	.1226	7329	2.4290490	113.90	3.333	.3812	345.0	5.900	58.47	.2257
17.22	.5871	.3541	.1658	17.19	.1219	7371	2.4290959	113.92	3.329	.3812	345.8	5.901	58.60	.2245
17.24	.5824	.3520	.1654	17.21	.1212	7413	2.4291426	113.94	3.325	.3812	346.6	5.901	58.74	.2232
17.26	.5779	.3501	.1651	17.23	.1205	7454	2.4291891	113.96	3.321	.3812	347.4	5.901	58.87	.2219
17.28	.5732	.3481	.1647	17.25	.1198	7497	2.4292355	113.98	3.318	.3812	348.2	5.901	59.01	.2207
17.30	.5687	.3461	.1643	17.27	.1192	7539	2.4292818	114.00	3.314	.3812	349.0	5.901	59.14	.2194
17.32	.5642	.3441	.1639	17.29	.1185	7583	2.4293278	114.01	3.310	.3812	349.8	5.902	59.27	.2182
17.34	.5597	.3422	.1636	17.31	.1178	7626	2.4293737	114.03	3.306	.3812	350.6	5.902	59.41	.2170
17.36	.5553	.3403	.1632	17.33	.1171	7669	2.4294195	114.05	3.302	.3812	351.4	5.902	59.54	.2157
17.38	.5509	.3383	.1628	17.35	.1165	7713	2.4294651	114.07	3.299	.3812	352.2	5.902	59.68	.2145
17.40	.5465	.3364	.1625	17.37	.1158	7757	2.4295105	114.09	3.295	.3812	353.1	5.903	59.81	.2133
17.42	.5423	.3345	.1621	17.39	.1152	7799	2.4295556	114.11	3.291	.3812	353.9	5.903	59.95	.2121
17.44	.5380	.3326	.1617	17.41	.1145	7844	2.4296001	114.13	3.287	.3811	354.7	5.903	60.09	.2109
17.46	.													

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TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma = 7/5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A_*}$	$\frac{1}{a_*}$	v	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
17.70	.4859	.3093	.1571	17.67	.1066	8434	2.4301741	114.36	3.239	.3811	365.3	5.906	61.86	.1962	.2476
17.72	.4821	.3076	.1567	17.69	.1060	8481	2.4302172	114.38	3.235	.3810	366.2	5.906	62.00	.1951	.2471
17.74	.4783	.3059	.1564	17.71	.1054	8529	2.4302601	114.40	3.231	.3810	367.0	5.906	62.14	.1941	.2465
17.76	.4747	.3042	.1561	17.73	.1048	8575	2.4303029	114.42	3.228	.3810	367.8	5.906	62.28	.1930	.2460
17.78	.4710	.3025	.1557	17.75	.1042	8623	2.4303455	114.44	3.224	.3810	368.7	5.907	62.41	.1919	.2454
17.80	.4674	.3009	.1554	17.77	.1037	8670	2.4303880	114.45	3.221	.3810	369.5	5.907	62.55	.1909	.2449
17.82	.4637	.2992	.1550	17.79	.1031	8719	2.4304304	114.47	3.217	.3810	370.3	5.907	62.69	.1898	.2443
17.84	.4602	.2975	.1547	17.81	.1025	8767	2.4304726	114.49	3.213	.3810	371.1	5.907	62.83	.1888	.2437
17.86	.4566	.2959	.1543	17.83	.1020	8815	2.4305147	114.51	3.210	.3810	372.0	5.907	62.97	.1878	.2432
17.88	.4531	.2943	.1540	17.85	.1014	8864	2.4305566	114.52	3.206	.3810	372.8	5.908	63.11	.1867	.2427
17.90	.4496	.2926	.1537	17.87	.1009	8913	2.4305984	114.54	3.203	.3810	373.7	5.908	63.25	.1857	.2421
17.92	.4462	.2910	.1533	17.89	.1003	8962	2.4306401	114.56	3.199	.3810	374.5	5.908	63.39	.1847	.2416
17.94	.4428	.2895	.1530	17.91	.9976	9010	2.4306816	114.58	3.195	.3810	375.3	5.908	63.53	.1837	.2411
17.96	.4394	.2879	.1526	17.93	.9921	9060	2.4307230	114.59	3.192	.3810	376.2	5.908	63.67	.1827	.2405
17.98	.4361	.2863	.1523	17.95	.9868	9109	2.4307643	114.61	3.188	.3810	377.0	5.909	63.80	.1817	.2400
18.00	.4328	.2848	.1520	17.97	.9815	9159	2.4308052	114.63	3.185	.3810	377.8	5.909	63.94	.1807	.2395
18.02	.4294	.2832	.1516	17.99	.9760	9210	2.4308463	114.65	3.181	.3809	378.7	5.909	64.08	.1797	.2389
18.04	.4261	.2816	.1513	18.01	.9707	9260	2.4308872	114.66	3.178	.3809	379.5	5.909	64.23	.1788	.2384
18.06	.4229	.2801	.1510	18.03	.9655	9311	2.4309279	114.68	3.174	.3809	380.4	5.909	64.37	.1778	.2379
18.08	.4197	.2786	.1507	18.05	.9602	9362	2.4309685	114.70	3.171	.3809	381.2	5.910	64.51	.1768	.2373
18.10	.4165	.2771	.1503	18.07	.9552	9411	2.4310089	114.72	3.167	.3809	382.1	5.910	64.65	.1759	.2368
18.12	.4134	.2756	.1500	18.09	.9500	9463	2.4310492	114.73	3.164	.3809	382.9	5.910	64.79	.1749	.2363
18.14	.4102	.2741	.1497	18.11	.9448	9515	2.4310894	114.75	3.160	.3809	383.7	5.910	64.93	.1740	.2357
18.16	.4071	.2726	.1494	18.13	.9398	9566	2.4311295	114.77	3.157	.3809	384.6	5.910	65.07	.1731	.2353
18.18	.4041	.2711	.1490	18.15	.9349	9617	2.4311694	114.78	3.153	.3809	385.4	5.911	65.21	.1721	.2348
18.20	.4010	.2696	.1487	18.17	.9297	9671	2.4312092	114.80	3.150	.3809	386.3	5.911	65.35	.1712	.2342
18.22	.3979	.2682	.1484	18.19	.9247	9723	2.4312488	114.82	3.146	.3809	387.1	5.911	65.49	.1703	.2337
18.24	.3949	.2667	.1481	18.21	.9198	9775	2.4312884	114.83	3.143	.3809	388.0	5.911	65.64	.1694	.2332
18.26	.3920	.2653	.1477	18.23	.9148	9828	2.4313278	114.85	3.139	.3809	388.8	5.911	65.78	.1685	.2327
18.28	.3890	.2639	.1474	18.25	.9099	9881	2.4313671	114.87	3.136	.3809	389.7	5.912	65.92	.1676	.2321
18.30	.3861	.2625	.1471	18.27	.9052	9933	2.4314062	114.89	3.133	.3809	390.5	5.912	66.06	.1667	.2317
18.32	.3832	.2611	.1468	18.29	.9003	9987	2.4314452	114.90	3.129	.3809	391.4	5.912	66.20	.1658	.2312
18.34	.3803	.2596	.1465	18.31	.8954	1004	2.4314841	114.92	3.126	.3808	392.3	5.912	66.35	.1649	.2306
18.36	.3775	.2583	.1462	18.33	.8907	1010	2.4315229	114.94	3.122	.3808	393.1	5.912	66.49	.1640	.2302
18.38	.3747	.2569	.1459	18.35	.8861	1015	2.4315616	114.95	3.119	.3808	394.0	5.913	66.63	.1632	.2297
18.40	.3718	.2555	.1455	18.37	.8812	1020	2.4316001	114.97	3.115	.3808	394.8	5.913	66.78	.1623	.2291
18.42	.3691	.2541	.1452	18.39	.8765	1026	2.4316385	114.99	3.112	.3808	395.7	5.913	66.92	.1614	.2287
18.44	.3663	.2528	.1449	18.41	.8719	1031	2.4316768	115.00	3.109	.3808	396.5	5.913	67.06	.1606	.2281
18.46	.3636	.2514	.1446	18.43	.8673	1037	2.4317150	115.02	3.105	.3808	397.4	5.913	67.21	.1597	.2277
18.48	.3609	.2501	.1443	18.45	.8628	1042	2.4317530	115.04	3.102	.3808	398.3	5.913	67.35	.1589	.2272
18.50	.3582	.2488	.1440	18.47	.8582	1048	2.4317909	115.05	3.099	.3808	399.1	5.914	67.49	.1580	.2267
18.52	.3555	.2475	.1437	18.49	.8536	1054	2.4318287	115.07	3.095	.3808	400.0	5.914	67.64	.1572	.2262
18.54	.3530	.2462	.1434	18.51	.8492	1059	2.4318664	115.08	3.092	.3808	400.9	5.914	67.78	.1564	.2257
18.56	.3503	.2448	.1431	18.53	.8446	1065	2.4319039	115.10	3.089	.3808	401.7	5.914	67.93	.1555	.2252
18.58	.3477	.2436	.1428	18.55	.8403	1070	2.4319413	115.12	3.085	.3808	402.6	5.914	68.07	.1547	.2248
18.60	.3452	.2423	.1425	18.57	.8359	1076	2.4319787	115.13	3.082	.3808	403.5	5.915	68.21	.1539	.2243
18.62	.3426	.2410	.1422	18.59	.8315	1082	2.4320159	115.15	3.079	.3808	404.3	5.915	68.36	.1531	.2238
18.64	.3400	.2397	.1419	18.61	.8270	1088	2.4320529	115.17	3.075	.3808	405.2	5.915	68.50	.1523	.2233
18.66	.3375	.2384	.1416	18.63	.8226	1093	2.4320899	115.18	3.072	.3807	406.1	5.915	68.65	.1515	.2228
18.68	.3351	.2372	.1413	18.65	.8185	1099	2.4321267	115.20	3.069	.3807	406.9	5.915	68.79	.1507	.2224
18.70	.3326	.2359	.1410	18.67	.8142	1105	2.4321635	115.21	3.065	.3807	407.8	5.915	68.94	.1499	.2219
18.72	.3301	.2347	.1407	18.69	.8099	1111	2.4322001	115.23	3.062	.3807	408.7	5.916	69.09	.1491	.2214
18.74	.3276	.2335	.1404	18.71	.8058	1116	2.4322366	115.25	3.059	.3807	409.6	5.916	69.23	.1484	.2209
18.76	.3253	.2322	.1401	18.73	.8015	1122	2.4322729	115.26	3.056	.3807	410.4	5.916	69.38	.1476	.2205
18.78	.3230	.2310	.1398	18.75	.7974	1128	2.4323092	115.28	3.052	.3807	411.3	5.916	69.52	.1468	.2200
18.80	.3206	.2298	.1395	18.77	.7931	1134	2.4323454	115.29	3.049	.3807	412.2	5.916	69.67	.1460	.2195
18.82	.3182	.2286	.1392	18.79	.7890	1140	2.4323814	115.31	3.046	.3807	413.1	5.917	69.82	.1453	.2191
18.84	.3159	.2274	.1389	18.81	.7849	1146	2.4324173	115.33	3.043	.3807	413.9	5.917	69.96	.1445	.2186
18.86	.3136	.2262	.1386	18.83	.7809	1152	2.4324531	115.34	3.039	.3807	414.8	5.917	70.11	.1438	.2182
18.88	.3113	.2251	.1383	18.85	.7768	1158	2.4324888	115.36	3.036	.3807	415.7	5.917	70.26	.1430	.2177
18.90	.3090	.2239	.1380	18.87	.7727	1164	2.4325244	115.38	3.033	.3807	416.6	5.917	70.40	.1423	.2172
18.92	.3068	.2227	.1378	18.89	.7687	1170	2.4325599	115.39	3.030	.3807	417.5	5.917	70.55	.1416	.2167
18.94	.3046	.2216	.1375	18.91	.7649	1176	2.4325953	115.41	3.027	.3807	418.3	5.918	70.70	.1408	.2163
18.96	.3024	.2204	.1372	18.93	.7608	1182	2.4326305	115.42	3.023	.3807	419.2	5.918	70.84	.1401	.2158
18.98	.3002	.2193	.1369	18.95	.7570	1188	2.4326657	115.44	3.020	.3807	420.1	5.918	70.99	.1394	.2154
19.00	.2980	.2181	.1366	18.97	.7530	1195	2.4327007	115.45	3.017	.3806	421.0	5.918	71.14	.1387	.2149
19.02	.2959	.2170	.1363	18.99	.7492	1201	2.4327356	115.47	3.014	.3806	421.9	5.918	71.29	.1379	.2145
19.04	.2937	.2159	.1361	19.01	.7454	1207	2.4327705	115.48	3.011	.3806	422.8	5.918	71.44	.1372	.2141
19.06	.2915	.2148	.1358	19.03	.7414	1213	2.4328052	115.50	3.008	.3806	423.7	5.919	71.58	.1365	.2136
19.08	.2894	.2136	.1355	19.05	.7376	1220	2.4328398	115.52	3.004	.3806	424.6	5.919	71.73	.1358	.2131
19.10	.2874	.2125	.1352	19.07	.7338	1226	2.4328743	115.53	3.001	.3806	425.5	5.919	71.88	.1351	.2127
19.12	.2854	.2115	.1349	19.09	.7302	1232	2.4329087	115.55	2.998	.3806	426.3	5.919	72.03	.1344	.2123
19.14	.2833	.2104	.1347	19.11	.7264	1239	2.4329430	115.56	2.995	.3806	427.2	5.919	72.18	.1337	.2118
19.16	.2812	.2093	.1344	19.13	.7227	1245	2.4329771	115.58	2.992	.3806	42				

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma=7.5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{1}{A^*}$	$\frac{V}{a^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_2}{p_{t2}}$
19.50	.2491	.1919	.1298	19.47	.6630	1357	2.4335424	115.83	2.940	.3805	443.5	5.922	.1221	.2041
19.52	.2473	.1909	.1295	19.49	.6595	1365	2.4335747	115.85	2.937	.3805	444.4	5.922	.1214	.2036
19.54	.2455	.1900	.1293	19.51	.6563	1371	2.4336070	115.86	2.934	.3805	445.3	5.922	.1208	.2032
19.56	.2438	.1890	.1290	19.53	.6530	1378	2.4336391	115.88	2.931	.3805	446.2	5.923	.1202	.2028
19.58	.2421	.1881	.1287	19.55	.6497	1385	2.4336712	115.89	2.928	.3805	447.1	5.923	.1196	.2024
19.60	.2404	.1871	.1285	19.57	.6464	1392	2.4337031	115.91	2.925	.3805	448.0	5.923	.1190	.2020
19.62	.2387	.1862	.1282	19.59	.6432	1399	2.4337350	115.92	2.922	.3805	448.9	5.923	.1184	.2016
19.64	.2371	.1853	.1280	19.61	.6401	1406	2.4337667	115.94	2.919	.3805	449.9	5.923	.1178	.2012
19.66	.2354	.1843	.1277	19.63	.6369	1413	2.4337984	115.95	2.916	.3805	450.8	5.923	.1173	.2008
19.68	.2337	.1834	.1275	19.65	.6336	1420	2.4338300	115.97	2.913	.3805	451.7	5.924	.1167	.2003
19.70	.2321	.1825	.1272	19.67	.6306	1427	2.4338615	115.98	2.910	.3805	452.6	5.924	.1161	.2000
19.72	.2305	.1816	.1269	19.69	.6274	1435	2.4338928	116.00	2.907	.3805	453.5	5.924	.1155	.1995
19.74	.2289	.1807	.1267	19.72	.6243	1442	2.4339241	116.01	2.904	.3805	454.5	5.924	.1149	.1991
19.76	.2273	.1798	.1264	19.74	.6213	1449	2.4339553	116.03	2.901	.3804	455.4	5.924	.1143	.1988
19.78	.2257	.1788	.1262	19.76	.6180	1456	2.4339864	116.04	2.898	.3804	456.3	5.924	.1138	.1983
19.80	.2241	.1780	.1259	19.78	.6150	1464	2.4340174	116.05	2.895	.3804	457.2	5.924	.1132	.1979
19.82	.2226	.1771	.1257	19.80	.6120	1471	2.4340483	116.07	2.892	.3804	458.1	5.925	.1127	.1975
19.84	.2210	.1762	.1254	19.82	.6090	1478	2.4340792	116.08	2.889	.3804	459.1	5.925	.1121	.1971
19.86	.2195	.1753	.1252	19.84	.6059	1486	2.4341099	116.10	2.886	.3804	460.0	5.925	.1116	.1967
19.88	.2179	.1745	.1249	19.86	.6029	1493	2.4341405	116.11	2.883	.3804	460.9	5.925	.1110	.1963
19.90	.2165	.1736	.1247	19.88	.6001	1500	2.4341711	116.13	2.880	.3804	461.9	5.925	.1105	.1960
19.92	.2150	.1727	.1244	19.91	.5971	1508	2.4342015	116.14	2.878	.3804	462.8	5.925	.1099	.1956
19.94	.2135	.1719	.1242	19.92	.5941	1515	2.4342319	116.15	2.875	.3804	463.7	5.926	.1094	.1952
19.96	.2120	.1710	.1240	19.94	.5913	1523	2.4342622	116.17	2.872	.3804	464.6	5.926	.1088	.1948
19.98	.2105	.1702	.1237	19.96	.5883	1531	2.4342924	116.18	2.869	.3804	465.6	5.926	.1083	.1944
20.00	.2091	.1694	.1235	19.98	.5855	1538	2.4343225	116.20	2.866	.3804	466.5	5.926	.1078	.1940
20.02	.2076	.1685	.1232	20.01	.5824	1546	2.4343526	116.21	2.863	.3803	467.5	5.927	.1072	.1936
20.04	.2061	.1676	.1230	20.03	.5794	1554	2.4343826	116.22	2.860	.3803	468.5	5.927	.1067	.1932
20.06	.2046	.1667	.1228	20.05	.5764	1562	2.4344126	116.23	2.857	.3802	469.5	5.927	.1061	.1928
20.08	.2031	.1658	.1226	20.07	.5734	1570	2.4344426	116.24	2.854	.3802	470.5	5.928	.1056	.1924
20.10	.2016	.1649	.1224	20.09	.5704	1578	2.4344726	116.25	2.851	.3802	471.5	5.928	.1050	.1920
20.12	.2001	.1640	.1222	20.11	.5674	1586	2.4345026	116.26	2.848	.3801	472.5	5.928	.1045	.1916
20.14	.1986	.1631	.1220	20.13	.5644	1594	2.4345326	116.27	2.845	.3801	473.5	5.929	.1039	.1912
20.16	.1971	.1622	.1218	20.15	.5614	1602	2.4345626	116.28	2.842	.3801	474.5	5.929	.1034	.1908
20.18	.1956	.1613	.1216	20.17	.5584	1610	2.4345926	116.29	2.839	.3801	475.5	5.929	.1028	.1904
20.20	.1941	.1604	.1214	20.19	.5554	1618	2.4346226	116.30	2.836	.3801	476.5	5.930	.1023	.1900
20.22	.1926	.1595	.1212	20.21	.5524	1626	2.4346526	116.31	2.833	.3801	477.5	5.930	.1017	.1896
20.24	.1911	.1586	.1210	20.23	.5494	1634	2.4346826	116.32	2.830	.3801	478.5	5.930	.1012	.1892
20.26	.1896	.1577	.1208	20.25	.5464	1642	2.4347126	116.33	2.827	.3801	479.5	5.931	.1006	.1888
20.28	.1881	.1568	.1206	20.27	.5434	1650	2.4347426	116.34	2.824	.3801	480.5	5.931	.1001	.1884
20.30	.1866	.1559	.1204	20.29	.5404	1658	2.4347726	116.35	2.821	.3801	481.5	5.931	.999	.1880
20.32	.1851	.1550	.1202	20.31	.5374	1666	2.4348026	116.36	2.818	.3801	482.5	5.932	.998	.1876
20.34	.1836	.1541	.1200	20.33	.5344	1674	2.4348326	116.37	2.815	.3801	483.5	5.932	.997	.1872
20.36	.1821	.1532	.1198	20.35	.5314	1682	2.4348626	116.38	2.812	.3801	484.5	5.932	.996	.1868
20.38	.1806	.1523	.1196	20.37	.5284	1690	2.4348926	116.39	2.809	.3801	485.5	5.933	.995	.1864
20.40	.1791	.1514	.1194	20.39	.5254	1698	2.4349226	116.40	2.806	.3801	486.5	5.933	.994	.1860
20.42	.1776	.1505	.1192	20.41	.5224	1706	2.4349526	116.41	2.803	.3801	487.5	5.933	.993	.1856
20.44	.1761	.1496	.1190	20.43	.5194	1714	2.4349826	116.42	2.800	.3801	488.5	5.934	.992	.1852
20.46	.1746	.1487	.1188	20.45	.5164	1722	2.4350126	116.43	2.797	.3801	489.5	5.934	.991	.1848
20.48	.1731	.1478	.1186	20.47	.5134	1730	2.4350426	116.44	2.794	.3801	490.5	5.934	.990	.1844
20.50	.1716	.1469	.1184	20.49	.5104	1738	2.4350726	116.45	2.791	.3801	491.5	5.935	.989	.1840
20.52	.1701	.1460	.1182	20.51	.5074	1746	2.4351026	116.46	2.788	.3801	492.5	5.935	.988	.1836
20.54	.1686	.1451	.1180	20.53	.5044	1754	2.4351326	116.47	2.785	.3801	493.5	5.935	.987	.1832
20.56	.1671	.1442	.1178	20.55	.5014	1762	2.4351626	116.48	2.782	.3801	494.5	5.936	.986	.1828
20.58	.1656	.1433	.1176	20.57	.4984	1770	2.4351926	116.49	2.779	.3801	495.5	5.936	.985	.1824
20.60	.1641	.1424	.1174	20.59	.4954	1778	2.4352226	116.50	2.776	.3801	496.5	5.936	.984	.1820
20.62	.1626	.1415	.1172	20.61	.4924	1786	2.4352526	116.51	2.773	.3801	497.5	5.937	.983	.1816
20.64	.1611	.1406	.1170	20.63	.4894	1794	2.4352826	116.52	2.770	.3801	498.5	5.937	.982	.1812
20.66	.1596	.1397	.1168	20.65	.4864	1802	2.4353126	116.53	2.767	.3801	499.5	5.937	.981	.1808
20.68	.1581	.1388	.1166	20.67	.4834	1810	2.4353426	116.54	2.764	.3801	500.5	5.938	.980	.1804
20.70	.1566	.1379	.1164	20.69	.4804	1818	2.4353726	116.55	2.761	.3801	501.5	5.938	.979	.1800
20.72	.1551	.1370	.1162	20.71	.4774	1826	2.4354026	116.56	2.758	.3801	502.5	5.938	.978	.1796
20.74	.1536	.1361	.1160	20.73	.4744	1834	2.4354326	116.57	2.755	.3801	503.5	5.939	.977	.1792
20.76	.1521	.1352	.1158	20.75	.4714	1842	2.4354626	116.58	2.752	.3801	504.5	5.939	.976	.1788
20.78	.1506	.1343	.1156	20.77	.4684	1850	2.4354926	116.59	2.749	.3801	505.5	5.939	.975	.1784
20.80	.1491	.1334	.1154	20.79	.4654	1858	2.4355226	116.60	2.746	.3801	506.5	5.940	.974	.1780
20.82	.1476	.1325	.1152	20.81	.4624	1866	2.4355526	116.61	2.743	.3801	507.5	5.940	.973	.1776
20.84	.1461	.1316	.1150	20.83	.4594	1874	2.4355826	116.62	2.740	.3801	508.5	5.940	.972	.1772
20.86	.1446	.1307	.1148	20.85	.4564	1882	2.4356126	116.63	2.737	.3801	509.5	5.941	.971	.1768
20.88	.1431	.1298	.1146	20.87	.4534	1890	2.4356426	116.64	2.734	.3801	510.5	5.941	.970	.1764
20.90	.1416	.1289	.1144	20.89	.4504	1898	2.4356726	116.65	2.731	.3801	511.5	5.941	.969	.1760
20.92	.1401	.1280	.1142	20.91	.4474	1906	2.4357026	116.66	2.728	.3801	512.5	5.942	.968	.1756
20.94	.1386	.1271	.1140	20.93	.4444	1914	2.4357326	116.67	2.725	.3801	513.5	5.942	.967	.1752
20.96	.1371	.1262	.1138	20.95	.4414	1922	2.4357626	116.68	2.722	.3801	514.5	5.942	.966	.1748
20.98	.1356	.1253	.1136	20.97	.4384	1930	2.4357926	116.69	2.719	.3801	515.5	5.943	.965	.1744
21.00	.1341	.1244	.1134	20.99	.4354	1938	2.4358226	116.70	2.716	.3801	516.5	5.943	.964	.1740
21.02	.1326	.1235	.1132	21.01	.4324	1946	2.4358526	116.71	2.713	.3801	517.5	5.943	.963	.1736
21.04	.1311	.1226	.1130	21.03	.4294	1954	2.4358826	116.72	2.710	.3801	518.5	5.944	.962	.1732
21.06	.1296	.1217	.1128	21.05	.4264	1962	2.4359126	116.73	2.707	.3801	519.5	5.944		

TABLE II.—SUPERSONIC FLOW—Continued

 $\gamma=7.5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{1}{A^*}$	$\frac{1}{a^*}$	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{02}}{p_{01}}$	$\frac{p_1}{p_{01}}$	
33.00	.6454	.1412	.4570	32.98	.4920	1837	2.443885	121.79	1.737	.3789	1270	5.973	212.7	.9053	.7129
33.20	.6188	.1370	.4516	33.18	.4774	1893	2.4439529	121.84	1.726	.3788	1286	5.973	215.3	.8785	.7044
33.40	.5935	.1330	.4462	33.39	.4634	1950	2.4440188	121.89	1.716	.3788	1301	5.973	217.9	.8527	.6960
33.60	.5692	.1291	.4409	33.59	.4499	2009	2.4440835	121.94	1.706	.3788	1317	5.974	220.5	.8277	.6876
33.80	.5462	.1253	.4358	33.79	.4368	2069	2.4441471	121.99	1.695	.3788	1333	5.974	223.1	.8037	.6796
34.00	.5242	.1217	.4307	33.99	.4242	2131	2.4442095	122.04	1.685	.3788	1349	5.974	225.7	.7805	.6716
34.20	.5032	.1182	.4257	34.19	.4120	2194	2.4442709	122.09	1.676	.3788	1364	5.975	228.4	.7581	.6638
34.40	.4832	.1148	.4208	34.39	.4002	2259	2.4443312	122.14	1.666	.3788	1380	5.975	231.0	.7364	.6561
34.60	.4640	.1116	.4159	34.59	.3889	2325	2.4443905	122.19	1.656	.3788	1397	5.975	233.7	.7155	.6486
34.80	.4457	.1084	.4112	34.79	.3779	2392	2.4444488	122.24	1.647	.3788	1413	5.975	236.4	.6952	.6411
35.00	.4283	.1054	.4065	34.99	.3672	2462	2.4445060	122.28	1.637	.3788	1429	5.976	239.1	.6757	.6338
35.20	.4116	.1024	.4019	35.19	.3570	2532	2.4445623	122.33	1.628	.3787	1445	5.976	241.9	.6568	.6267
35.40	.3957	.9956	.3974	35.39	.3471	2605	2.4446177	122.37	1.619	.3787	1462	5.976	244.6	.6385	.6197
35.60	.3804	.9804	.3930	35.59	.3375	2679	2.4446721	122.42	1.610	.3787	1478	5.976	247.4	.6210	.6126
35.80	.3658	.9644	.3886	35.79	.3282	2754	2.4447256	122.47	1.601	.3787	1495	5.977	250.2	.6039	.6059
36.00	.3519	.9486	.3843	35.99	.3192	2832	2.4447783	122.51	1.592	.3787	1512	5.977	252.9	.5874	.5991
36.20	.3386	.9327	.3801	36.19	.3106	2911	2.4448300	122.55	1.583	.3787	1529	5.977	255.8	.5714	.5925
36.40	.3258	.9166	.3760	36.39	.3022	2992	2.4448810	122.60	1.574	.3787	1546	5.977	258.6	.5560	.5860
36.60	.3136	.9003	.3719	36.59	.2941	3075	2.4449311	122.64	1.566	.3787	1563	5.978	261.4	.5410	.5797
36.80	.3019	.8837	.3679	36.79	.2862	3159	2.4449803	122.68	1.557	.3787	1580	5.978	264.3	.5265	.5734
37.00	.2907	.8678	.3639	36.99	.2786	3246	2.4450288	122.72	1.549	.3787	1597	5.978	267.1	.5126	.5671
37.20	.2800	.8517	.3600	37.19	.2712	3334	2.4450765	122.77	1.540	.3787	1614	5.978	270.0	.4990	.5611
37.40	.2697	.8355	.3562	37.39	.2641	3424	2.4451235	122.81	1.532	.3787	1632	5.979	272.8	.4858	.5551
37.60	.2598	.8193	.3524	37.59	.2572	3516	2.4451697	122.85	1.524	.3787	1649	5.979	275.8	.4732	.5492
37.80	.2504	.8031	.3487	37.79	.2504	3611	2.4452152	122.89	1.516	.3786	1667	5.979	278.8	.4608	.5434
38.00	.2414	.7869	.3451	37.99	.2440	3706	2.4452599	122.93	1.508	.3786	1685	5.979	281.7	.4489	.5377
38.20	.2327	.7706	.3415	38.19	.2377	3805	2.4453040	122.97	1.500	.3786	1702	5.980	284.7	.4373	.5321
38.40	.2244	.7543	.3379	38.39	.2316	3905	2.4453474	123.00	1.492	.3786	1720	5.980	287.7	.4260	.5266
38.60	.2164	.7380	.3345	38.59	.2257	4007	2.4453901	123.04	1.485	.3786	1738	5.980	290.7	.4152	.5212
38.80	.2087	.7217	.3310	38.79	.2199	4112	2.4454321	123.08	1.477	.3786	1756	5.980	293.7	.4046	.5158
39.00	.2013	.7054	.3277	38.99	.2144	4219	2.4454735	123.12	1.469	.3786	1774	5.980	296.7	.3944	.5105
39.20	.1943	.6891	.3243	39.19	.2090	4327	2.4455143	123.16	1.462	.3786	1793	5.981	299.7	.3845	.5053
39.40	.1875	.6728	.3211	39.39	.2038	4438	2.4455545	123.19	1.454	.3786	1811	5.981	302.8	.3749	.5002
39.60	.1810	.6565	.3178	39.59	.1987	4552	2.4455940	123.23	1.447	.3786	1829	5.981	305.9	.3655	.4952
39.80	.1748	.6402	.3147	39.79	.1938	4667	2.4456330	123.27	1.440	.3786	1848	5.981	309.0	.3565	.4902
40.00	.1688	.6239	.3115	39.99	.1890	4783	2.4456714	123.30	1.433	.3786	1867	5.981	312.1	.3477	.4853
40.20	.1630	.6076	.3084	40.19	.1844	4906	2.4457092	123.34	1.425	.3786	1885	5.982	315.2	.3392	.4805
40.40	.1574	.5913	.3054	40.39	.1799	5028	2.4457464	123.37	1.418	.3786	1904	5.982	318.3	.3309	.4757
40.60	.1521	.5750	.3024	40.59	.1755	5154	2.4457831	123.41	1.411	.3786	1923	5.982	321.5	.3229	.4710
40.80	.1470	.5587	.2995	40.79	.1713	5281	2.4458193	123.44	1.404	.3785	1942	5.982	324.6	.3151	.4665
41.00	.1420	.5424	.2965	40.99	.1671	5412	2.4458549	123.48	1.396	.3785	1961	5.982	327.8	.3075	.4619
41.20	.1373	.5261	.2937	41.19	.1631	5544	2.4458901	123.51	1.391	.3785	1980	5.982	331.0	.3001	.4575
41.40	.1327	.5098	.2909	41.39	.1592	5680	2.4459247	123.54	1.384	.3785	2000	5.983	334.2	.2929	.4531
41.60	.1283	.4935	.2881	41.59	.1555	5818	2.4459588	123.58	1.377	.3785	2019	5.983	337.4	.2860	.4487
41.80	.1241	.4772	.2854	41.79	.1518	5959	2.4459924	123.61	1.371	.3785	2038	5.983	340.7	.2793	.4444
42.00	.1201	.4610	.2827	41.99	.1482	6102	2.4460256	123.64	1.364	.3785	2058	5.983	343.9	.2727	.4402
42.20	.1161	.4448	.2800	42.19	.1448	6248	2.4460583	123.67	1.358	.3785	2078	5.983	347.2	.2663	.4360
42.40	.1124	.4286	.2774	42.39	.1414	6397	2.4460905	123.71	1.351	.3785	2097	5.983	350.5	.2602	.4319
42.60	.1087	.4124	.2748	42.59	.1381	6549	2.4461223	123.74	1.345	.3785	2117	5.984	353.8	.2541	.4279
42.80	.1052	.3962	.2722	42.79	.1349	6704	2.4461536	123.77	1.339	.3785	2137	5.984	357.1	.2483	.4239
43.00	.1019	.3800	.2697	42.99	.1318	6861	2.4461845	123.80	1.333	.3785	2157	5.984	360.5	.2426	.4200
43.20	.9861	.3638	.2672	43.19	.1288	7022	2.4462150	123.83	1.326	.3785	2177	5.984	363.8	.2370	.4161
43.40	.9548	.3476	.2648	43.39	.1259	7186	2.4462451	123.86	1.320	.3785	2197	5.984	367.2	.2316	.4122
43.60	.9246	.3314	.2623	43.59	.1230	7352	2.4462747	123.89	1.314	.3785	2218	5.984	370.6	.2264	.4084
43.80	.8956	.3152	.2600	43.79	.1203	7522	2.4463039	123.92	1.308	.3785	2238	5.984	374.0	.2213	.4048
44.00	.8676	.2990	.2576	43.99	.1176	7694	2.4463326	123.95	1.302	.3785	2259	5.985	377.4	.2163	.4011
44.20	.8405	.2828	.2553	44.19	.1150	7870	2.4463612	123.98	1.296	.3785	2279	5.985	380.8	.2115	.3975
44.40	.8144	.2666	.2530	44.39	.1124	8049	2.4463893	124.01	1.291	.3785	2300	5.985	384.3	.2068	.3939
44.60	.7893	.2504	.2507	44.59	.1099	8232	2.4464170	124.04	1.285	.3785	2321	5.985	387.7	.2022	.3904
44.80	.7650	.2342	.2485	44.79	.1075	8418	2.4464443	124.07	1.279	.3784	2341	5.985	391.2	.1977	.3869
45.00	.7416	.2180	.2463	44.99	.1051	8606	2.4464713	124.10	1.273	.3784	2362	5.985	394.7	.1934	.3835
45.20	.7190	.2018	.2441	45.19	.1028	8798	2.4464979	124.12	1.268	.3784	2383	5.985	398.2	.1892	.3801
45.40	.6971	.1856	.2420	45.39	.1006	8995	2.4465241	124.15	1.262	.3784	2405	5.986	401.7	.1851	.3767
45.60	.6760	.1694	.2399	45.59	.9840	9194	2.4465500	124.18	1.257	.3784	2426	5.986	405.3	.1810	.3735
45.80	.6557	.1532	.2378	45.79	.9629	9396	2.4465756	124.21	1.251	.3784	2447	5.986	408.8	.1771	.3702
46.00	.6361	.1370	.2357	45.99	.9422	9603	2.4466009	124.23	1.246	.3784	2469	5.986	412.4	.1733	.3670
46.20	.6171	.1208	.2337	46.19	.9220	9813	2.4466258	124.26	1.240	.3784	2490	5.986	416.0	.1696	.3638
46.40	.5987	.1046	.2317	46.39	.9023	1003	2.4466504	124.29	1.235	.3784	2512	5.986	419.6	.1660	.3607
46.60	.5810	.884	.2297	46.59	.8832	1024	2.4466746	124.31	1.230	.3784	2533	5.986	423.2	.1625	.3576
46.80	.5639	.723	.2278	46.79	.8646	1047	2.4466986	124.34	1.224	.3784	2555	5.986	426.8	.1591	.3546
47.00	.5474	.562	.2258	46.99	.8464	1069	2.4467223	124.37	1.219	.3784	2577	5.986	430.5	.1557	.3516
47.20	.5314	.401	.2239	47.19	.8287	1092	2.4467456	124.39	1.214	.3784	2599	5.987	434.1	.1525	.3486
47.40	.5159	.240	.2221	47.39	.8114	1115	2.4467687	124.42	1.209	.3784	2621	5.987	437.8	.1493	.3457
47.60	.5009	.079	.2202	47.59	.7945	1139	2.4467915	124.44	1.204	.3784	2643	5.987	441.5	.1462	.3427
47.80	.4865	.018	.2184	47											

TABLE II.—SUPERSONIC FLOW—Concluded

 $\gamma=7.5$

M or M_1	$\frac{p}{p_1}$	$\frac{\rho}{\rho_1}$	$\frac{T}{T_1}$	β	$\frac{q}{p_1}$	$\frac{A}{A_*}$	$\frac{V}{a_*}$	ν	μ	M_2	$\frac{p_2}{p_1}$	$\frac{\rho_2}{\rho_1}$	$\frac{T_2}{T_1}$	$\frac{p_{t2}}{p_{t1}}$	$\frac{p_1}{p_{t2}}$
55.00	.1826	.1106	.1659	54.99	.3868	2341	2.4474679	125.25	1.042	.3783	3529	5.991	589.1	.7111	.2567
56.00	.1609	.1011	.1592	55.99	.3533	2562	2.4475394	125.34	1.024	.3783	3659	5.990	610.7	.6499	.2476
57.00	.1422	.9256	.1537	56.99	.3235	2798	2.4476071	125.43	1.005	.3783	3790	5.991	632.7	.5950	.2390
58.00	.1259	.8485	.1484	57.99	.2965	3052	2.4476714	125.52	.9879	.3783	3925	5.991	655.1	.5455	.2308
59.00	.1118	.7791	.1434	58.99	.2723	3324	2.4477325	125.60	.9712	.3782	4061	5.991	677.8	.5009	.2231
60.00	.9937	.7165	.1387	59.99	.2504	3615	2.4477905	125.68	.9550	.3782	4200	5.992	700.9	.4603	.2157
61.00	.8852	.6596	.1342	60.99	.2305	3920	2.4478457	125.76	.9393	.3782	4341	5.992	724.5	.4241	.2087
62.00	.7900	.6082	.1299	61.99	.2126	4258	2.4478982	125.84	.9241	.3782	4485	5.992	748.4	.3911	.2020
63.00	.7065	.5615	.1258	62.99	.1963	4612	2.4479483	125.91	.9095	.3782	4630	5.993	772.7	.3611	.1957
64.00	.6328	.5190	.1219	63.99	.1814	4990	2.4479961	125.98	.8953	.3782	4779	5.993	797.4	.3338	.1896
65.00	.5678	.4803	.1182	64.99	.1679	5391	2.4480416	126.05	.8815	.3782	4929	5.993	822.5	.3089	.1838
66.00	.5103	.4451	.1147	65.99	.1556	5818	2.4480851	126.12	.8682	.3782	5082	5.994	847.9	.2863	.1783
67.00	.4594	.4129	.1113	66.99	.1444	6271	2.4481267	126.18	.8552	.3782	5237	5.994	873.8	.2655	.1730
68.00	.4141	.3834	.1080	67.99	.1340	6754	2.4481665	126.24	.8426	.3782	5395	5.994	900.1	.2466	.1679
69.00	.3740	.3565	.1049	68.99	.1246	7264	2.4482045	126.30	.8304	.3782	5554	5.994	926.7	.2291	.1631
70.00	.3382	.3318	.1019	69.99	.1160	7804	2.4482410	126.36	.8185	.3782	5717	5.994	953.7	.2134	.1585
71.00	.3062	.3091	.9913	70.99	.1081	8376	2.4482759	126.42	.8070	.3782	5881	5.994	981.1	.1988	.1540
72.00	.2777	.2892	.9736	71.99	.1008	8984	2.4483094	126.48	.7958	.3782	6048	5.994	1009	.1854	.1498
73.00	.2522	.2690	.9574	72.99	.9406	9625	2.4483414	126.54	.7849	.3781	6217	5.994	1037	.1730	.1457
74.00	.2293	.2513	.9422	73.99	.8789	1030	2.4483722	126.59	.7742	.3781	6389	5.995	1066	.1617	.1418
75.00	.2088	.2351	.9281	74.99	.8220	1102	2.4484018	126.64	.7639	.3781	6562	5.995	1095	.1512	.1381
76.00	.1903	.2200	.9149	75.99	.7693	1177	2.4484302	126.69	.7539	.3781	6739	5.995	1124	.1415	.1345
77.00	.1737	.2061	.9026	76.99	.7207	1256	2.4484576	126.74	.7441	.3781	6917	5.995	1154	.1326	.1310
78.00	.1587	.1932	.8912	77.99	.6757	1340	2.4484838	126.78	.7345	.3781	7095	5.995	1184	.1243	.1276
79.00	.1451	.1813	.8805	78.99	.6341	1428	2.4485091	126.83	.7253	.3781	7281	5.995	1215	.1166	.1244
80.00	.1329	.1703	.8706	79.99	.5954	1521	2.4485335	126.88	.7162	.3781	7467	5.995	1245	.1095	.1214
81.00	.1219	.1600	.8615	80.99	.5591	1618	2.4485569	126.92	.7074	.3781	7654	5.995	1277	.1030	.1184
82.00	.1118	.1505	.8531	81.99	.5254	1720	2.4485795	126.96	.6987	.3781	7845	5.995	1308	.9682	.1155
83.00	.1027	.1417	.8453	82.99	.4934	1828	2.4486013	127.00	.6903	.3781	8037	5.995	1341	.9113	.1127
84.00	.9448	.1334	.8381	83.99	.4637	1940	2.4486223	127.05	.6821	.3781	8232	5.996	1373	.8585	.1101
85.00	.8697	.1258	.8316	84.99	.4369	2059	2.4486426	127.09	.6741	.3781	8429	5.996	1406	.8092	.1075
86.00	.8014	.1186	.8256	85.99	.4149	2182	2.4486622	127.12	.6662	.3781	8629	5.996	1439	.7632	.1050
87.00	.7391	.1120	.8202	86.99	.3916	2312	2.4486811	127.16	.6586	.3781	8830	5.996	1473	.7204	.1026
88.00	.6823	.1058	.8152	87.99	.3699	2448	2.4486994	127.20	.6511	.3781	9035	5.996	1507	.6804	.1003
89.00	.6305	.9995	.8108	88.99	.3495	2590	2.4487170	127.24	.6438	.3781	9241	5.996	1541	.6431	.9805
90.00	.5831	.9452	.8069	89.99	.3305	2739	2.4487341	127.27	.6366	.3781	9450	5.996	1576	.6032	.9588
91.00	.5397	.8944	.8034	90.99	.3129	2894	2.4487506	127.31	.6296	.3781	9661	5.996	1611	.5755	.9378
92.00	.5000	.8469	.8004	91.99	.2962	3057	2.4487666	127.34	.6228	.3781	9875	5.997	1647	.5450	.9175
93.00	.4636	.8023	.7978	92.99	.2807	3226	2.4487820	127.38	.6160	.3781	1009	5.997	1683	.5163	.8978
94.00	.4302	.7606	.7956	93.99	.2661	3403	2.4487970	127.41	.6095	.3781	1031	5.997	1719	.4894	.8790
95.00	.3995	.7214	.7937	94.99	.2524	3589	2.4488115	127.44	.6031	.3781	1053	5.997	1756	.4642	.8605
96.00	.3712	.6846	.7922	95.99	.2395	3781	2.4488255	127.47	.5968	.3781	1075	5.997	1793	.4405	.8427
97.00	.3453	.6501	.7911	96.99	.2274	3982	2.4488392	127.50	.5907	.3781	1099	5.997	1831	.4183	.8254
98.00	.3214	.6176	.7904	97.99	.2161	4191	2.4488524	127.53	.5847	.3781	1121	5.997	1869	.3974	.8087
99.00	.2993	.5870	.7900	98.99	.2054	4410	2.4488652	127.56	.5787	.3781	1143	5.997	1907	.3778	.7923
100.00	.2790	.5583	.7898	100.00	.1953	4637	2.4488776	127.59	.5730	.3781	1167	5.997	1945	.3593	.7765

NOTATIONS FOR TABLES I AND II

 M or M_1 local Mach number or Mach number upstream of a normal shock wave $\frac{p}{p_1}$ ratio of static pressure to total pressure $\frac{\rho}{\rho_1}$ ratio of static density to total density $\frac{T}{T_1}$ ratio of static temperature to total temperature β $\sqrt{M^2-1}$ $\frac{q}{p_1}$ ratio of dynamic pressure, $\frac{1}{2}\rho V^2$, to total pressure $\frac{A}{A_*}$ ratio of local cross-sectional area of an isentropic stream tube to cross-sectional area at the point where $M=1$ $\frac{V}{a_*}$ ratio of local speed to speed of sound at the point where $M=1$ ν Prandtl-Meyer angle (angle through which a supersonic stream is turned to expand from $M=1$ to $M>1$), deg μ Mach angle, $\sin^{-1} \frac{1}{M}$, deg M_2 Mach number downstream of a normal shock wave $\frac{p_2}{p_1}$ static pressure ratio across a normal shock wave $\frac{\rho_2}{\rho_1}$ static density ratio across a normal shock wave $\frac{T_2}{T_1}$ static temperature ratio across a normal shock wave $\frac{p_{t2}}{p_{t1}}$ total pressure ratio across a normal shock wave $\frac{p_1}{p_{t2}}$ ratio of static pressure upstream of a normal shock wave to total pressure downstream

CHARTS

The charts that follow present numerical values of certain physical quantities that are functions of two variables and hence are cumbersome to tabulate. These charts are designed to provide accuracy to three significant figures.

Charts 1 through 8 and chart 25 are for a perfect gas. The values presented in charts 1 through 4 and chart 25 were calculated for a ratio of specific heats of 7/5. The values presented in charts 5 through 8 were taken from references 6 and 14 and are for a ratio of specific heats of 1.405.

Charts 9 through 24 provide correction factors to account for the effects of caloric imperfections on the quantities tabulated in tables I and II and plotted in charts 2, 3, and 4.

On many charts, points corresponding to static temperatures of 5000° R and 100° R (−360° F) have been indicated. These temperatures represent very approximately the limits of validity of the charts. Exact limits cannot be stated simply as they depend on pressure as well as temperature. At temperatures near 5000° R dissociation effects, which were neglected in the calculations, can be significant at high altitudes though perhaps not at sea level. At temperatures less than about 100° R, air may condense at the pressures encountered in many wind tunnels.

On the Reynolds number chart (chart 25), points corresponding to a static temperature of 180° R (−280° F) also are indicated since this is the lowest temperature for which experimental viscosity data have been obtained. At temperatures much lower than −280° F, Sutherland's equation (A2) may significantly underestimate the true viscosity.

The contents of the charts are as follows:

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4. Variation of Mach number downstream of a shock wave with flow-deflection angle for various upstream Mach numbers. Perfect gas, $\gamma=7/5$	46
5. Variation of shock-wave angle with cone semivertex angle for various upstream Mach numbers. Perfect gas, $\gamma=1.405$	48

Chart

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7. Variation of Mach number at the surface of a cone with cone semivertex angle for various upstream Mach numbers. Perfect gas, $\gamma=1.405$	52
8. Variation of the initial slope of the normal-force curve with upstream Mach number for various cone semivertex angles. Perfect gas, $\gamma=1.405$	54
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25. Variation of Reynolds number per unit length with Mach number for various total temperatures. Perfect gas, $\gamma=7/5$	61

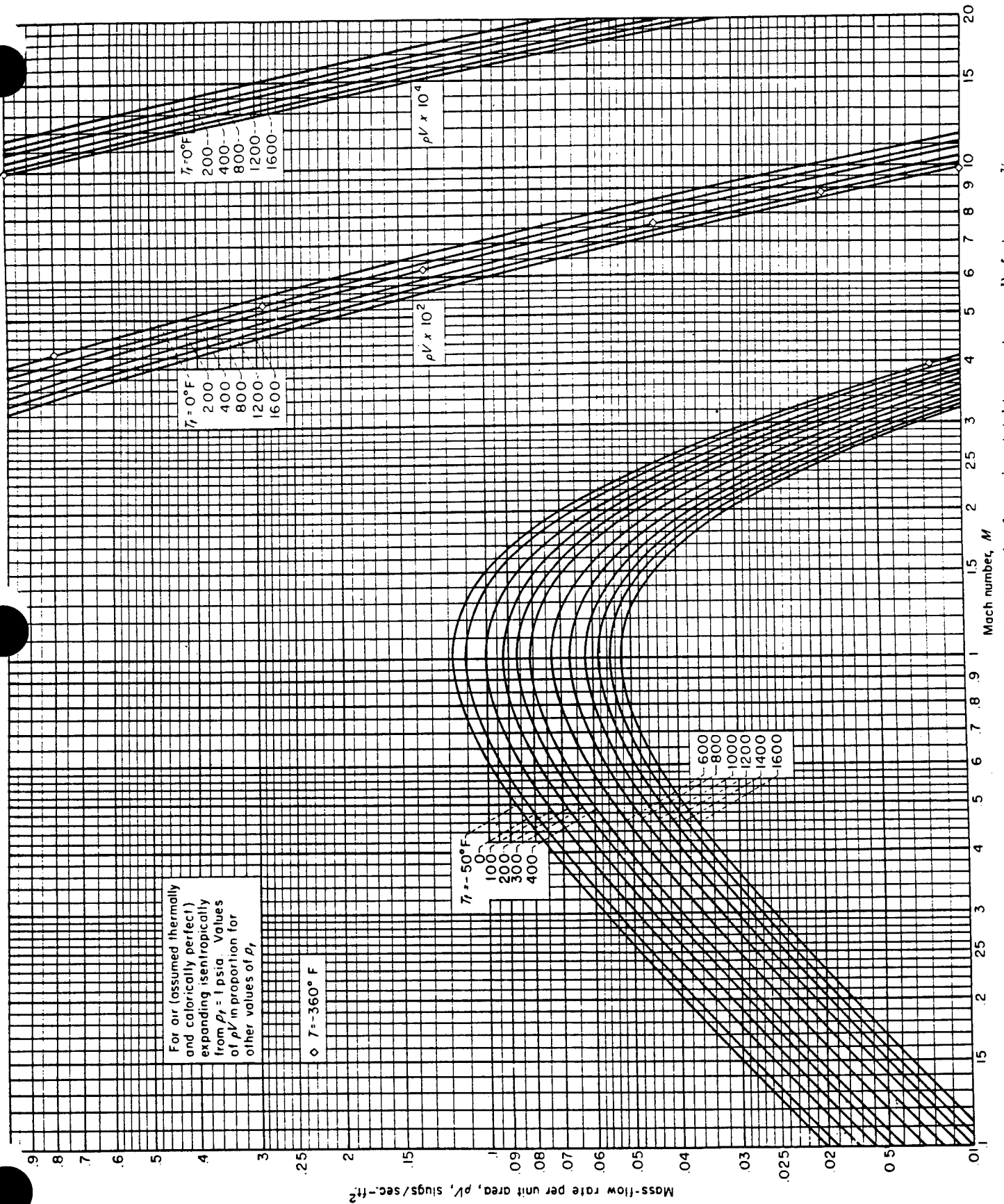


CHART 1.—Variation of mass-flow rate per unit area with Mach number for various total temperatures. Perfect gas, $\gamma = 1.4$.

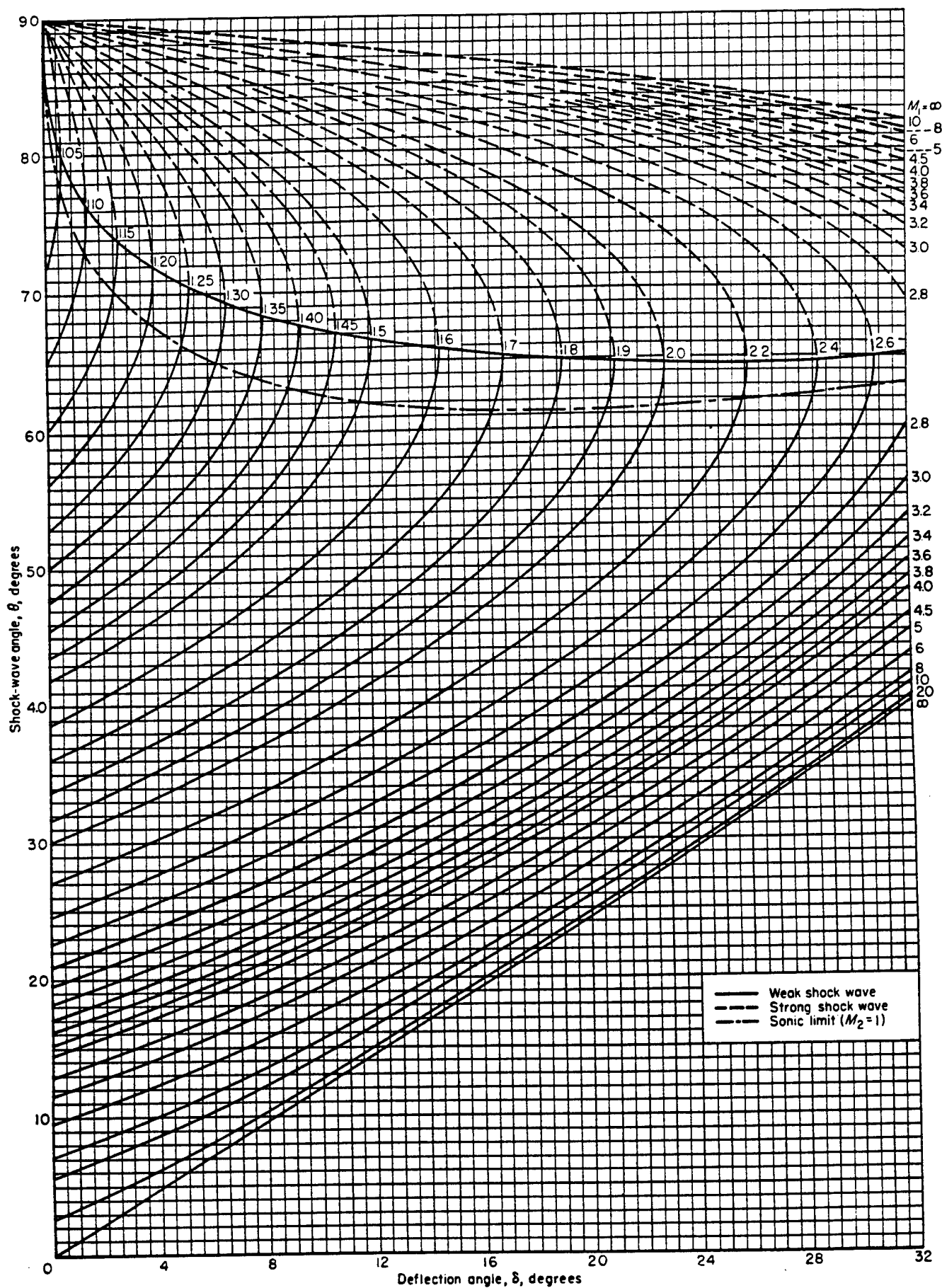
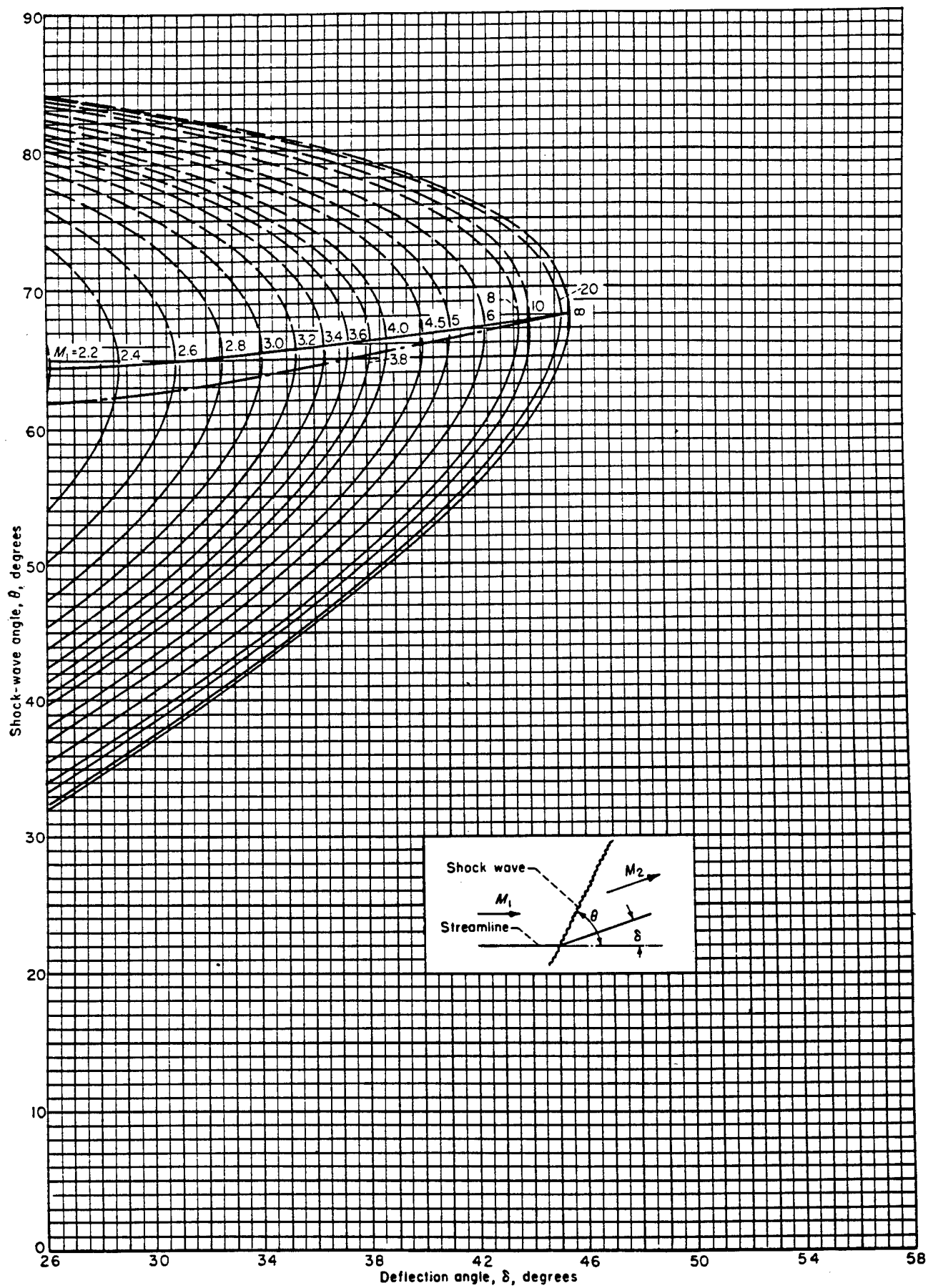


CHART 2.—Variation of shock-wave angle with flow-deflection angle for various upstream Mach numbers. Perfect gas, $\gamma = \frac{7}{5}$.



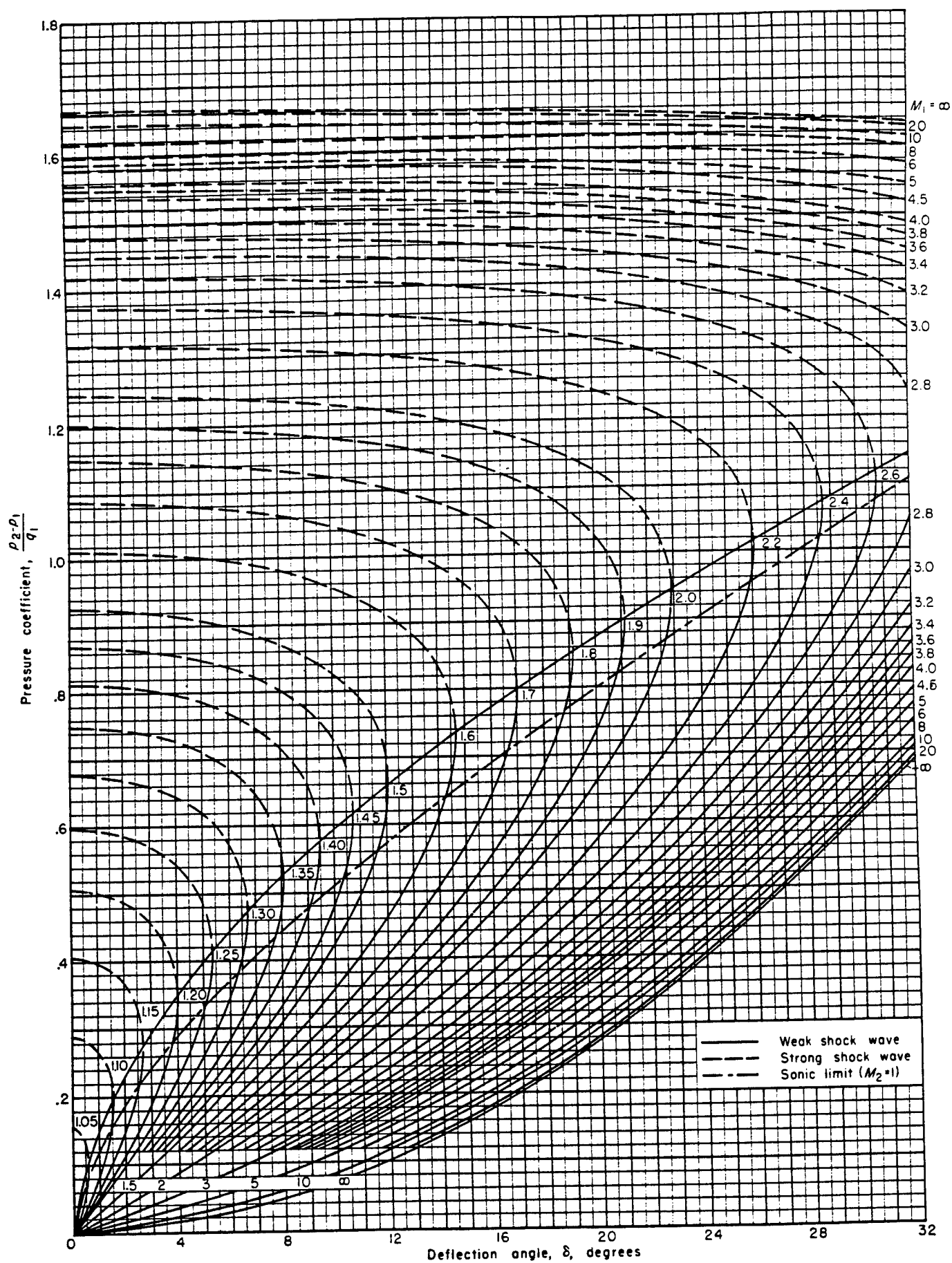
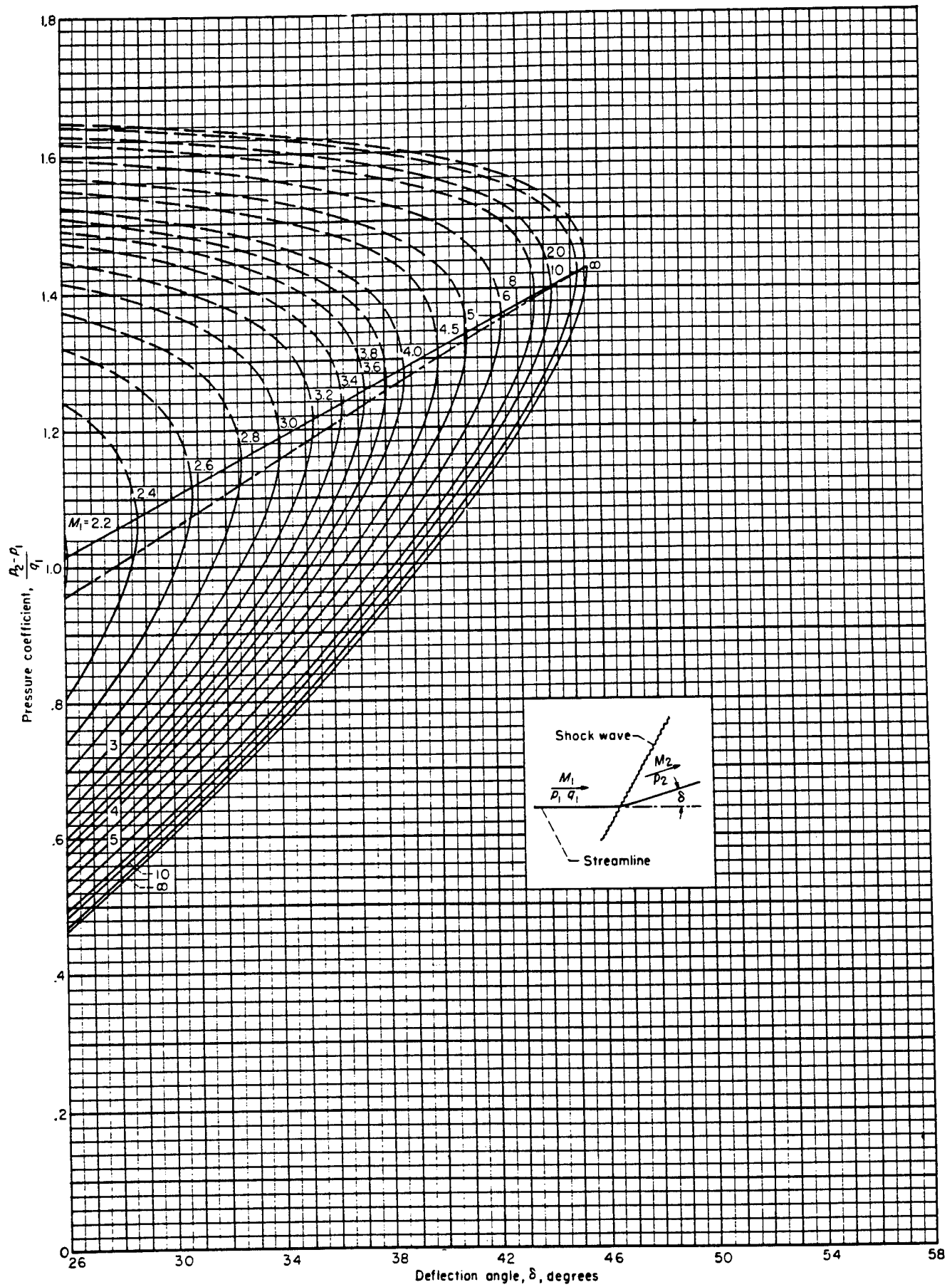


CHART 3.—Variation of pressure coefficient across shock waves with flow-deflection angle for various upstream Mach numbers. Perfect gas, $\gamma = 1.4$.



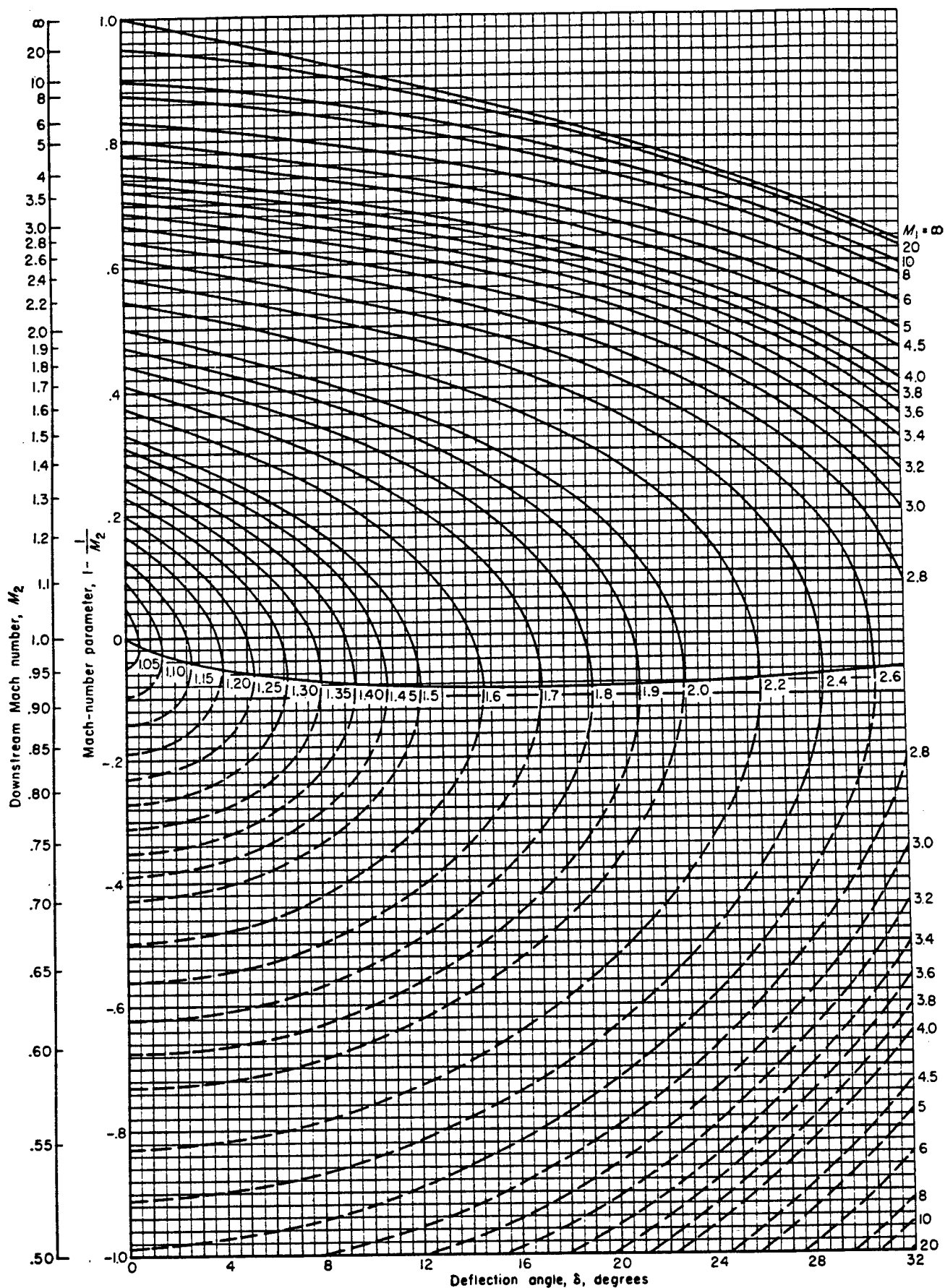


CHART 4.—Variation of Mach number downstream of a shock wave with flow-deflection angle for various upstream Mach numbers. Perfect gas $\gamma = \frac{7}{5}$.

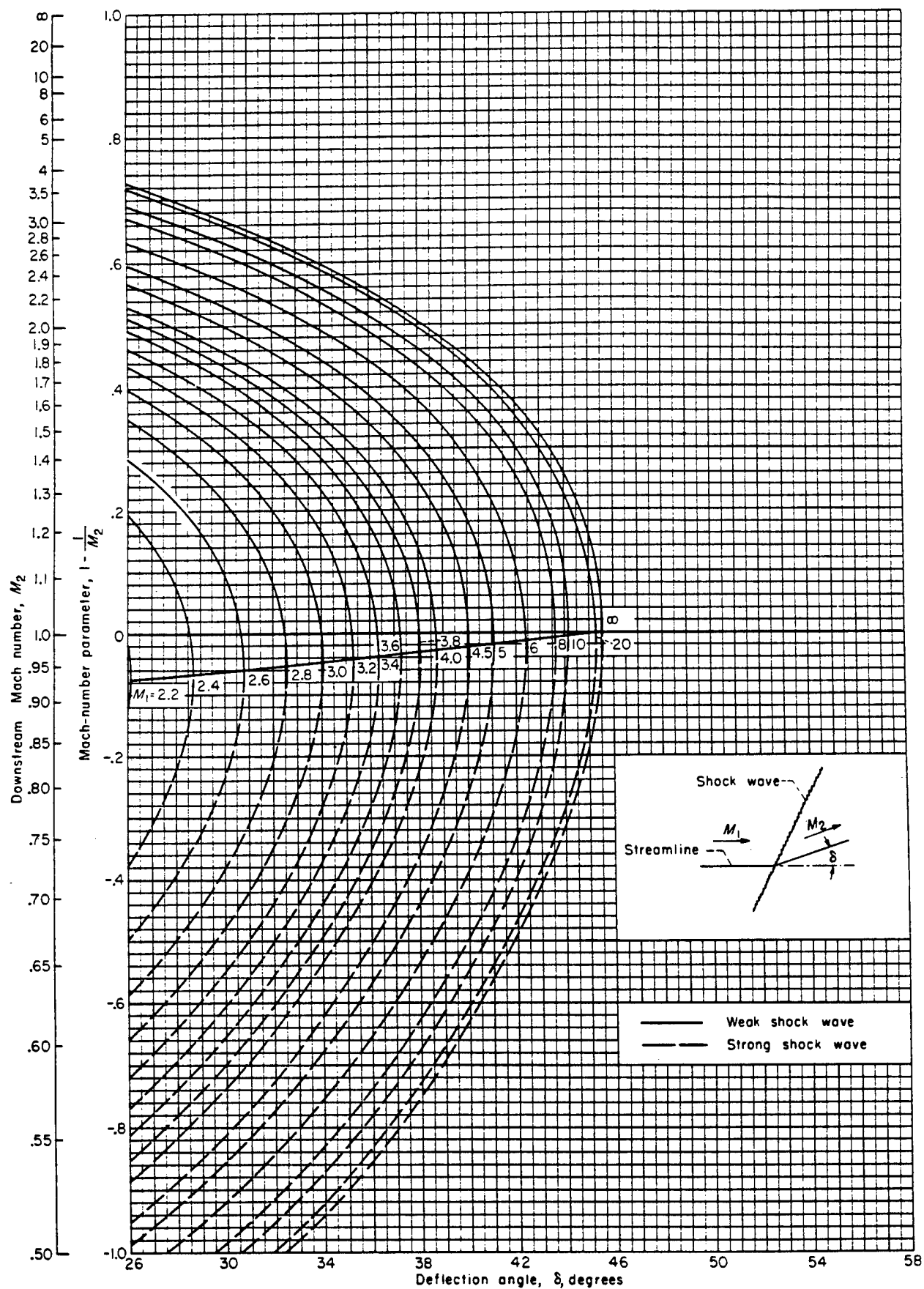


CHART 4.—Concluded

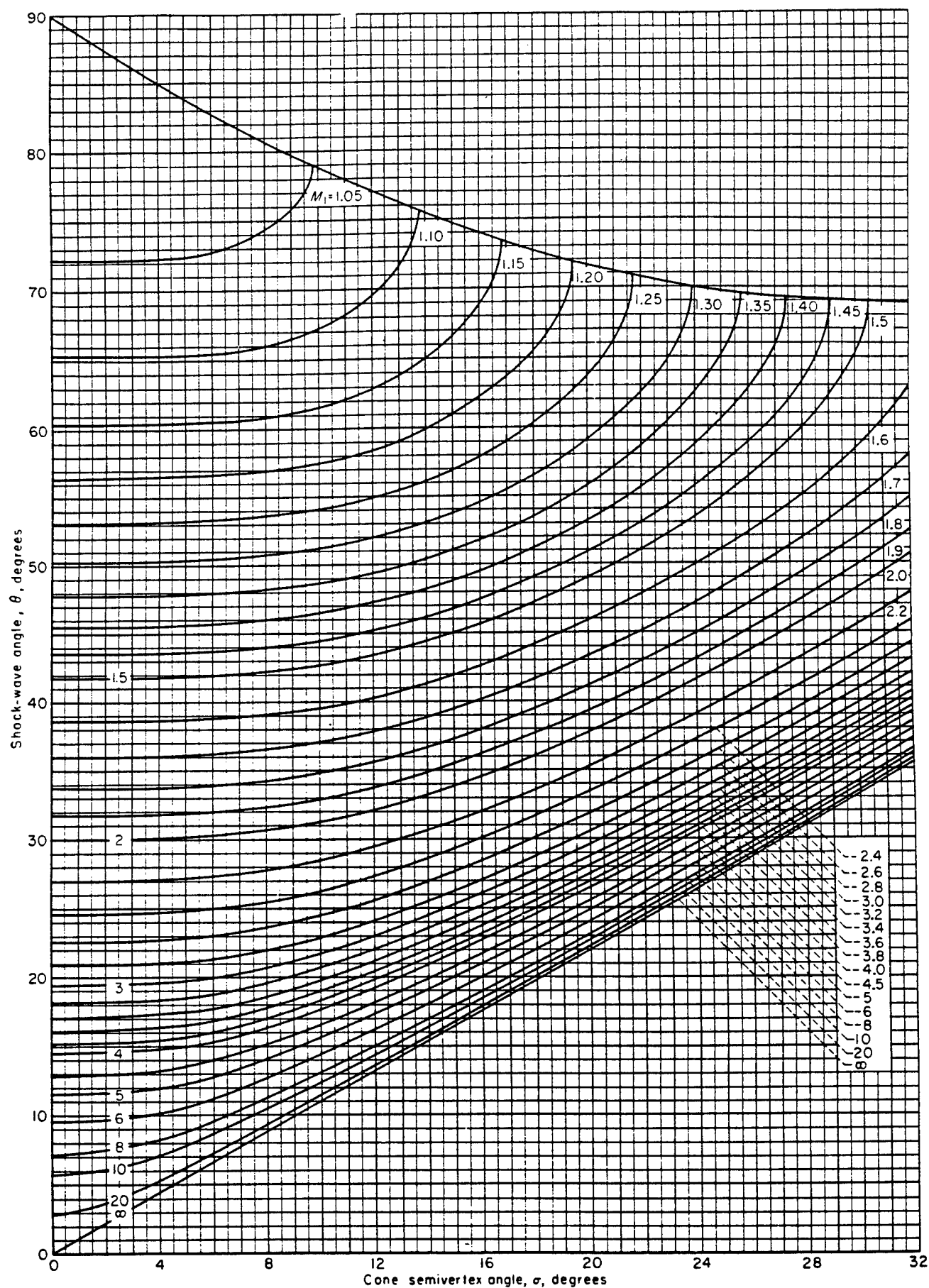


CHART 5.—Variation of shock-wave angle with cone semivertex angle for various upstream Mach numbers. Perfect gas, $\gamma=1.405$.

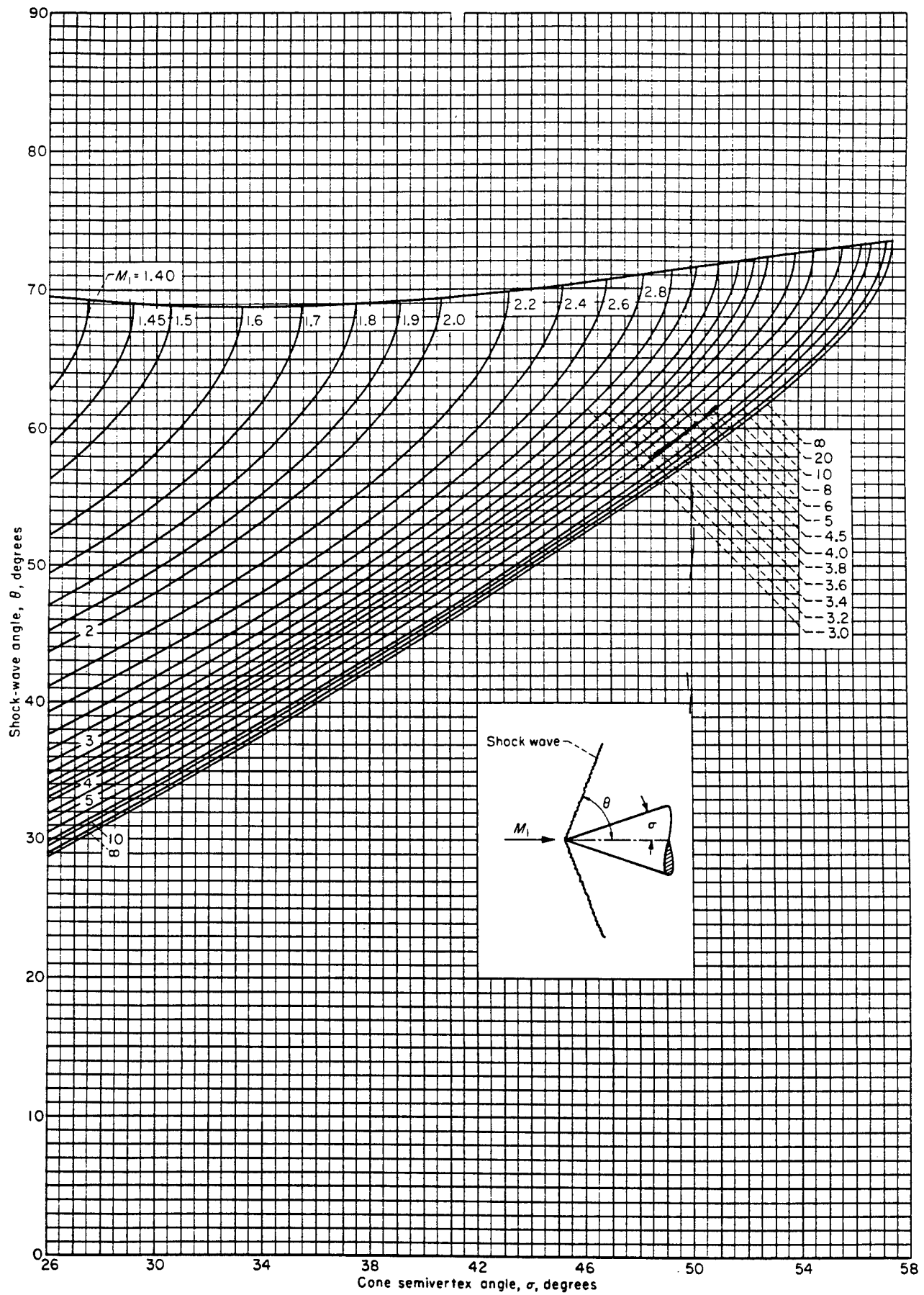


CHART 5.—Concluded

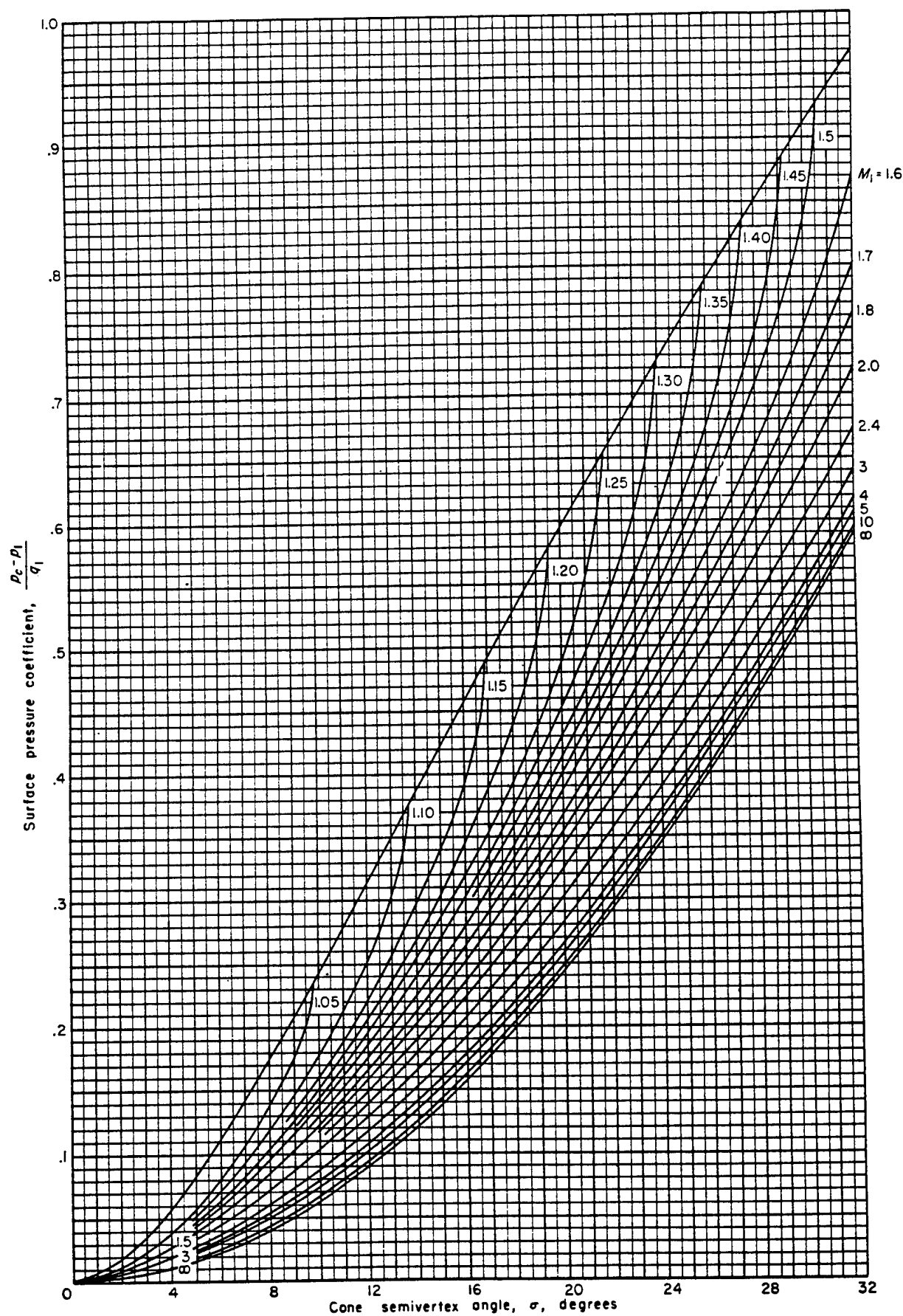
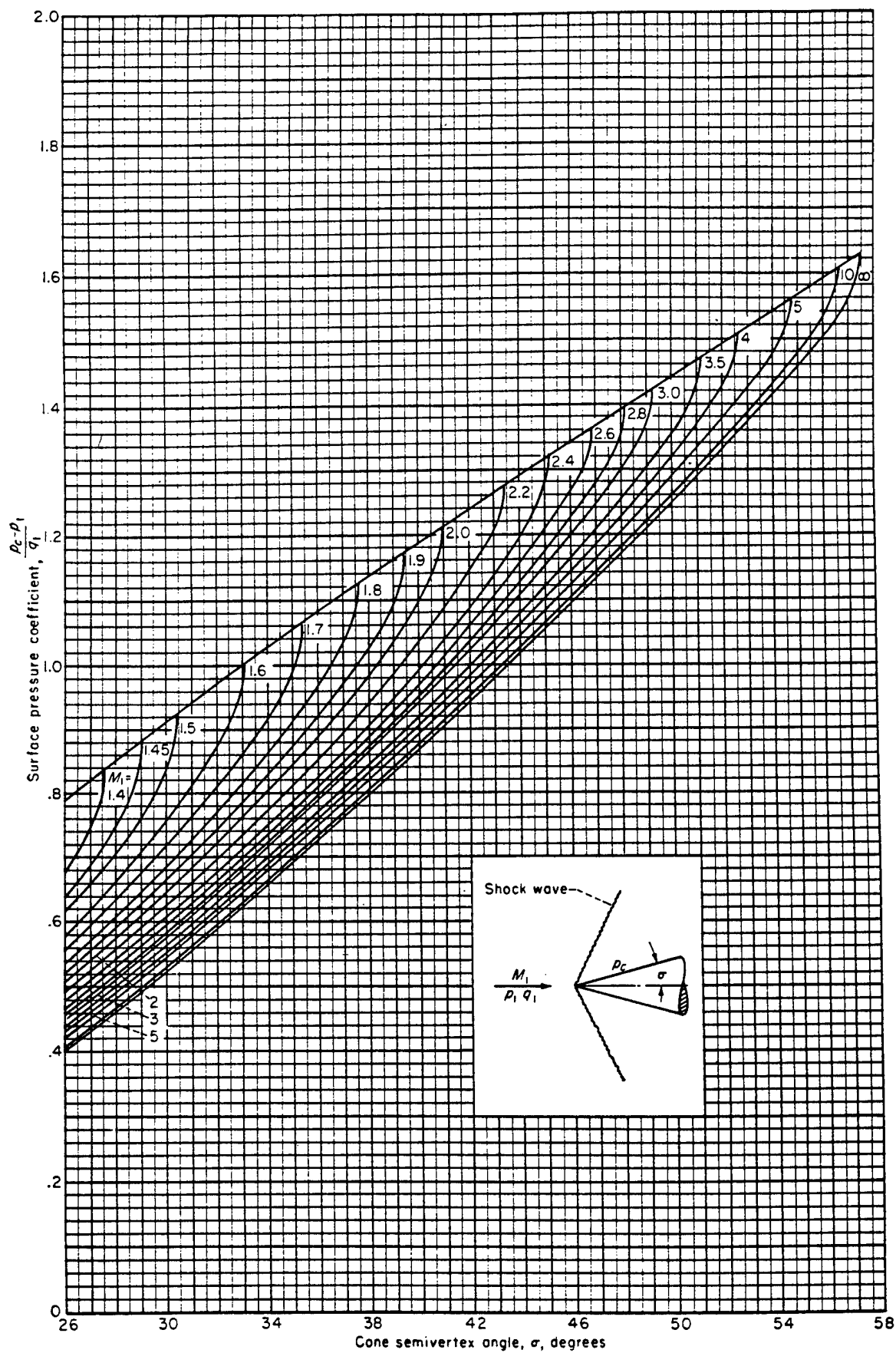


CHART 6.—Variation of surface pressure coefficient with cone semivertex angle for various upstream Mach numbers. Perfect gas, $\gamma = 1.405$.



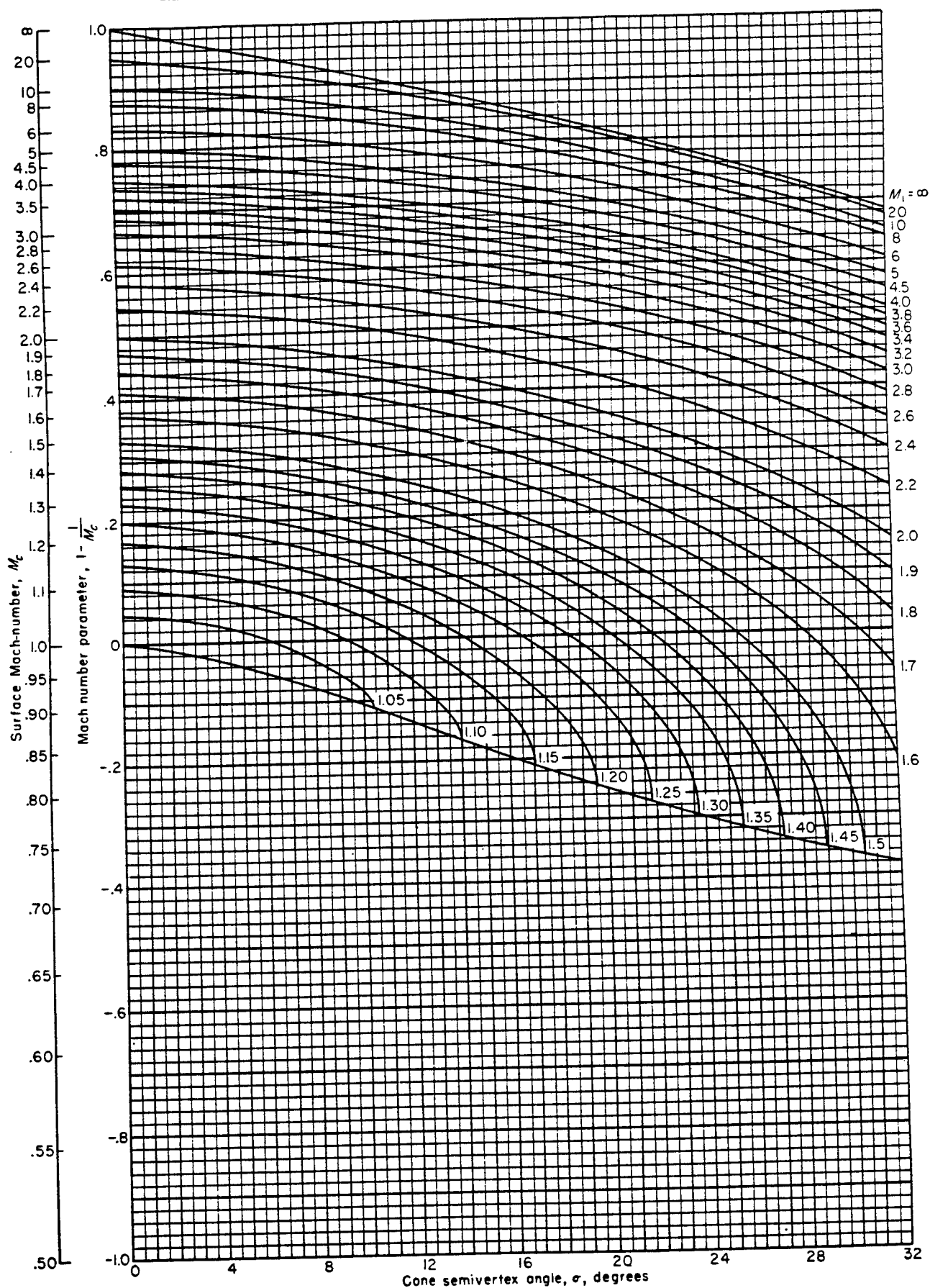


CHART 7.—Variation of Mach number at the surface of a cone with cone semivertex angle for various upstream Mach numbers. Perfect gas, $\gamma = 1.405$.

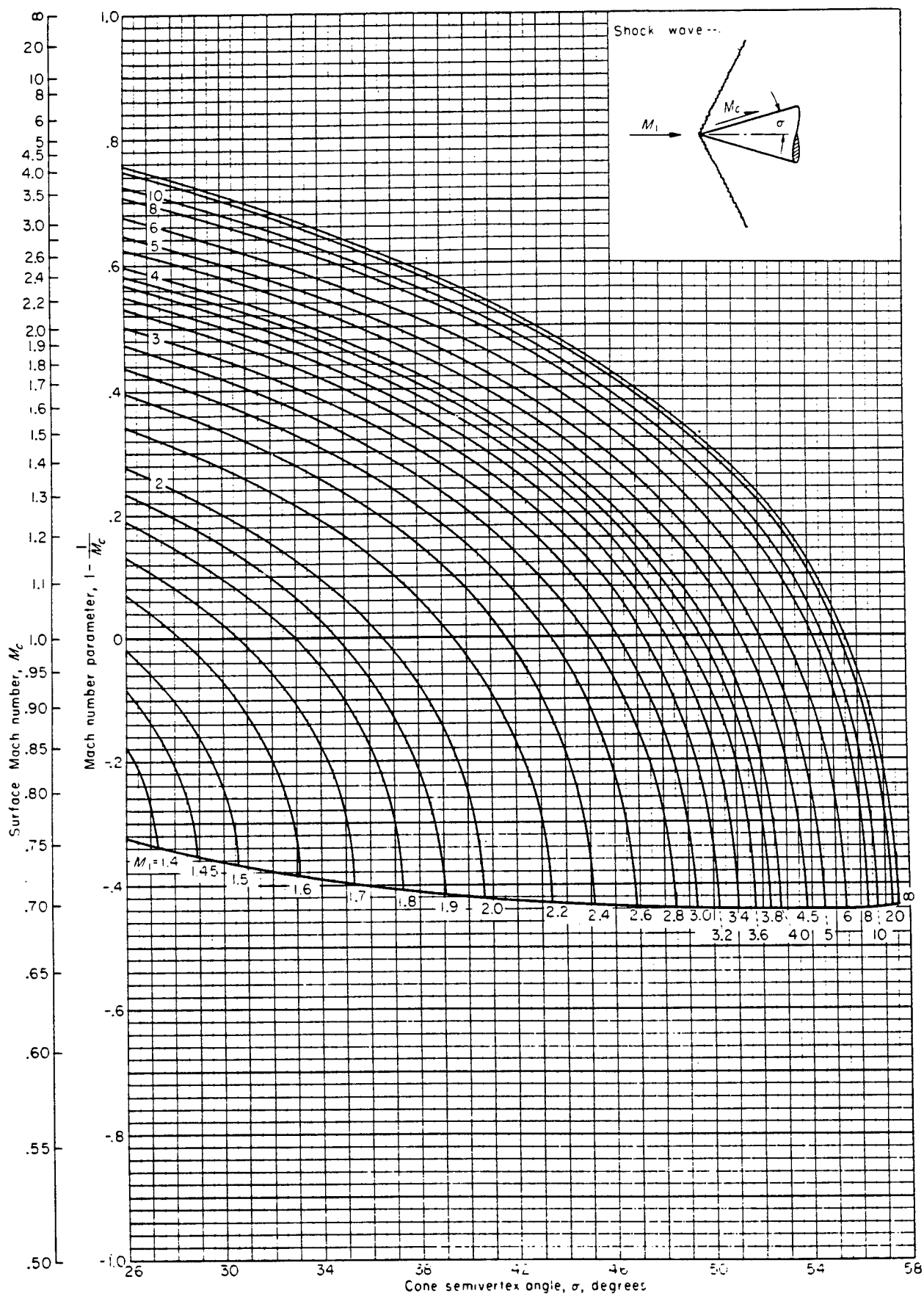


CHART 7.—Concluded

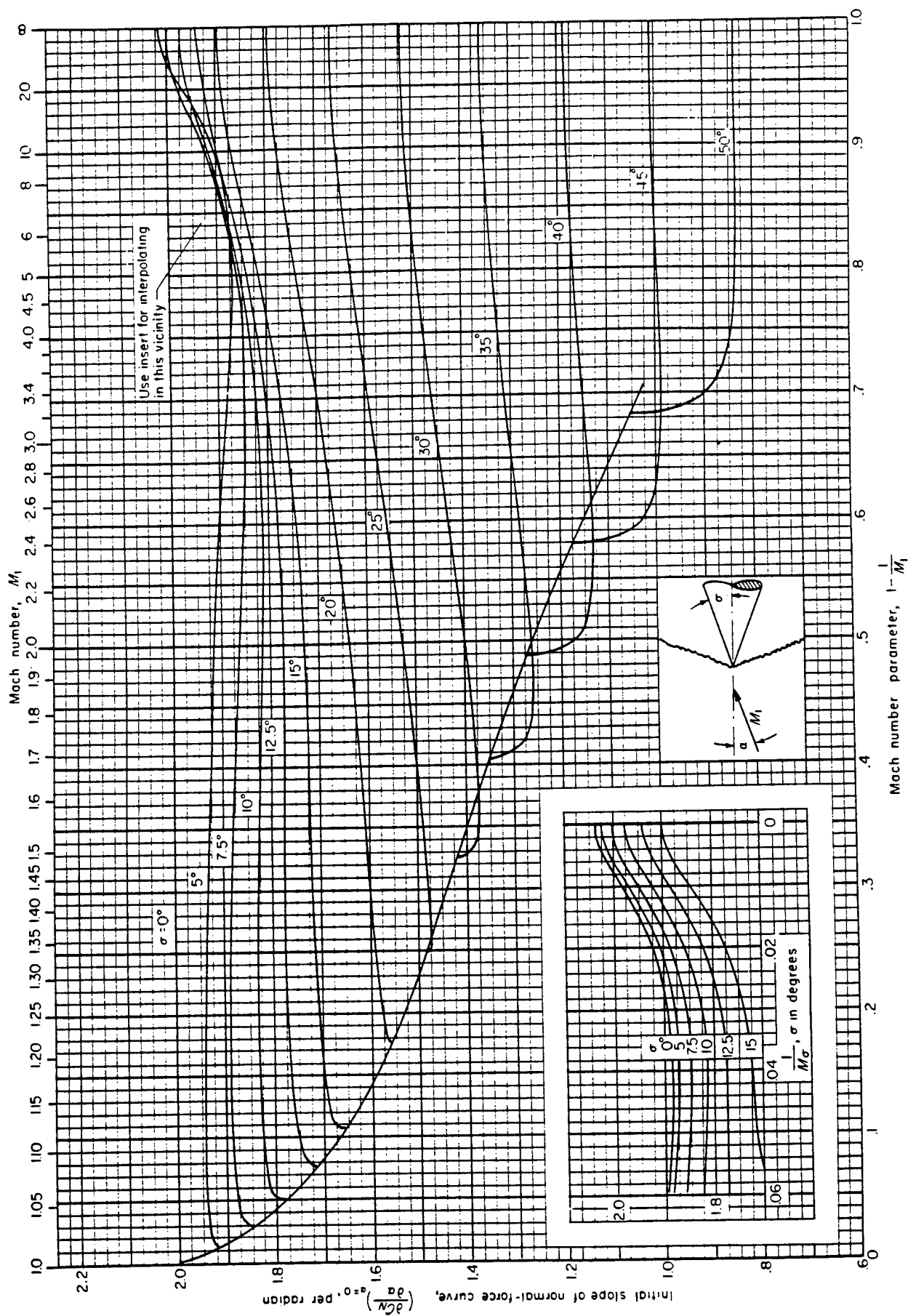


CHART 8.—Variation of the initial slope of the normal-force curve with upstream Mach number for various cone semivertex angles. Perfect gas, $\gamma = 1.405$.

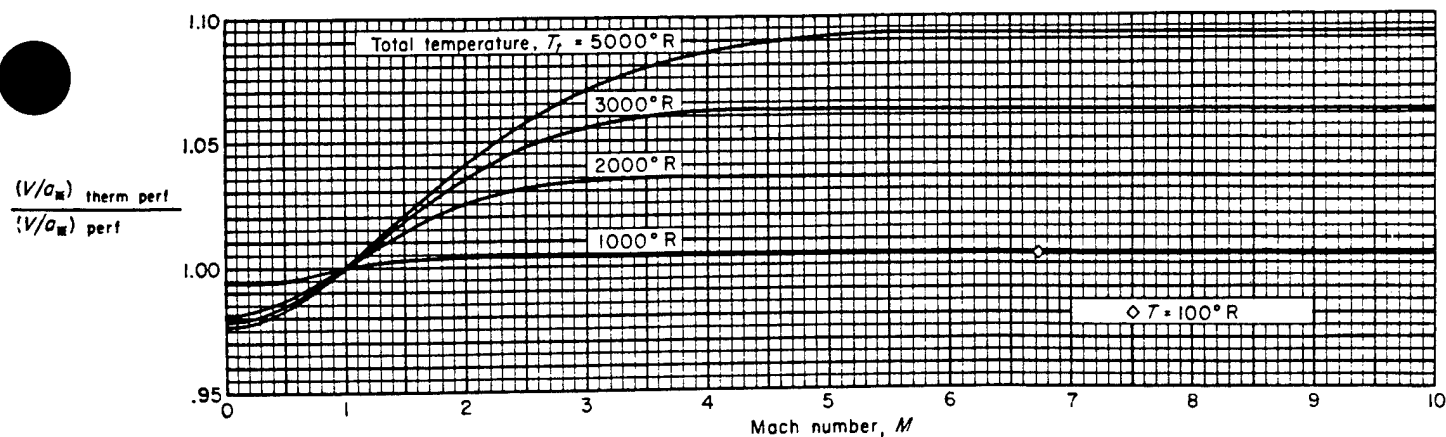


CHART 9.—Effect of caloric imperfections on the ratio of local speed to speed of sound at the point where $M=1$.

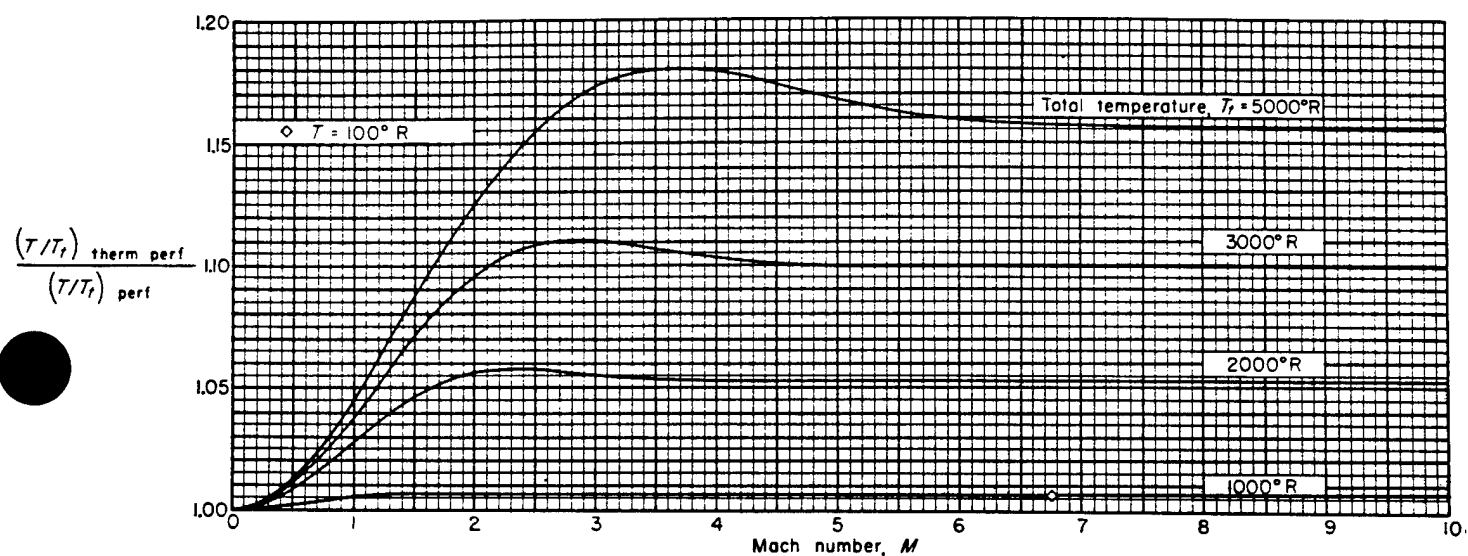


CHART 10.—Effect of caloric imperfections on the ratio of static temperature to total temperature.

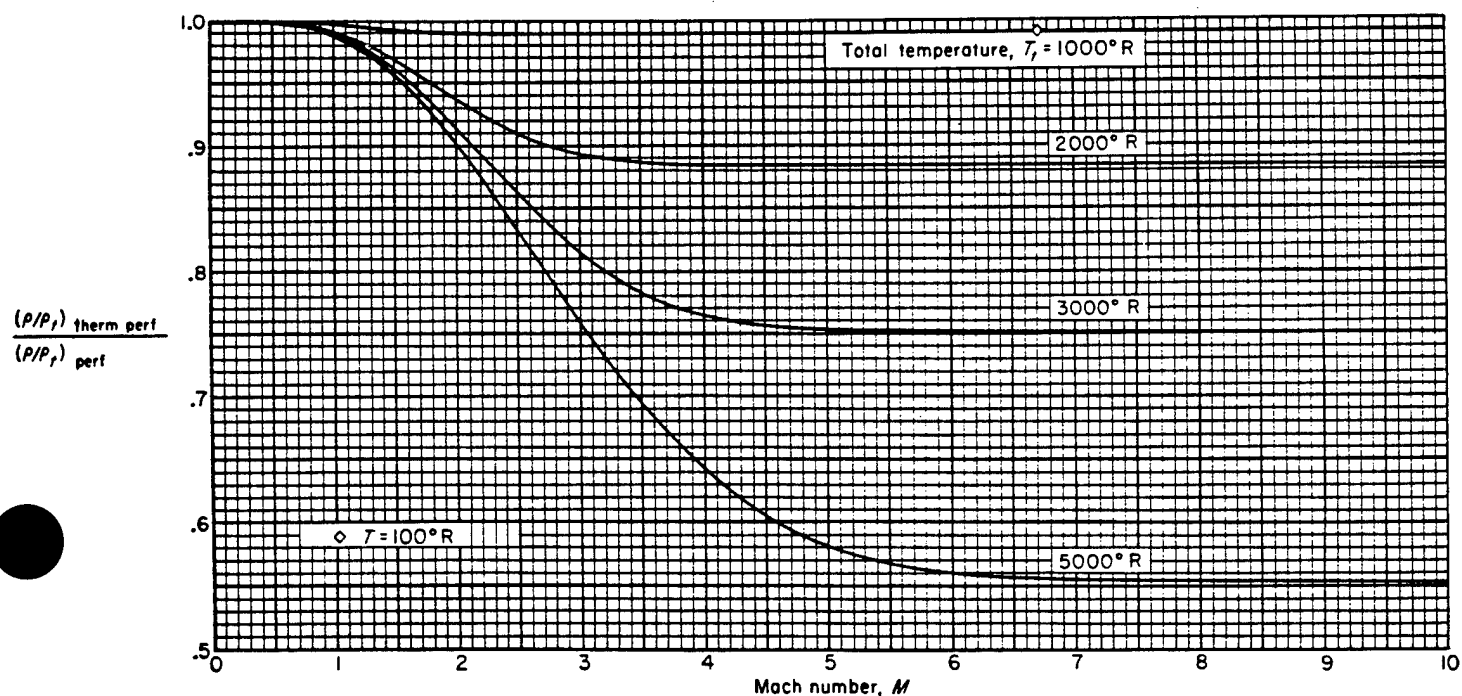


CHART 11.—Effect of caloric imperfections on the ratio of static density to total density.

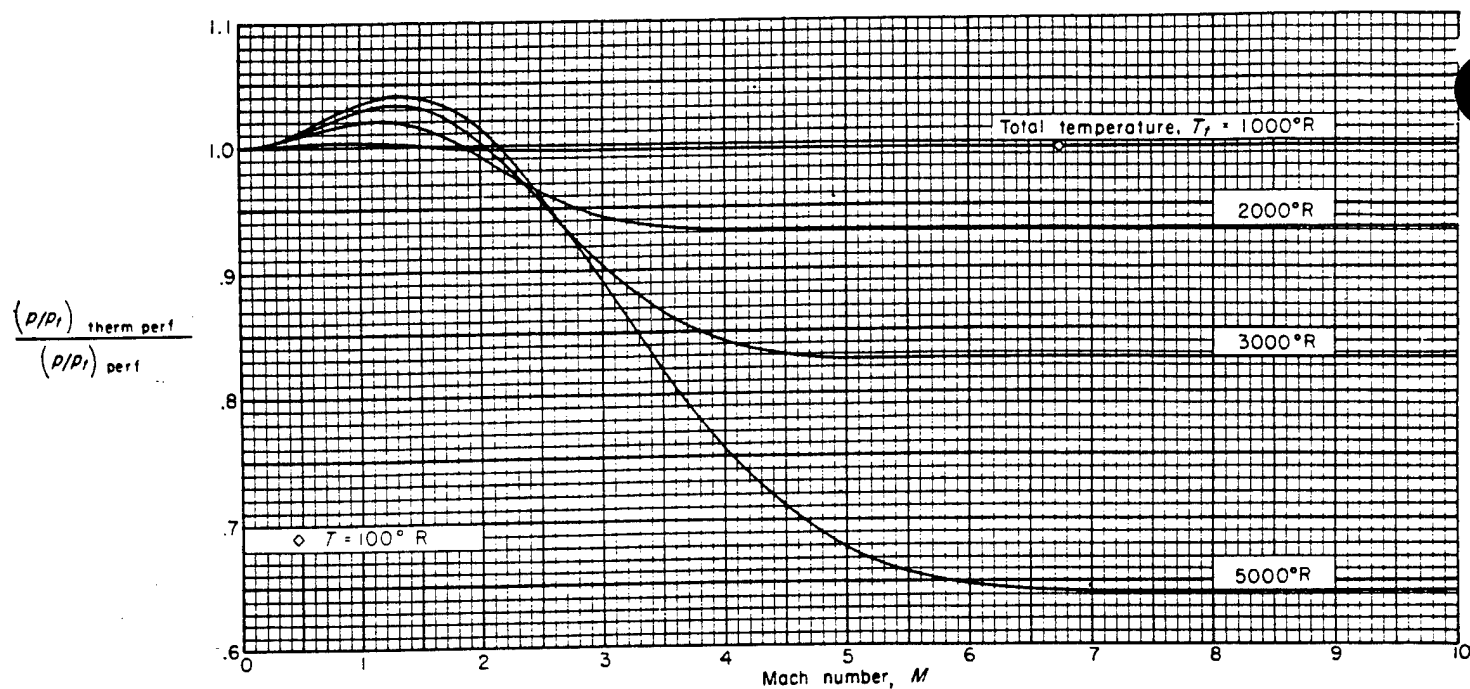


CHART 12.—Effect of caloric imperfections on the ratio of static pressure to total pressure.

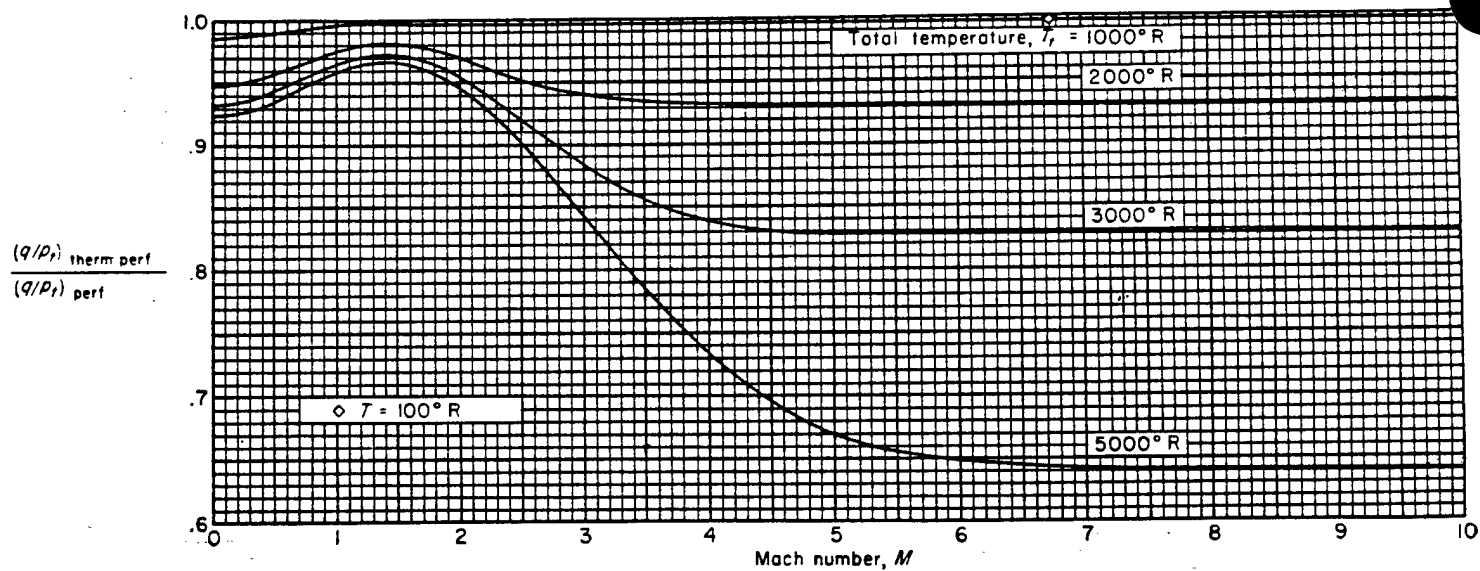


CHART 13.—Effect of caloric imperfections on the ratio of dynamic pressure to total pressure.

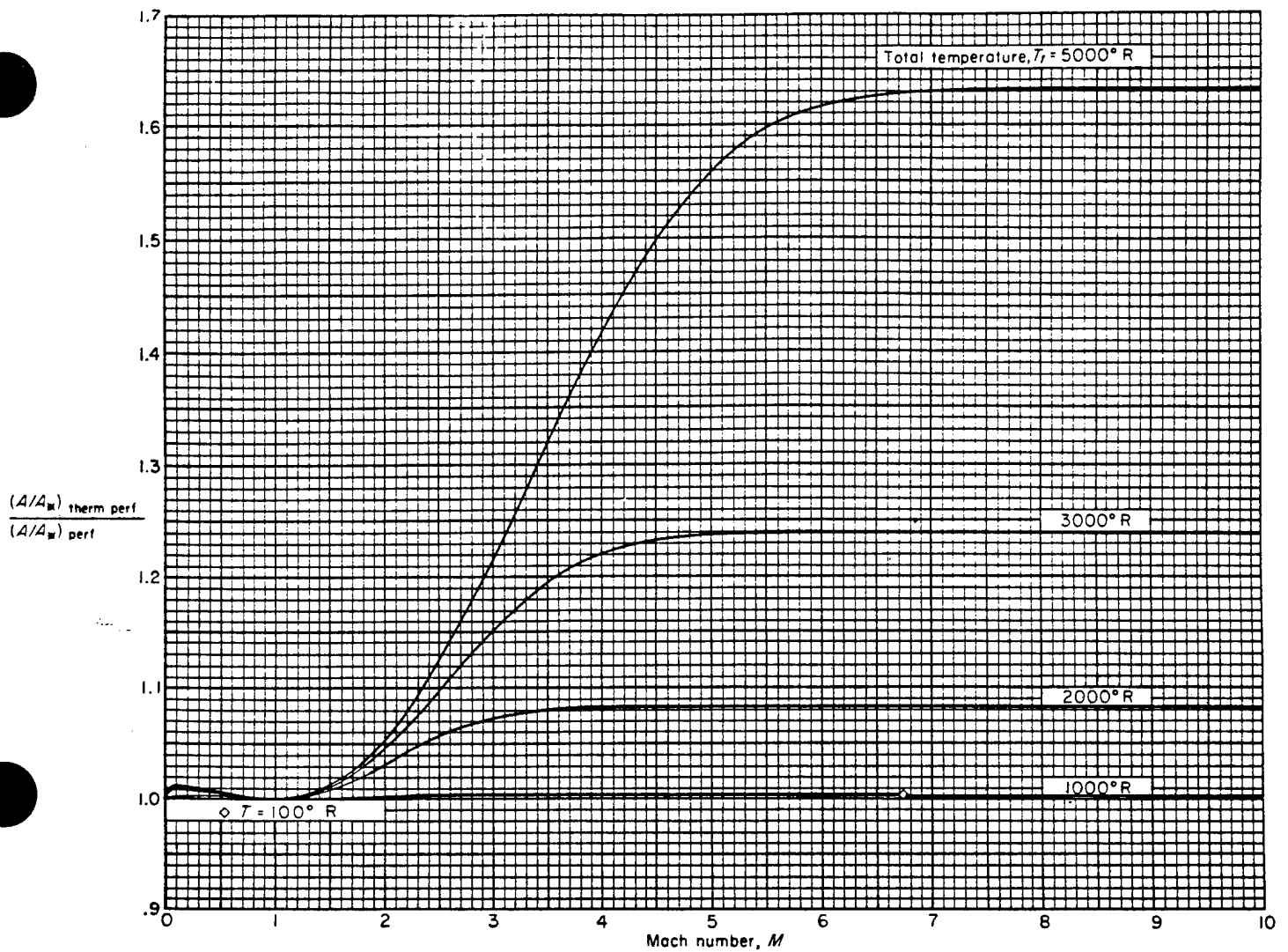


CHART 14.—Effect of caloric imperfections on the ratio of local cross-sectional area of a stream tube to the cross-sectional area at the point where $M=1$.

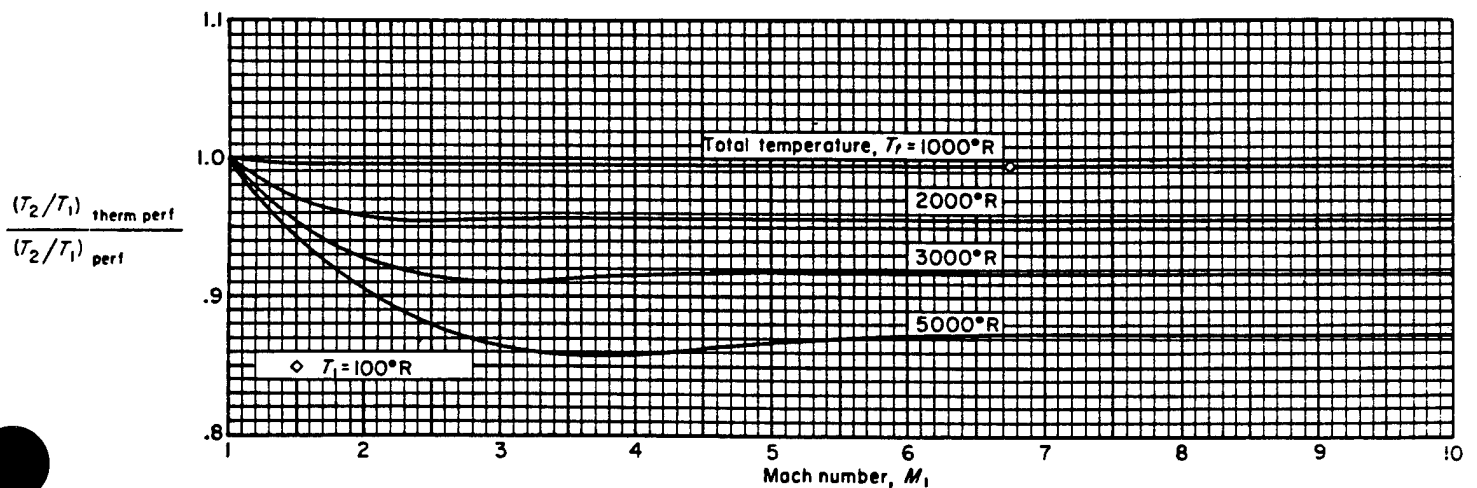


CHART 15.—Effect of caloric imperfections on the static-temperature ratio across a normal shock wave.

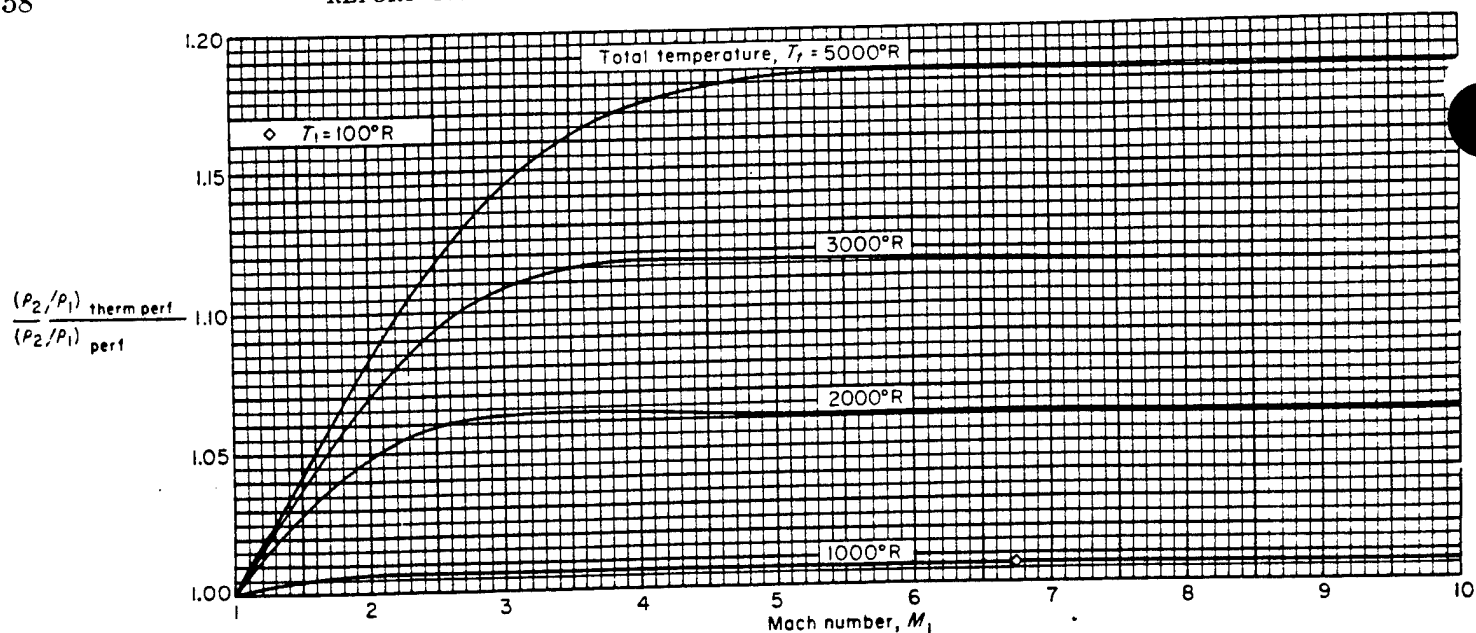


CHART 16.—Effect of caloric imperfections on the static-density ratio across a normal shock wave.

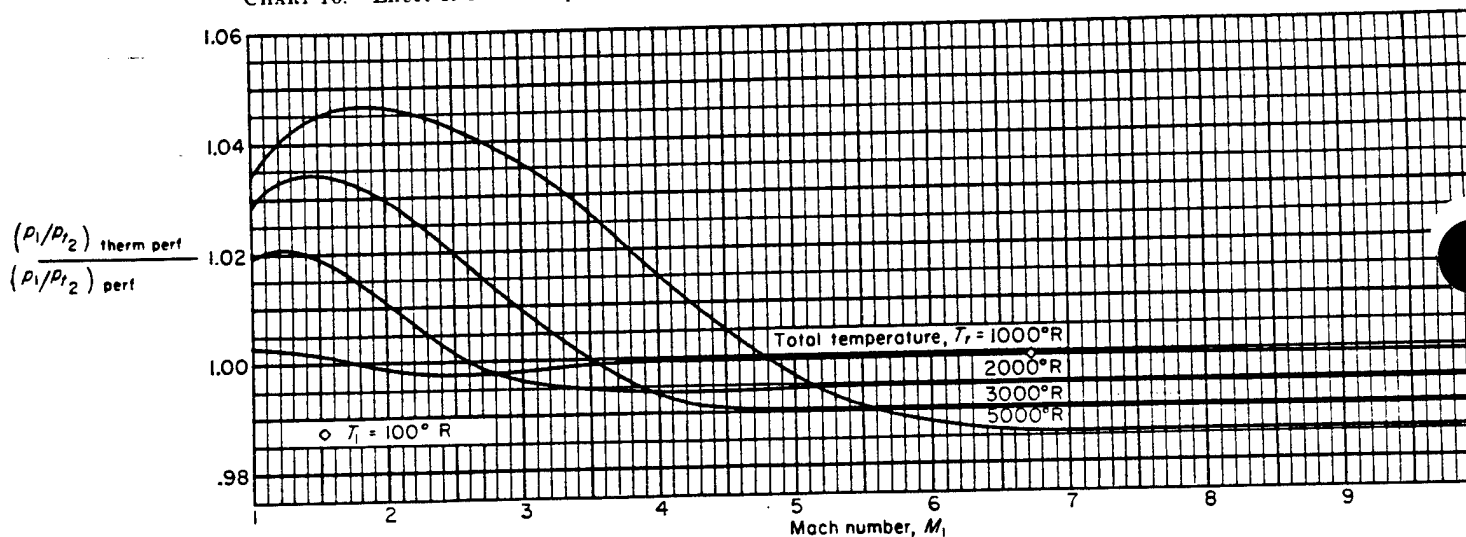


CHART 17.—Effect of caloric imperfections on the ratio of static pressure upstream of a normal shock wave to total pressure downstream.

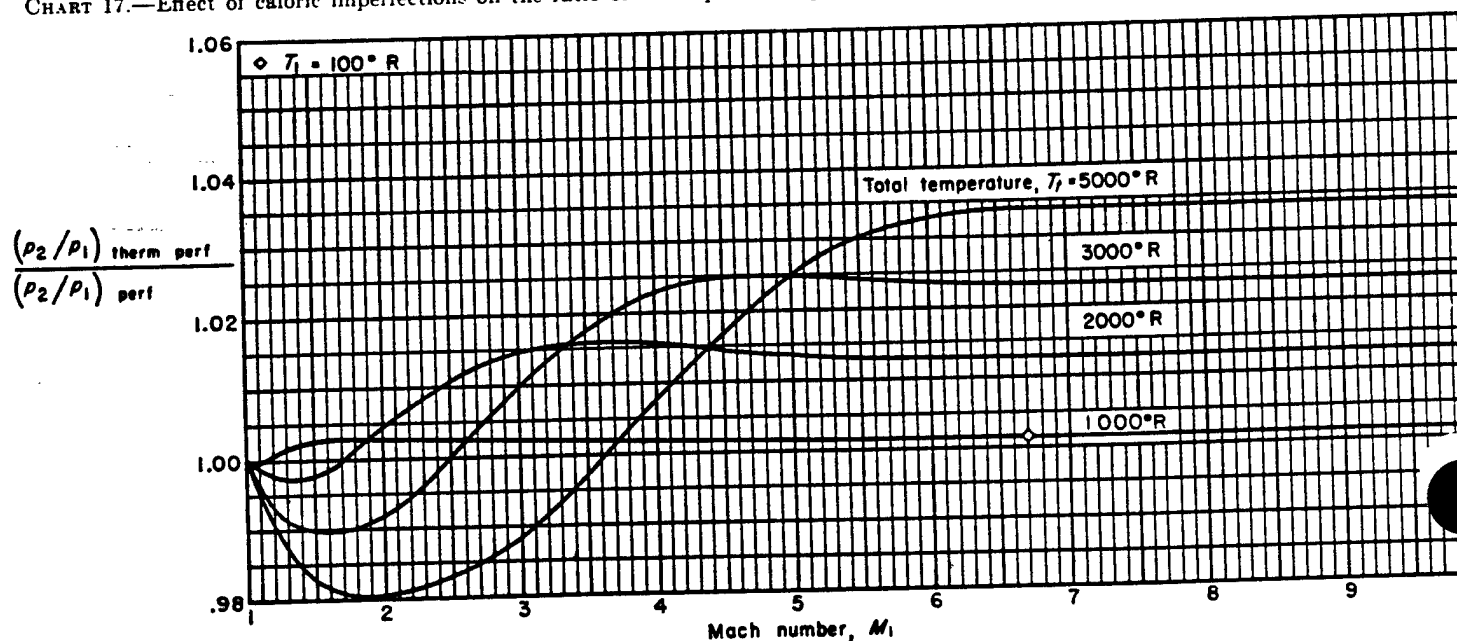


CHART 18.—Effect of caloric imperfections on the static-pressure ratio across a normal shock wave.

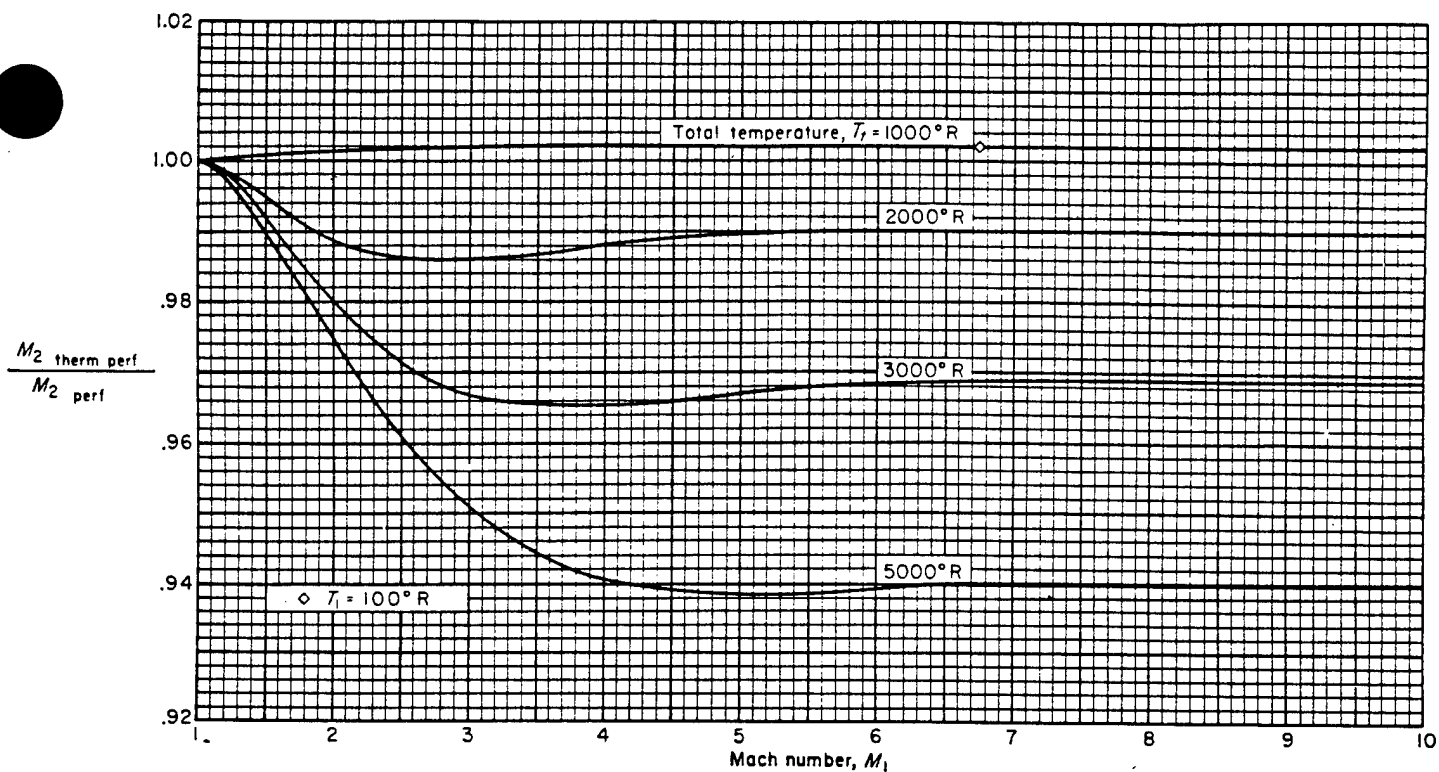


CHART 19.—Effect of caloric imperfections on the Mach number downstream of a normal shock wave.

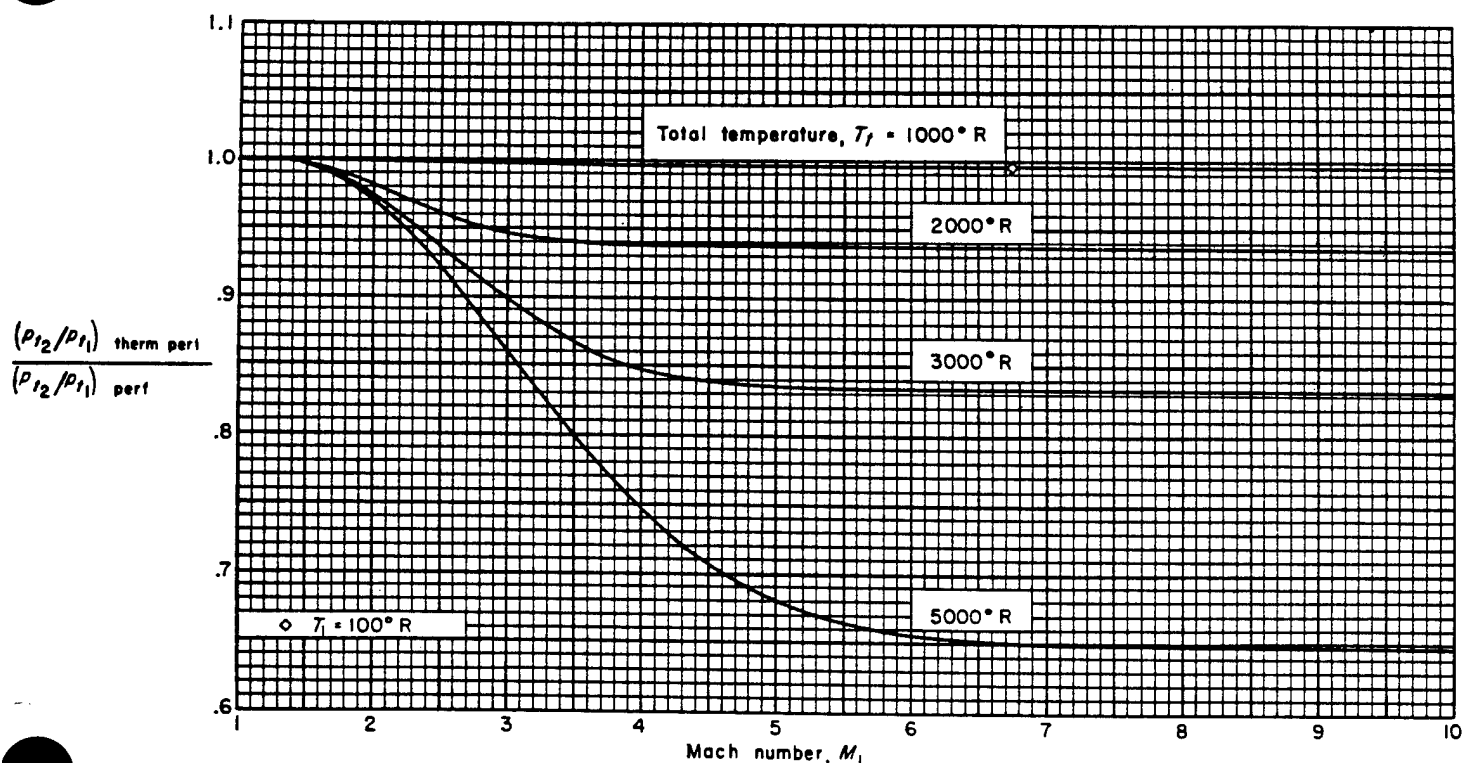


CHART 20.—Effect of caloric imperfections on the total-pressure ratio across a normal shock wave.

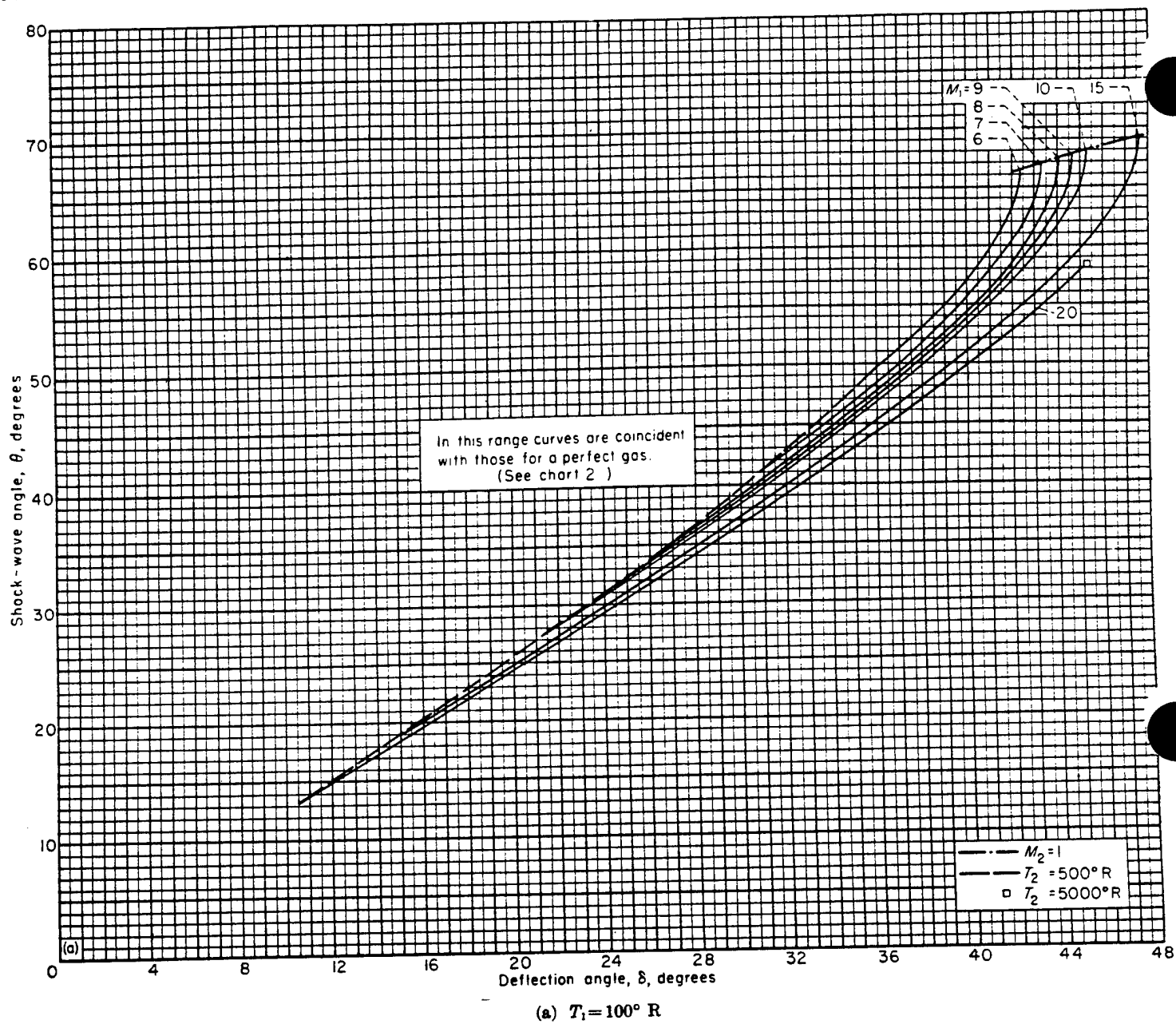


CHART 21.—Effect of caloric imperfections on the variation with flow-deflection angle of the shock-wave angle for a weak oblique shock wave

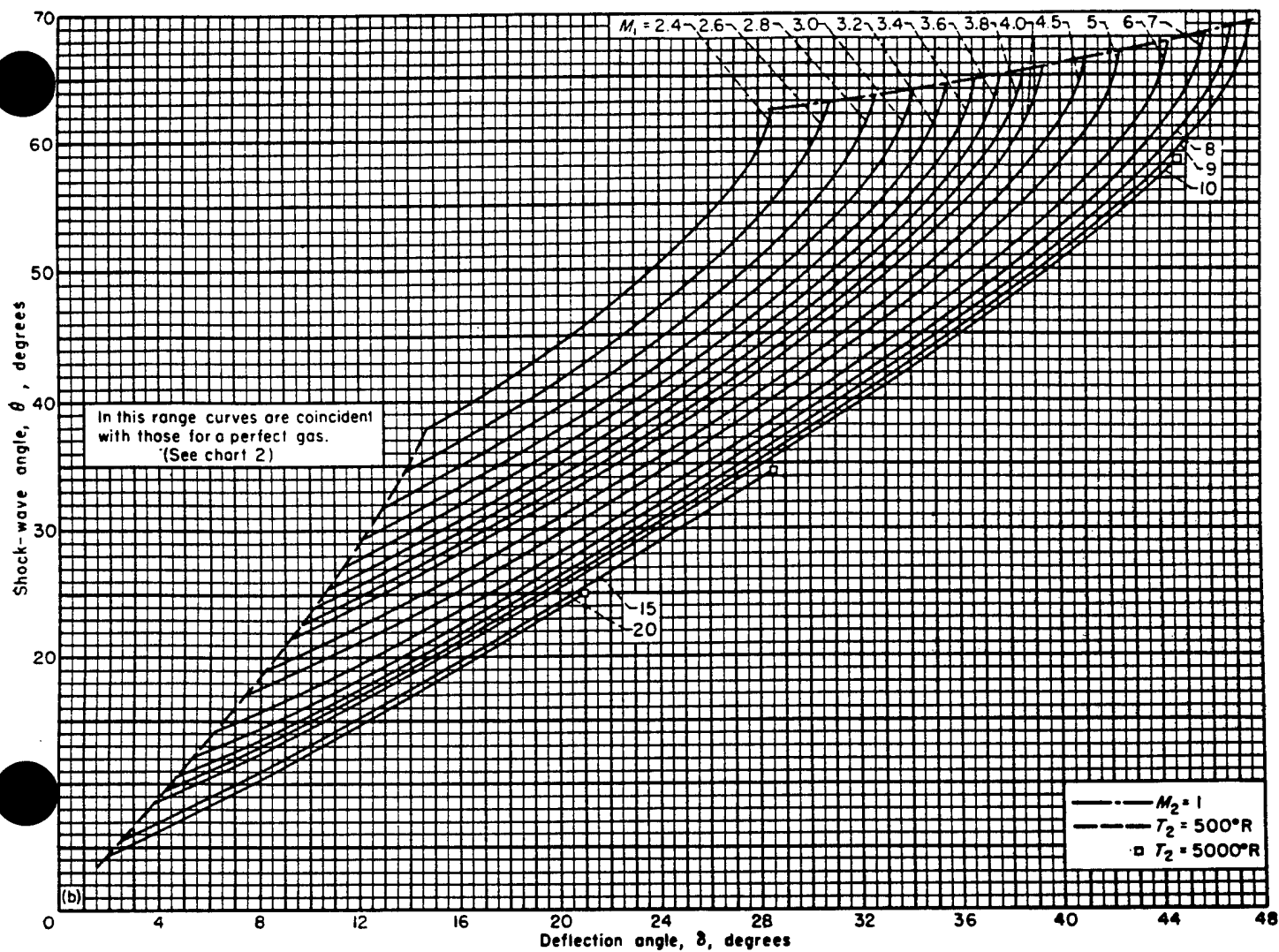
(b) $T_1 = 390^\circ R$

CHART 21.—Continued

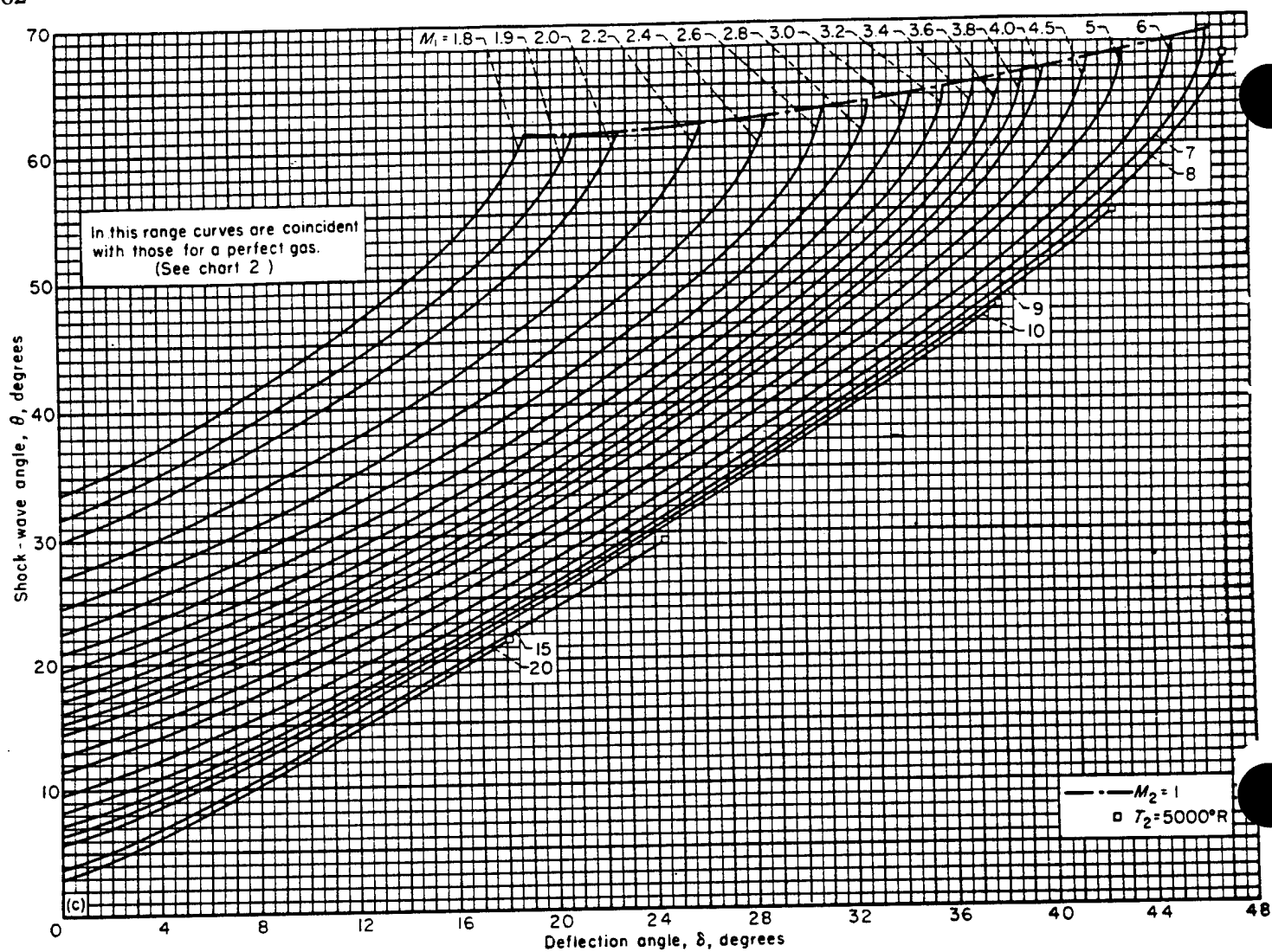
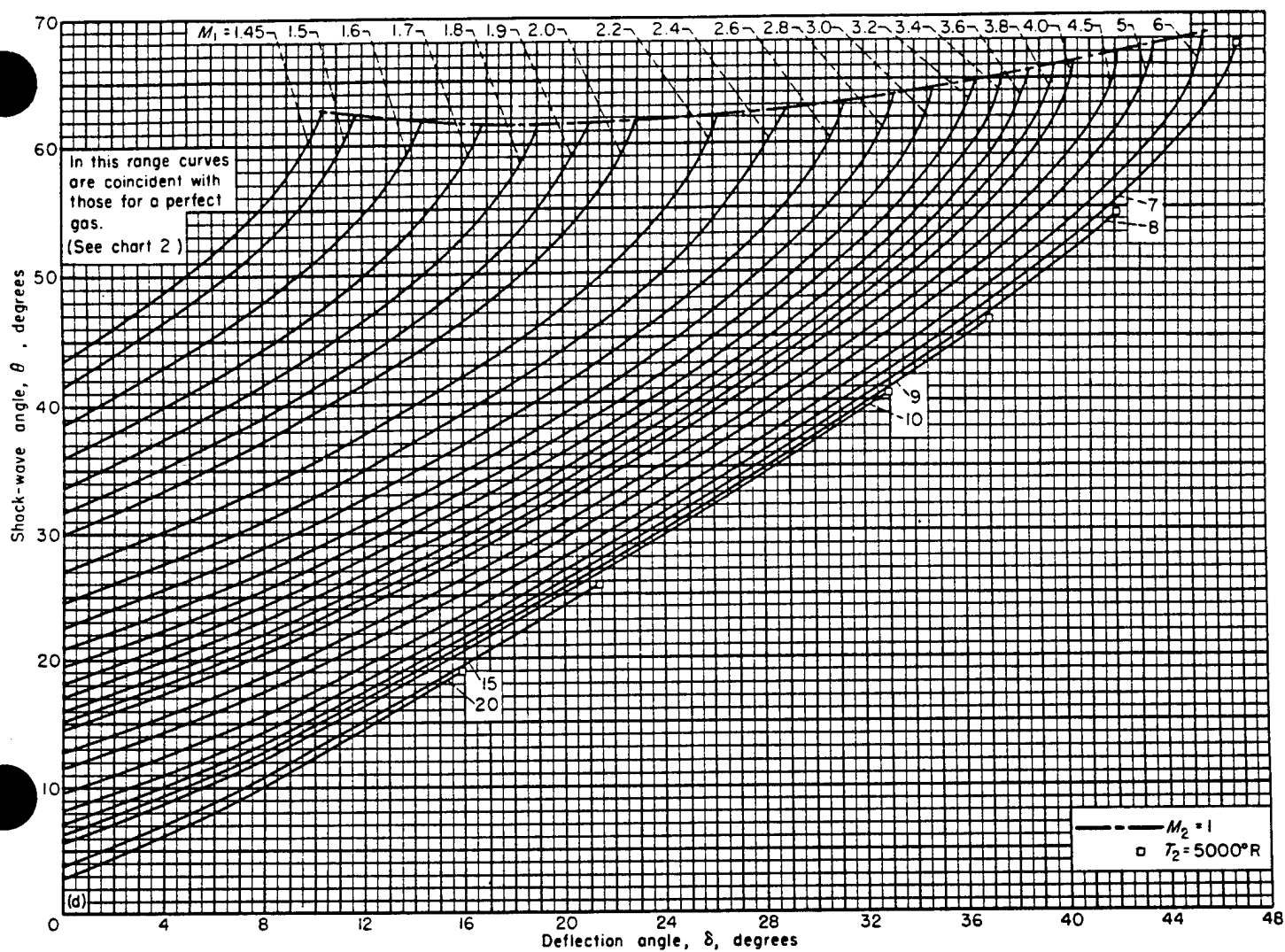
(c) $T_1 = 500^\circ R$

CHART 21.—Continued



(d) $T_1 = 630^\circ\text{R}$
 CHART 21.—Concluded

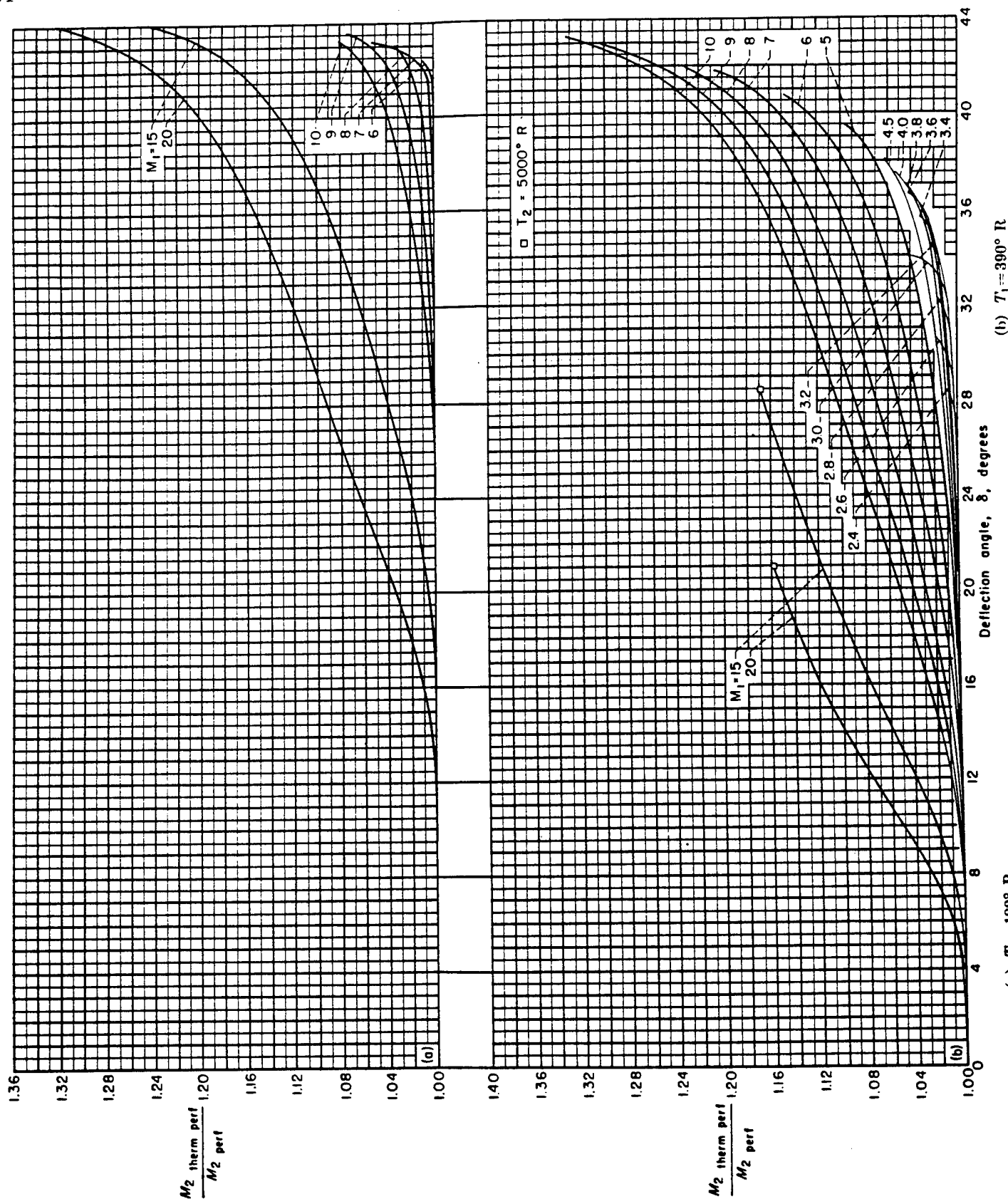


CHART 22.—Effect of calorific imperfections on the variation of Mach number downstream of a weak oblique shock

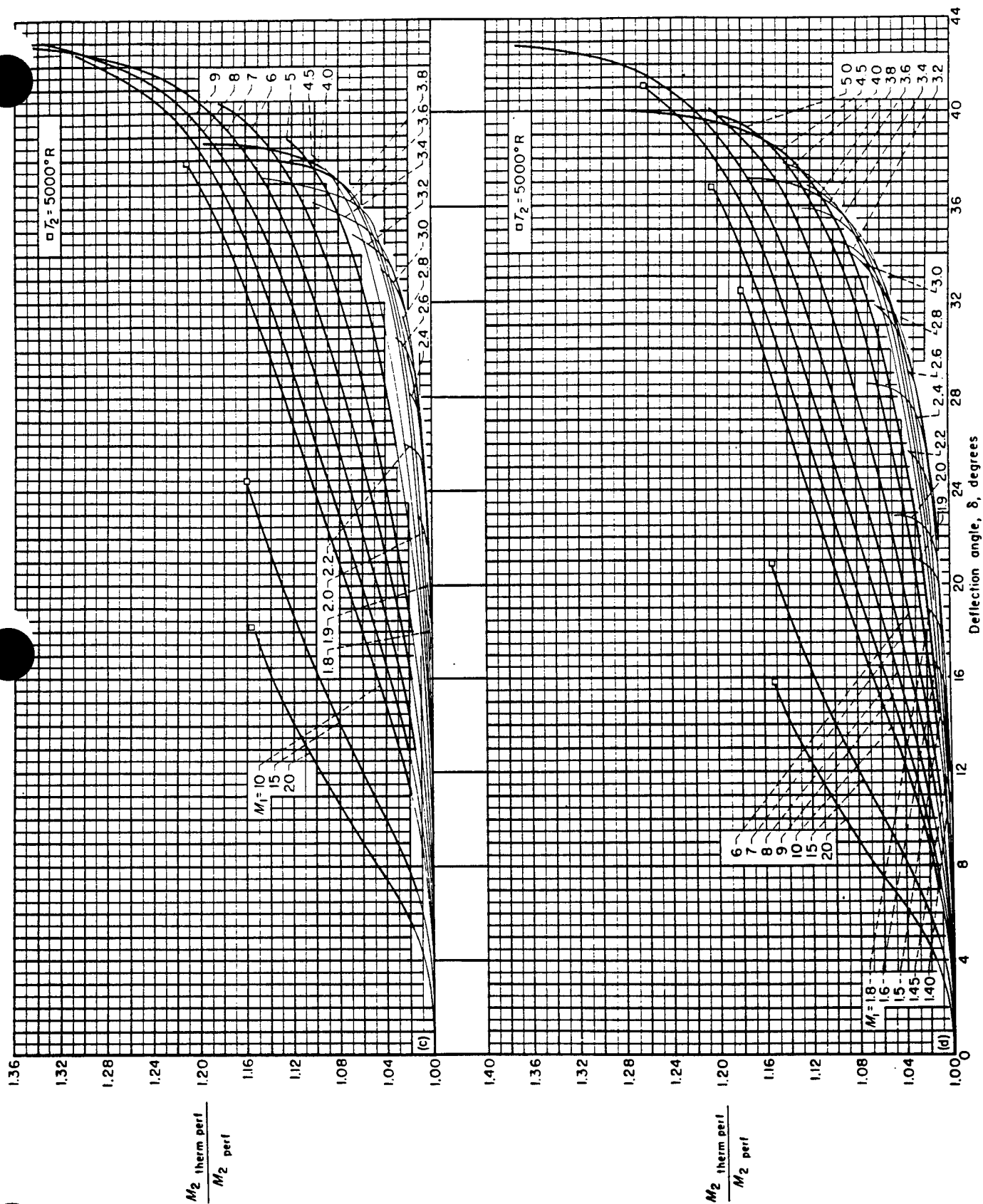
(d) $T_1 = 6300^\circ \text{R}$ (c) $T_1 = 5000^\circ \text{R}$

CHART 22.—Concluded

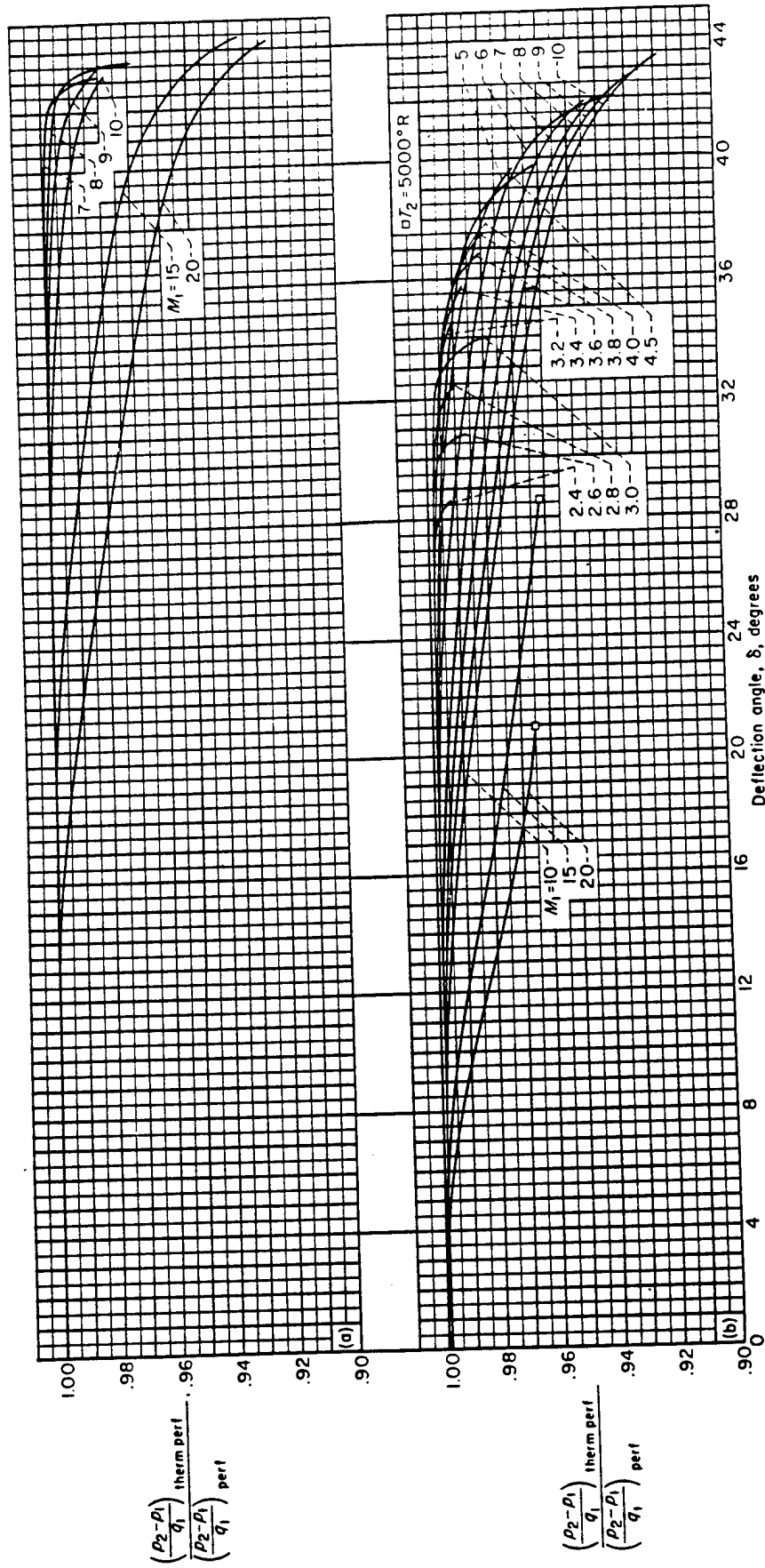


CHART 23.—Effect of caloric imperfections on the variation with flow-deflection angle of the pressure coefficient across a weak oblique shock wave.

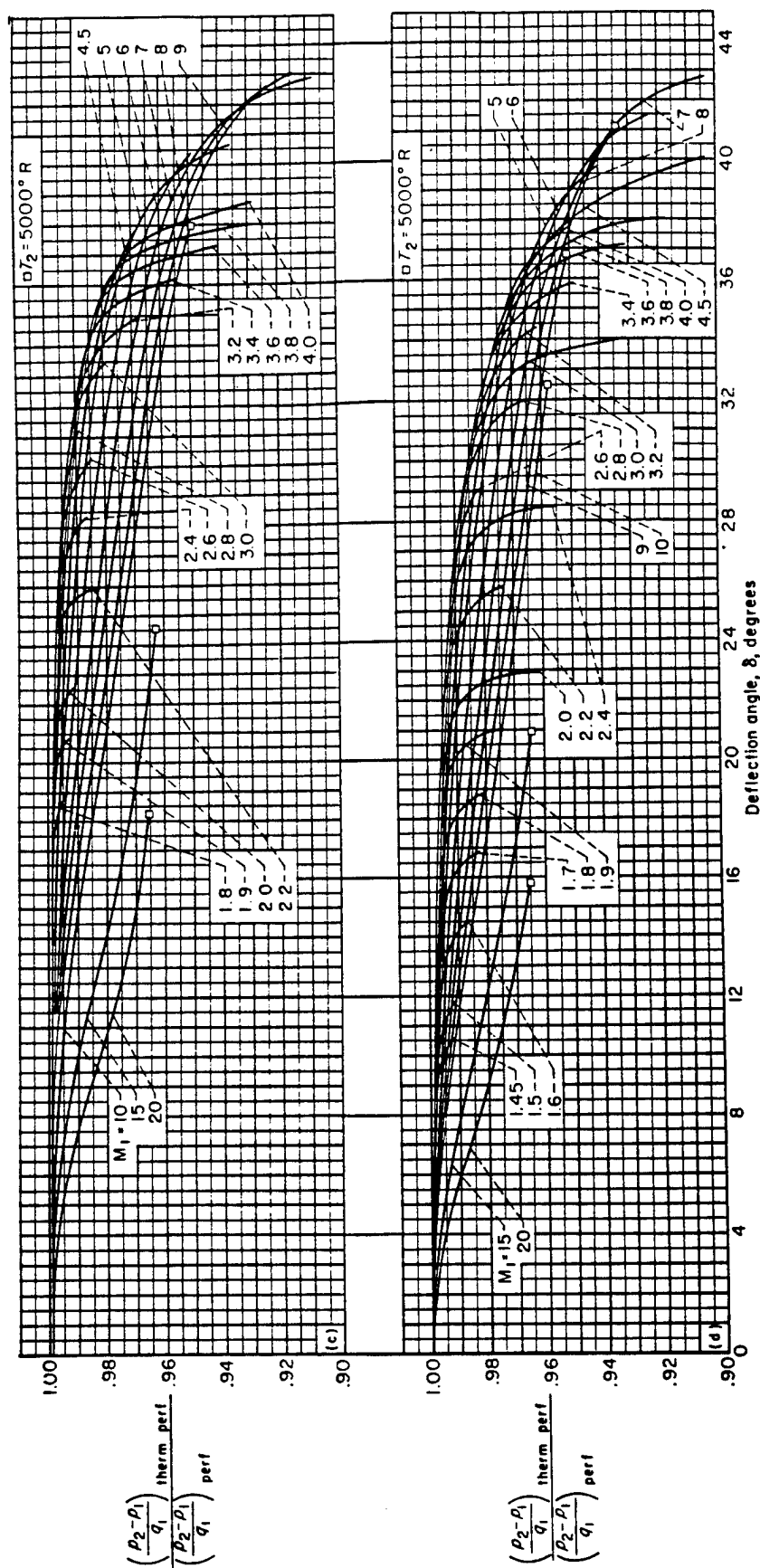
(c) $T_1 = 500^\circ \text{ R}$ (d) $T_1 = 630^\circ \text{ R}$

CHART 23.—Concluded

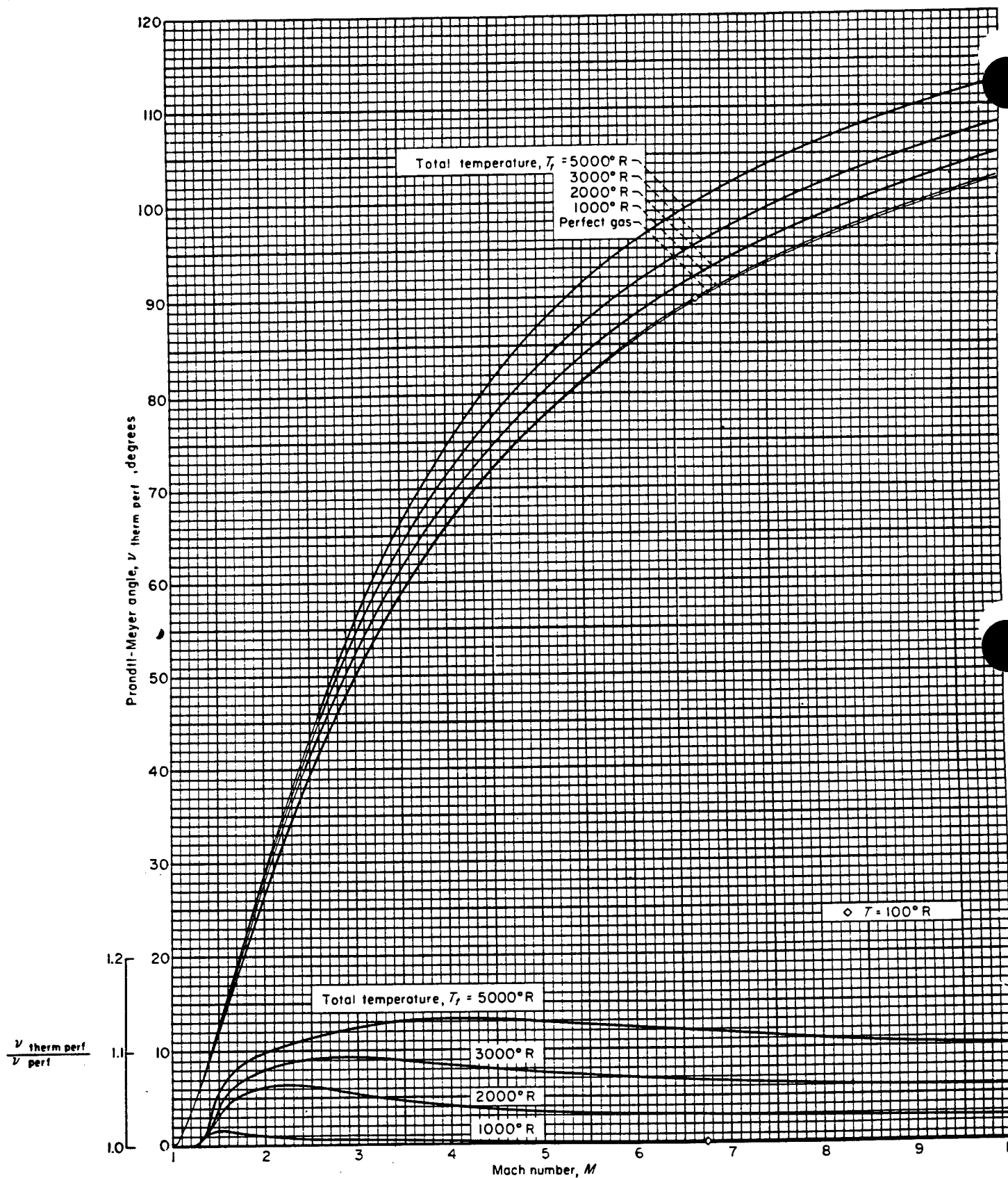


CHART 24.—Effect of caloric imperfections on the Prandtl-Meyer angle.

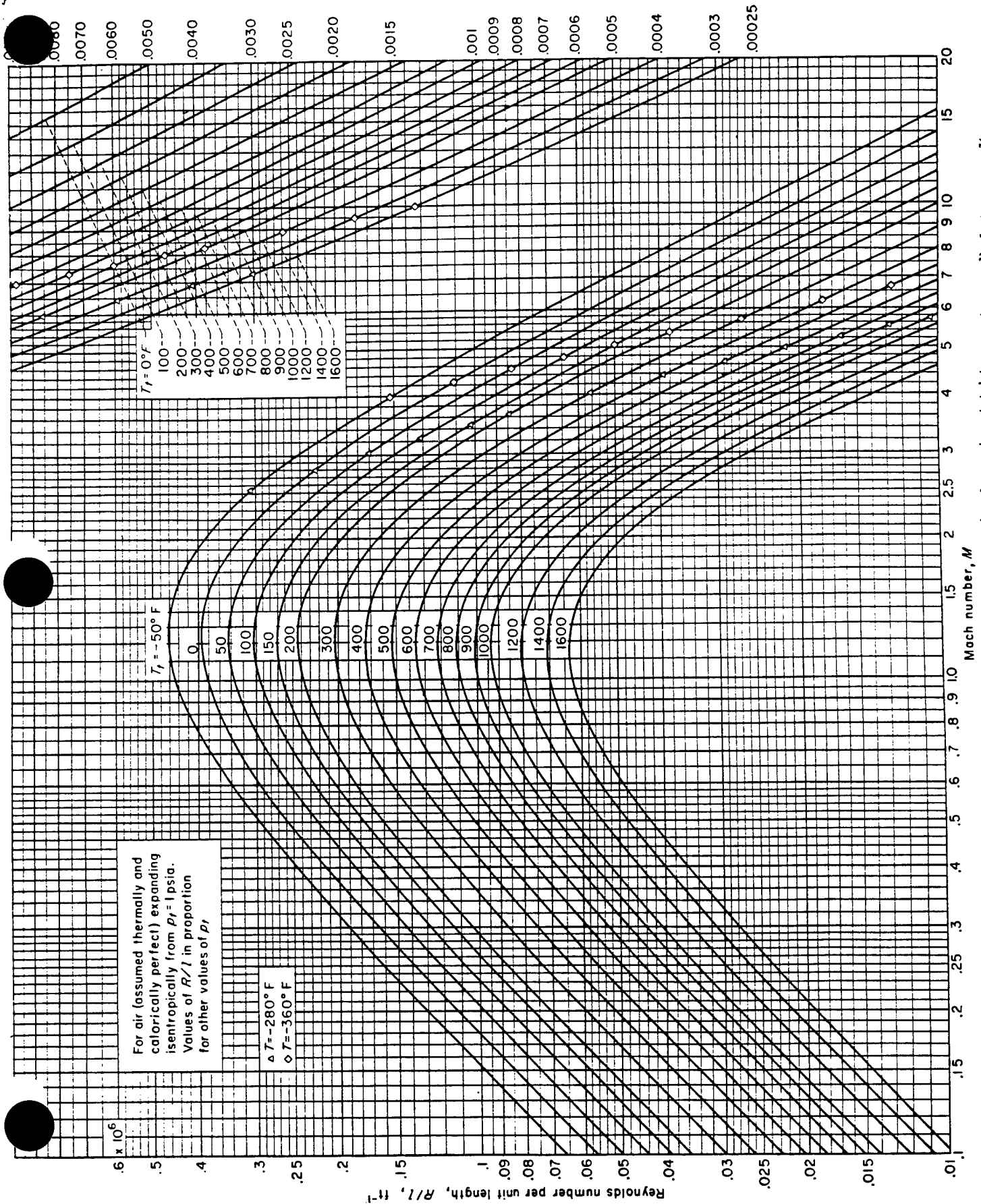


CHART 25.—Variation of Reynolds number per unit length with Mach number for various total temperatures. Perfect gas, $\gamma = 1/5$.