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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS STANDARD NOMENCLATURE FOR AIRSPEEDS WITH TABLES AND CHARTS FOR USE IN CALCULATION OF AIRSPEEDS

Langley Memorial Aeronautical Laboratory
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REPORT No. 837

STANDARD NOMENCLATURE FOR AIRSPEEDS WITH TABLES AND CHARTS FOR USE IN CALCULATION OF AIRSPEED

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft (or mi)
Time	t	second	s	second (or hour)	sec (or hr)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb
Power	P	horsepower (metric)		horsepower	hp
Speed	V	kilometers per hour	kph	miles per hour	mph
		meters per second	mps	feet per second	fps

2. GENERAL SYMBOLS

Weight $= mg$

Standard acceleration of gravity $= 9.80665$ m/s² or 32.1740 ft/sec²

Mass $= \frac{W}{g}$

Moment of inertia $= mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

Coefficient of viscosity

ν Kinematic viscosity

ρ Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C and 760 mm; or 0.002378 lb-ft^{-4} sec^2

Specific weight of "standard" air, 1.2255 kg/m³ or 0.07651 lb/cu ft

3. AERODYNAMIC SYMBOLS

Area

Area of wing

Gap

Span

Chord

Aspect ratio, $\frac{b^2}{S}$

True air speed

Dynamic pressure, $\frac{1}{2}\rho V^2$

Lift, absolute coefficient $C_L = \frac{L}{qS}$

D Drag, absolute coefficient $C_D = \frac{D}{qS}$

D_0 Profile drag, absolute coefficient $C_{D_0} = \frac{D_0}{qS}$

D_i Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$

D_p Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$

C Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$

i_w Angle of setting of wings (relative to thrust line)

i_t Angle of stabilizer setting (relative to thrust line)

Q Resultant moment

Ω Resultant angular velocity

R Reynolds number, $\rho \frac{Vl}{\mu}$ where l is a linear dimension (e.g., for an airfoil of 1.0 ft chord, 100 mph, standard pressure at 15° C, the corresponding Reynolds number is 935,400; or for an airfoil of 1.0 m chord, 100 mps, the corresponding Reynolds number is 6,865,000)

α Angle of attack

ϵ Angle of downwash

α_0 Angle of attack, infinite aspect ratio

α_i Angle of attack, induced

α_a Angle of attack, absolute (measured from zero-lift position)

γ Flight-path angle

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REPORT No. 837

STANDARD NOMENCLATURE FOR AIRSPEEDS WITH TABLES AND CHARTS FOR USE IN CALCULATION OF AIRSPEED

By William S. Aiken, Jr.

SUMMARY

Symbols and definitions of various airspeed terms that have been adopted as standard by the NACA Subcommittee on Aircraft Structural Design are presented. The equations, charts, and tables required in the evaluation of true airspeed, calibrated airspeed, equivalent airspeed, impact and dynamic pressures, and Mach and Reynolds numbers have been compiled. Tables of the standard atmosphere to an altitude of 65,000 feet and a tentative extension to an altitude of 100,000 feet are given along with the basic equations and constants on which both the standard atmosphere and the tentative extension are based.

INTRODUCTION

In analyses of aerodynamic data very often wind-tunnel or flight measurements must be converted into airspeed and related quantities that are used in engineering calculations. Attempts to accomplish such conversion by use of available methods have been complicated by the diversity of symbols and definitions and by the necessity of referring to equations, charts, and tables from a number of different sources. A standard set of symbols and definitions of various airspeed terms that were adopted by the NACA Subcommittee on Aircraft Structural Design and a compilation of the necessary equations, charts, and tables for converting measured pressures and temperatures into airspeeds, determining Mach numbers and Reynolds numbers, and determining other quantities such as dynamic and impact pressures that are of interest are therefore presented herein.

In the preparation of the present paper, results that have been included in previous papers have been extended to include higher altitudes and quantities not given in the previous papers, since recent requests have indicated the need for such an extension of standard-atmosphere tables.

The tables and figures have been arranged for ease in determination of the airspeed, which is usually based on the interpretation of measurements of differential pressures obtained with some pitot-static arrangement. The interrelation of the various airspeed quantities is independent of the method used in the measurement. Instrument and installation errors have been assumed to have been taken into account.

STANDARD SYMBOLS AND DEFINITIONS

At the November 1944 meeting of the NACA Subcommittee on Aircraft Structural Design, representatives from the Army, Navy, CAA, NACA, and several aircraft manufacturers adopted as standard the following symbols and definitions for airspeeds:

V true airspeed

V_i indicated airspeed (the reading of a differential-pressure airspeed indicator, calibrated in accordance with the accepted standard adiabatic formula to indicate true airspeed for standard sea-level conditions only, uncorrected for instrument and installation errors)

V_c calibrated airspeed (the airspeed related to differential pressure by the accepted standard adiabatic formula used in the calibration of differential-pressure airspeed indicators and equal to true airspeed for standard sea-level conditions)

V_e equivalent airspeed ($V\sigma^{1/2}$)

Use of equivalent airspeed in combination with various subscripts is customary, particularly in structural design, to designate various design conditions. It is suggested that the foregoing symbols be retained intact when further subscripts are necessary.

Most of the following symbols, which are used herein, have already been accepted as standard and are used throughout aeronautical literature. The units given apply to the development of the equations in the present report.

V	true airspeed, feet per second
V_c	calibrated airspeed, feet per second
V_e	equivalent airspeed, feet per second
a	speed of sound in ambient air, feet per second
M	Mach number (V/a)
ρ	mass density of ambient air, slugs per cubic foot
ρ_0	standard mass density of dry ambient air at sea level, 0.002378 slug per cubic foot
σ	density ratio (ρ/ρ_0)
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
q_c	impact pressure, pounds per square foot (total pressure minus static pressure p)
p	static pressure of free stream, pounds per square foot
p_0	static pressure of free stream under standard sea-level conditions, pounds per square foot
t	temperature, °F or °C
Δt	difference between free-air temperature and temperature of standard atmosphere, °F

T absolute temperature, °F absolute or °C absolute
T_{std} standard-atmosphere free-air temperature, °F absolute
T_0 standard sea-level absolute temperature, 518.4 °F absolute
T_m harmonic mean absolute temperature, °F absolute (defined in equation (B5))
f compressibility factor defined in equation (11)
f_0 compressibility factor defined in equation (16)
γ ratio of specific heat at constant pressure to specific heat at constant volume (assumed equal to 1.4 for air)
h absolute altitude, feet
h_p pressure altitude, feet
g acceleration of gravity, 32.1740 feet per second per second
m modulus for common logarithms, $\log_{10} e$ (0.434294)
μ coefficient of viscosity, slugs per foot-second
ν kinematic viscosity, square feet per second (μ/ρ)
R Reynolds number $\left(\rho \frac{Vl}{\mu}\right)$
R_{std} Reynolds number for standard atmospheric conditions
l characteristic length, feet

CALCULATION OF AIRSPEED AND RELATED QUANTITIES

Because pitot-static arrangements are used as the basis for the determination of airspeed, aeronautical engineering practice has developed to include the use of a number of airspeed terms and quantities, each of which has a particular field of usefulness. True airspeed is principally of use to aerodynamicists, and indicated and calibrated airspeeds are principally of use to pilots. Equivalent airspeed is used by structural engineers, since all load specifications have long been based on this quantity.

Definite relationships exist between true airspeed, Mach number, Reynolds number, calibrated airspeed, and equivalent airspeed, and all these quantities may be related either to the dynamic pressure q or to the impact pressure q_c. Some of the relations presented herein apply to the calculation of true airspeed and Mach number from airspeed measurements obtained with an airspeed indicator of standard calibration. Other relations apply to the calculation of true airspeed when the impact pressure is measured directly.

If it is assumed that the total-head tube and the static-head tube measure their respective pressures correctly and that these tubes are connected to an appropriate instrument, the impact pressure measured is given by the adiabatic equation when $V<a$:

$$q_c=p\left[\left(1+\frac{\gamma-1}{2\gamma}\frac{\rho}{p}V^2\right)^{\frac{\gamma}{\gamma-1}}-1\right] \tag{1}$$

Standard airspeed indicators used in Army and Navy airplanes since 1925 have been calibrated according to equation (1) for standard sea-level conditions: that is, according to the equation when $V<a$,

$$q_c=p_0\left[\left(1+\frac{\gamma-1}{2\gamma}\frac{\rho_0}{p_0}V_c^2\right)^{\frac{\gamma}{\gamma-1}}-1\right] \tag{2}$$

where the subscript 0 denotes standard sea-level conditions and V_c is the calibrated airspeed. The calibrated airspeed is, therefore, equal to true airspeed only for standard sea-level conditions.

DETERMINATION OF TRUE AIRSPEED FROM CALIBRATED AIRSPEED

The formula that relates the true airspeed to the calibrated airspeed may be found by equating the right-hand terms of equations (1) and (2) as follows:

$$p\left[\left(1+\frac{\gamma-1}{2\gamma}\frac{\rho}{p}V^2\right)^{\frac{\gamma}{\gamma-1}}-1\right]=p_0\left[\left(1+\frac{\gamma-1}{2\gamma}\frac{\rho_0}{p_0}V_c^2\right)^{\frac{\gamma}{\gamma-1}}-1\right] \tag{3}$$

Because the exact numerical solution of equation (3) for true airspeed is involved and requires a great deal of time, a number of charts for the determination of the true airspeed from the calibrated airspeed for various atmospheric conditions have been derived. (See references 1 to 3.) A typical chart (taken from reference 1) that shows the relationship between Mach number, calibrated airspeed, pressure altitude, temperature, and true airspeed is given in figure 1. This chart is widely used because of its convenience. Airspeed may be obtained from this chart with an accuracy within 2 miles per hour when standard conditions hold and when values of airspeed and pressure altitude explicitly given by the chart are chosen; the possible errors increase to within 5 miles per hour, however, when the temperature conditions are not standard and when interpolation is required for both altitude and airspeed.

For some purposes, charts such as figure 1 are not sufficiently accurate. A series of logarithmic tables that may be used to determine the true airspeed in knots from observed values of calibrated airspeed, pressure altitude, and free-air temperature is given in reference 4. Logarithmic tables of the type given in reference 4 are of limited usefulness since they cannot be used conveniently to evaluate the intermediate quantities (impact pressure and Mach number) that are involved in the computation of true airspeed.

A series of tables (tables I to V) is given in the present report to permit determination of impact pressure q_c in pounds per square foot, Mach number M, and true airspeed V in miles per hour or knots for observed values of V_c in miles per hour or knots, pressure altitude h_p in feet, and temperature in degrees Fahrenheit or Centigrade. The accuracy of the tables is far greater than that with which experimental data can normally be obtained. With ordinary care in interpolation, errors should be less than 0.25 mile per hour throughout the greater part of the airspeed and altitude ranges.

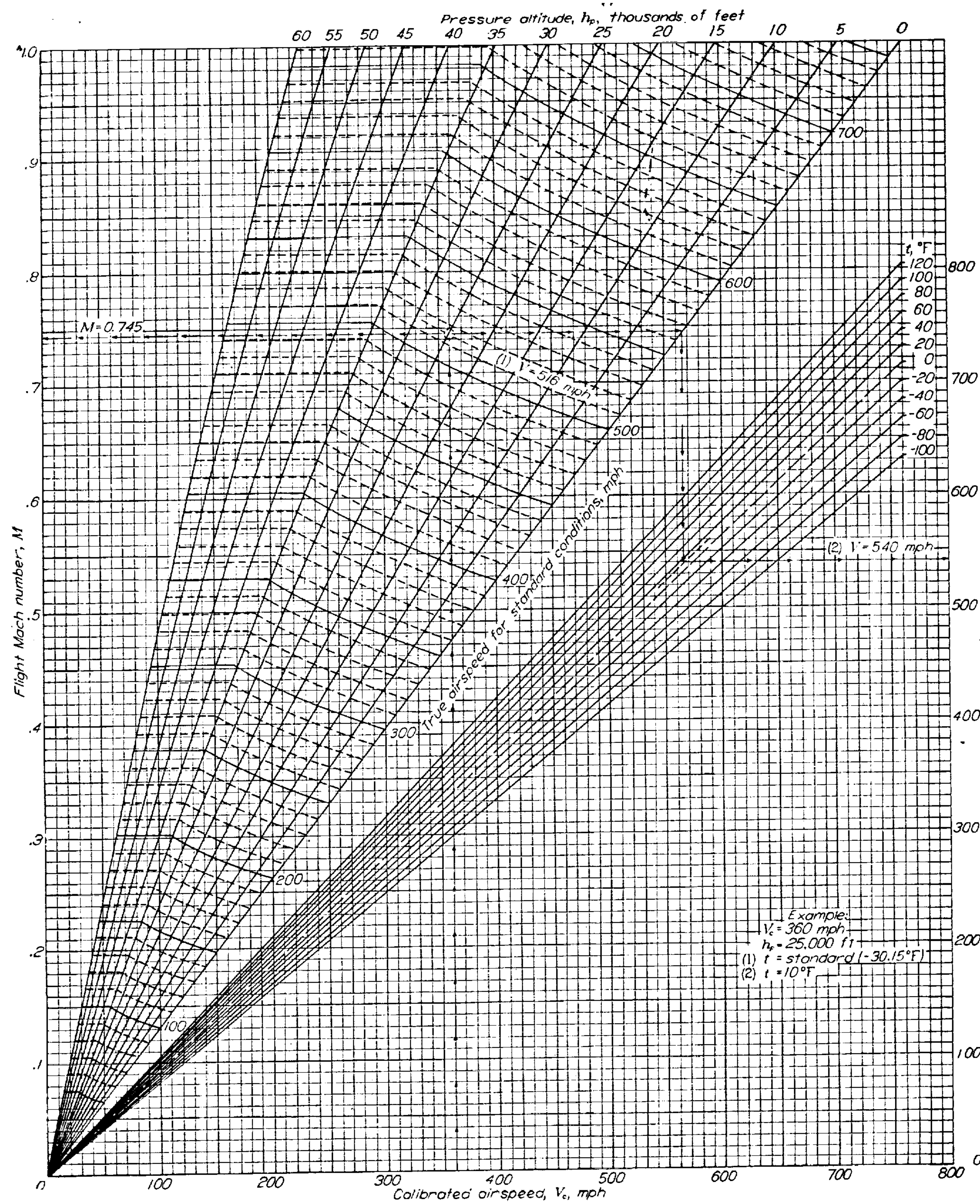


FIGURE 1.—Chart of airspeed against Mach number. (From reference 1.) Airspeed indicator is assumed to be calibrated to read true airspeed for standard sea-level conditions.

Table I, which gives values of impact pressure q_c in pounds per square foot for values of V_c in miles per hour, was computed directly from equation (2); standard values were used for all the constants occurring in this equation. Table II gives values of impact pressure q_c in pounds per square foot for values of V_c in knots. In computing the values of q_c in table II, the conversion from feet to nautical miles used was as follows:

1 nautical mile=6080.2 feet

Tables I and II give the impact pressures for V_c in increments of 1 mile per hour and 1 knot for speeds corresponding to Mach numbers at sea level from 0 to 1.000.

Table III gives values of static pressure p in pounds per square foot for various values of pressure altitude h_p from −1,000 to 60,000 feet in increments of 100 feet and from 60,000 to 100,000 in increments of 1,000 feet for standard atmospheric conditions. (The use of the term "standard atmosphere" throughout this report includes values for the standard atmosphere up to an altitude of 65,000 feet and for the tentative extension of the standard atmosphere from 65,000 to 100,000 feet.) The values given in table III were computed from the equation

$$h_p=\frac{p_0}{\rho_0 g m}\frac{T_m}{T_0}\log_{10}\frac{p_0}{p} \tag{4}$$

which is given as equation (4) of reference 5 with slightly different symbols.

From tables I or II and III the ratio of impact pressure to static pressure q_c/p may be established and the Mach number, which is a function of this ratio, may then be found. The relation between Mach number and q_c/p may be found from equation (1) as

$$M=\left\{5\left[\left(\frac{q_c}{p}+1\right)^{2/7}-1\right]\right\}^{1/2} \tag{5}$$

Table IV gives values of Mach number for various values of the ratio q_c/p.

The Mach number M is defined as the ratio of the true airspeed to the speed of sound in ambient air and thus, with the Mach number determined, the true airspeed may be found by the use of

$$V=Ma \tag{6}$$

The speed of sound in ambient air is found from the equation

$$a=\sqrt{\gamma\frac{p}{\rho}} \tag{7}$$

which may be rewritten in the following forms when the value of γ is assumed equal to 1.4 and the air is assumed to follow the gas law

$$\rho=\rho_0\frac{p}{p_0}\frac{T_0}{T}$$

If a is in miles per hour and T is in degrees Fahrenheit absolute

$$a=33.42\sqrt{T} \tag{8}$$

If a is in knots and T is in degrees Fahrenheit absolute

$$a=29.02\sqrt{T} \tag{8a}$$

If a is in miles per hour and T is in degrees Centigrade absolute

$$a=44.84\sqrt{T} \tag{8b}$$

If a is in knots and T is in degrees Centigrade absolute

$$a=38.94\sqrt{T} \tag{8c}$$

Table V gives the speed of sound for values of free-air temperature in degrees Fahrenheit, and table VI gives the speed of sound for temperatures in degrees Centigrade Tables V and VI give the speed of sound both in miles per hour and in knots.

In order to illustrate the use of tables I to VI to determine the true airspeed from calibrated airspeed, the following example is presented:

Given:

Calibrated airspeed V_c=398 miles per hour
Pressure altitude h_p=22,000 feet
Temperature t=−12° F

To find:

True airspeed V in miles per hour

Step (1)

From table I, for V_c=398 miles per hour,
q_c=433.7 pounds per square foot

Step (2)

From table III, for h_p=22,000 feet,
p=893.3 pounds per square foot

Step (3)

From these values,
$$\frac{q_c}{p}=\frac{433.7}{893.3}=0.4855$$

Step (4)

From table IV, for $\frac{q_c}{p}=0.4855$,
M=0.7736

Step (5)

From table V, for t=−12° F,
a=706.9 miles per hour

Step (6)

By use of equation (6),
$V=Ma=0.7736\times706.9$ miles per hour
=546.8 miles per hour

DETERMINATION OF TRUE AIRSPEED FROM IMPACT PRESSURE

In order to convert measurements of impact pressure to true airspeed, the static pressure and the speed of sound must be known. It is convenient first to determine the Mach number from measurements of the impact pressure and the static pressure. Table IV may be used to find the Mach number from the ratio q_c to p and tables V and VI may be used to find the speed of sound for various values of the free-air temperature. The true airspeed may then be determined from equation (6).

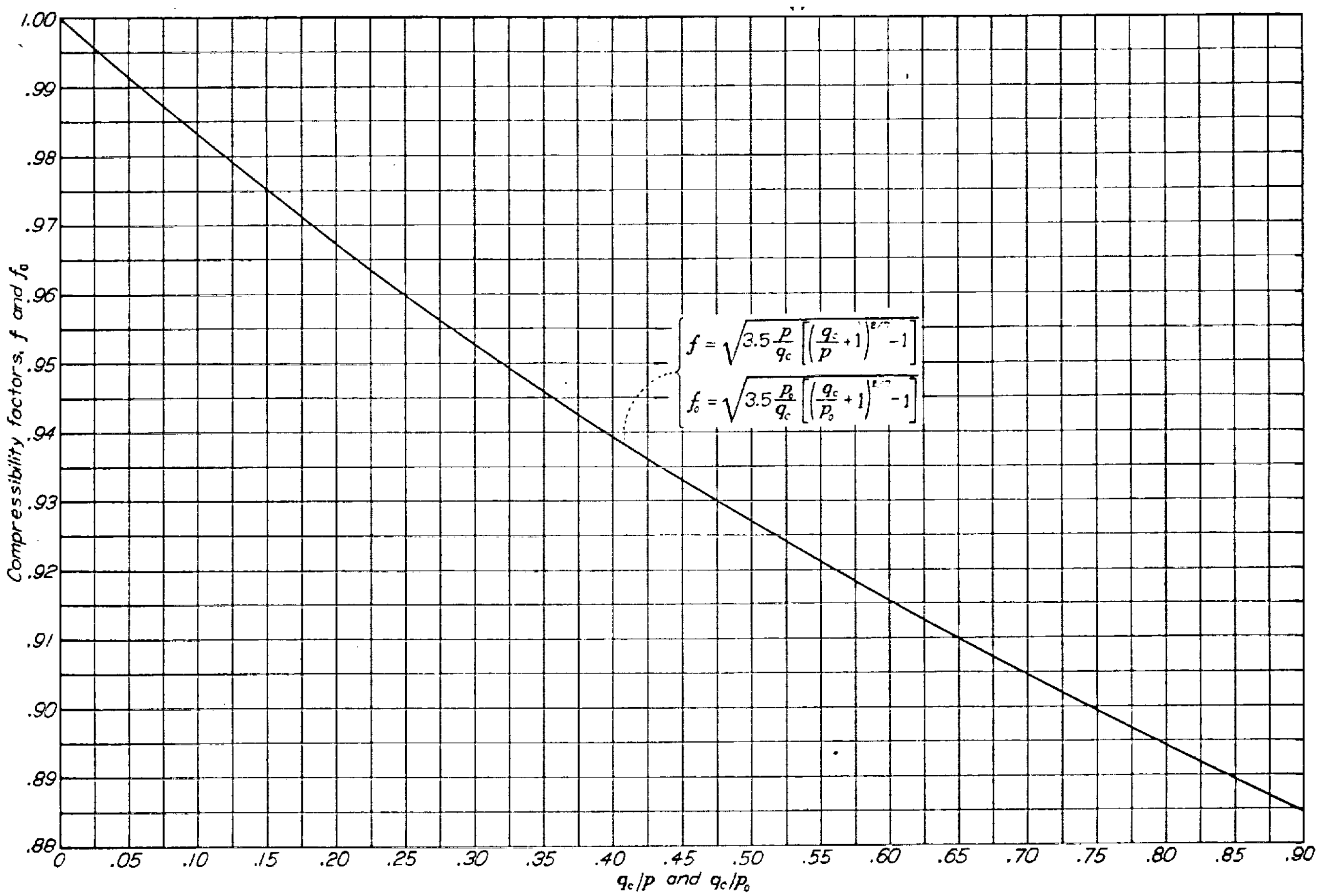


FIGURE 2.—Compressibility factors.

DETERMINATION OF DYNAMIC PRESSURE AND EQUIVALENT AIRSPEED

In order to reduce flight-test data to coefficient form or to demonstrate compliance with certain structural requirements, either the dynamic pressure q or the equivalent airspeed V must be determined. The relations of dynamic pressure and equivalent airspeed to impact pressure, static pressure, calibrated airspeed, and Mach number are therefore presented.

Since the dynamic pressure q is by definition

$$q=\frac{1}{2}\rho V^2 \tag{9}$$

it may be expressed as a function of the impact pressure by solving equation (1) for true airspeed and substituting the resultant expression into equation (9), which reduces to

$$q=f^2q_c \tag{10}$$

where

$$f=\sqrt{\frac{\gamma}{\gamma-1}\frac{p}{q_c}\left[\left(\frac{q_c}{p}+1\right)^{\frac{\gamma-1}{\gamma}}-1\right]} \tag{11}$$

Values of the compressibility factor f are given in figure 2 as a function of q_c/p. The dynamic pressure may also be expressed as a function of Mach number and static pressure from equations (6), (7), and (9) as

$$q=\frac{\gamma}{2}pM^2 \tag{12}$$

Since the equivalent airspeed V_e is by definition

$$V_e=V\sigma^{1/2}=V\sqrt{\frac{\rho}{\rho_0}} \tag{13}$$

the relation between the equivalent airspeed in miles per hour, Mach number, and pressure ratio can be derived from equations (6), (8), (13), and the gas-law equation as

$$V_e=760.9M\sqrt{\frac{p}{p_0}} \tag{14}$$

The variation, determined from equation (14), of equivalent airspeed with Mach number for pressure altitudes from 0 to 100,000 feet is given in figure 3. For convenience, the true airspeed that applies to the standard atmosphere computed from equations (13) and (14) is also included in figure 3.

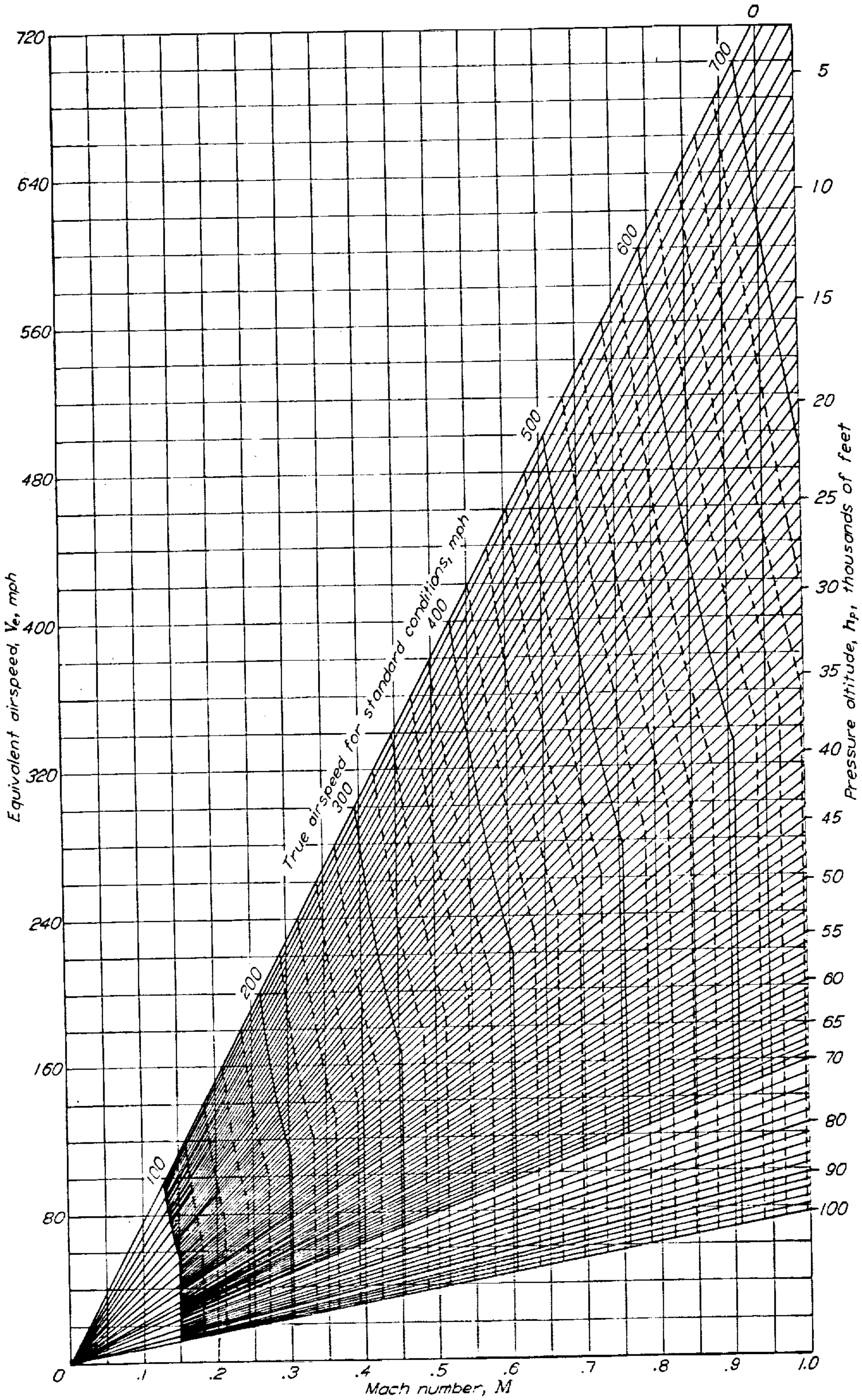


FIGURE 3.—Variation of equivalent airspeed with Mach number and pressure altitude.

Finally, expressions that will relate the true airspeed, the calibrated airspeed, and the equivalent airspeed are determined. If equation (2) is solved for V_c:

$$V_c=\sqrt{\frac{\gamma}{\gamma-1}\frac{p_0}{q_c}\left[\left(\frac{q_c}{p_0}+1\right)^{\frac{\gamma-1}{\gamma}}-1\right]}\sqrt{\frac{2q_c}{\rho_0}} \tag{15}$$

If

$$\sqrt{\frac{\gamma}{\gamma-1}\frac{p_0}{q_c}\left[\left(\frac{q_c}{p_0}+1\right)^{\frac{\gamma-1}{\gamma}}-1\right]}=f_0 \tag{16}$$

equation (15) becomes

$$V_c=f_0\sqrt{\frac{2q_c}{\rho_0}} \tag{17}$$

The compressibility factor f_0 is given in figure 2 as a function of q_c/p_0. Similarly, the true airspeed may be written

$$V=f\sqrt{\frac{2q_c}{\rho}} \tag{18}$$

From equations (17) and (18)

$$V=V_c\frac{f}{f_0}\sqrt{\frac{\rho_0}{\rho}} \tag{19}$$

When equations (13) and (19) are summarized

$$V=V_c\frac{f}{f_0}\sqrt{\frac{\rho_0}{\rho}}=V_e\sqrt{\frac{\rho_0}{\rho}} \tag{20}$$

For convenience, equations relating the various airspeed quantities are listed in appendix A.

DETERMINATION OF REYNOLDS NUMBER

In comparisons of flight and wind-tunnel results charts relating the Reynolds number to the Mach number have been found convenient.

Reynolds number is defined by the formula

$$R=\frac{Vl\rho}{\mu}=\frac{Vl}{\nu} \tag{21}$$

where l is a characteristic length such as the chord. Equation (21) may be written so that the Reynolds number is expressed as a function of Mach number and absolute temperature in degrees Fahrenheit for unit values of the characteristic length l as

$$\frac{R}{l}=\frac{49.02M\sqrt{T}}{\nu} \tag{22}$$

In order to facilitate the determination of Reynolds number, figure 4 has been prepared to show the variation of the factor R_{std}/l with Mach number and pressure altitude, where R_{std} is the Reynolds number computed on the basis of the standard atmosphere. Figure 4 (a) holds for pressure altitudes from sea level to 60,000 feet, and figure 4 (b) holds for pressure altitudes from 60,000 to 100,000 feet.

In order to account for free-air conditions other than standard, figure 5 is given to be used in conjunction with figure 4. When $\mu=\frac{2.318}{10^8}\frac{T^{3/2}}{T+216}$ (justification for the use of this equation given in the section entitled "Properties of Standard Atmosphere") is substituted into equation (21), the Reynolds number factor may be written

$$\frac{R}{l}=1.232pM\frac{T+216}{T^2}10^6 \tag{23}$$

The Reynolds number factor in the standard atmosphere becomes

$$\frac{R_{std}}{l}=1.232pM\frac{T_{std}+216}{T_{std}^2}10^6 \tag{24}$$

When equation (23) is divided by equation (24)

$$\frac{R}{R_{std}}=\left(\frac{T_{std}}{T}\right)^2\left(\frac{T+216}{T_{std}+216}\right) \tag{25}$$

Figure 5 gives R/R_{std} as a function of pressure altitude and the deviation Δt of the free-air temperature from standard temperature for a given pressure altitude. In equation form,

$$\Delta t=T-T_{std} \tag{26}$$

The curves of figure 5 become straight lines for pressure altitudes above 35,332 feet, since T_{std} is constant above this altitude range.

In order to illustrate the procedure to be used in determining Reynolds number, the following example is presented:

Given:

- Mach number $M=0.75$
- Pressure altitude $h_p=35{,}000$ feet
- Characteristic length $l=10$ feet
- Deviation of free-air temperature from standard temperature $\Delta t=-10°$ F

To find:

- Reynolds number R

Step (1)

From figure 4 (a), for $M=0.75$ and $h_p=35{,}000$ feet,

$$\frac{R_{std}}{l}=1{,}800{,}000 \text{ per foot}$$

Step (2)

For $l=10$ feet,

$$R_{std}=18{,}000{,}000$$

Step (3)

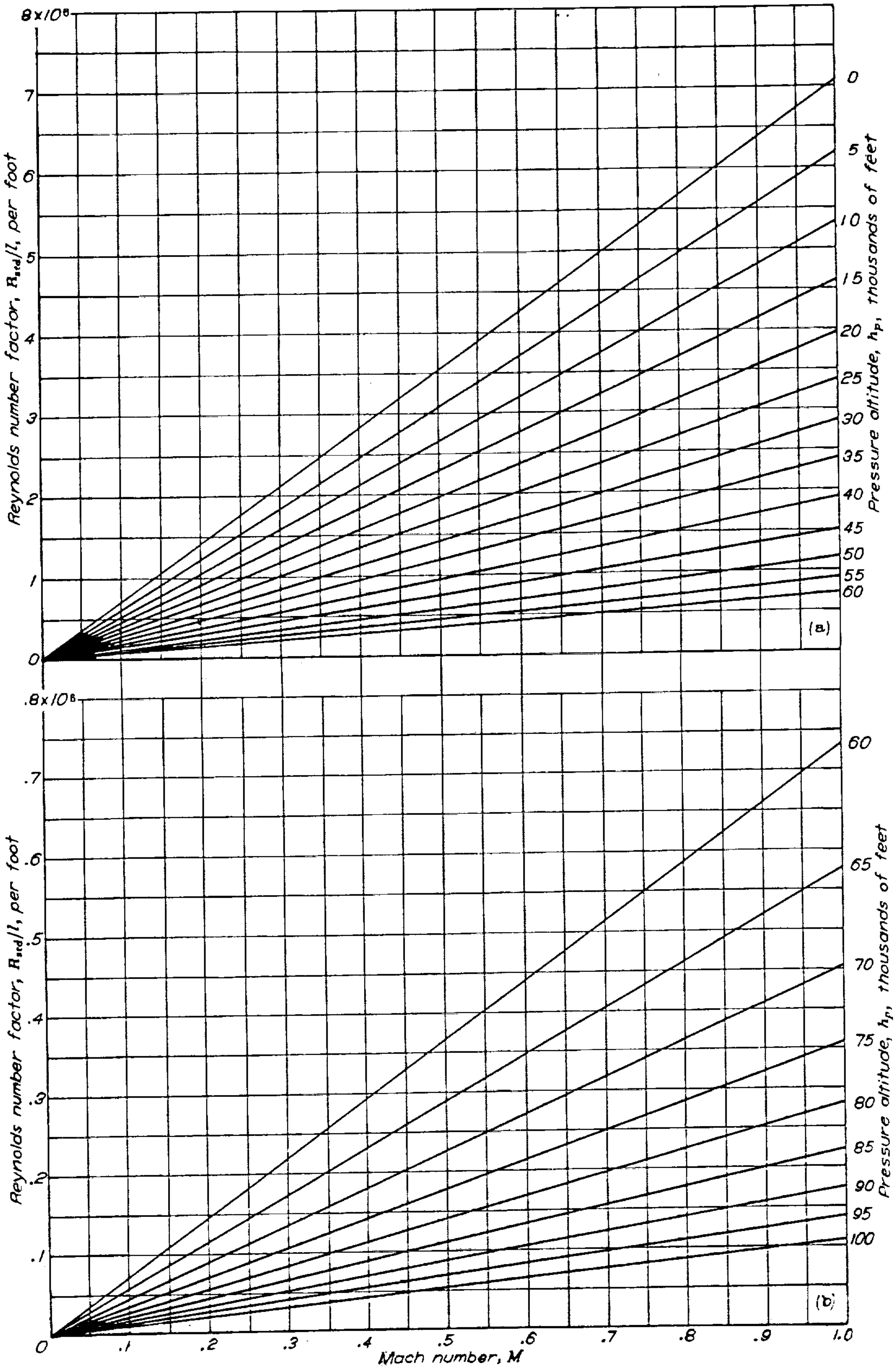
From figure 5, for $h_p=35{,}000$ feet and $\Delta t=-10°$ F,

$$\frac{R}{R_{std}}=1.036$$

Step (4)

From these values,

$$R=18{,}600{,}000$$



(a) Pressure altitudes from 0 to 60,000 feet.

(b) Pressure altitudes from 60,000 to 100,000 feet.

FIGURE 4.—Variation of Reynolds number factor in the standard atmosphere.

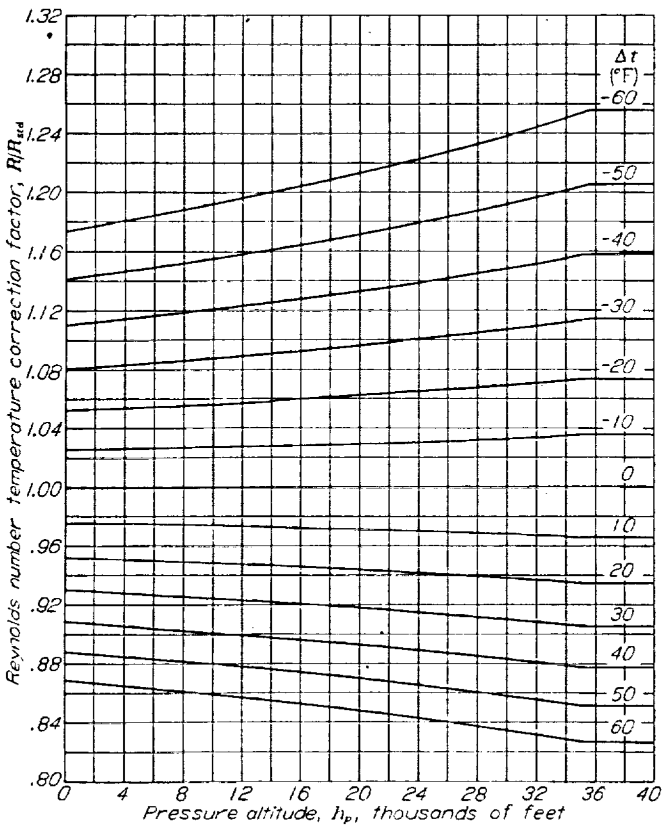


FIGURE 5.—Variation of Reynolds number temperature correction factor with pressure altitude and the deviation Δt of the free-air temperature from the temperature of the standard atmosphere.

PROPERTIES OF STANDARD ATMOSPHERE

For many purposes, such as performance and load calculations, the concept of a standard atmosphere has proved to be very useful. The United States standard atmosphere was officially adopted in 1925 (reference 6). In reference 6 tables are given that are of most use in the calibration of instruments. The properties of this atmosphere were originally tabulated by Diehl (reference 5).

Table VII gives the standard atmospheric values up to altitudes of 65,000 feet and includes quantities that have been found to be of use in the interpretation of airspeed and related factors. These quantities are the pressure in pounds per square foot, the pressure in inches of water, the speed of sound, the coefficient of viscosity μ, and the kinematic viscosity ν. All the quantities given in table VII are in the English system of units for every 500 feet of altitude up to 65,000 feet.

The values given in table VII for the coefficient of viscosity μ and the kinematic viscosity ν are not standard values since a standardization of air viscosity has not been agreed upon as yet. The values listed for μ and ν are believed to be sufficiently accurate, however, to be useful in calculations requiring viscosity of air.

For altitudes from sea level to 35,000 feet, the pressure p in pounds per square foot and in inches of water was determined from the ratio p/p_0 given in reference 5 and values of the pressure at sea level of 2116.2 pounds per square foot and 407.1 inches of water. The sea-level pressure in pounds per square foot is based on the pressure in inches of mercury at 32° F of 29.921. The sea-level pressure in inches of water is based on the pressure in inches of mercury at 32° F and water at 59° F. The pressure p in inches of mercury for altitudes up to 35,000 feet is taken directly from reference 5.

The quantities mass density ρ and density ratio σ are also taken directly from reference 5 for the altitudes from 0 to 35,000 feet. For altitudes over 35,000 feet the pressures, the mass density, and the density ratio were recalculated, since a minor error was discovered in the calculations of reference 5 for the pressure ratio for altitudes above 35,332 feet.

The quantity $1/\sqrt{\sigma}$ is given to facilitate the computation of the true airspeed V from the equivalent airspeed V_e.

The absolute temperature in degrees Fahrenheit was obtained from reference 5 except for altitudes above 32,000 feet, where interpolation was necessary at the 500-foot stations.

For ready reference, the standard values and the variation with altitude of temperature and density originally used in the computations for the standard atmosphere are included in appendix B of the present paper.

The speed of sound in miles per hour computed from equation (8) is given in table VII. A value of $\gamma=1.4$ was assumed to hold for the temperature range that is included in table VII.

The coefficient of viscosity μ was computed from the formula

$$\mu=\frac{2.318}{10^8}\frac{T^{3/2}}{T+216} \tag{27}$$

Equation (27) was obtained from reference 7 by converting the equation given therein to the English system of units and by starting with a value of $\mu=3.725\times10^{-7}$ consistent with the standard sea-level conditions.

The kinematic viscosity of air ν was obtained from the definition

$$\nu=\frac{\mu}{\rho} \tag{28}$$

TENTATIVE EXTENSION OF STANDARD ATMOSPHERE

The NACA Special Subcommittee on the Upper Atmosphere at a meeting on June 24, 1946, resolved that the tentative extension of the standard atmosphere from 65,000 to 100,000 feet be based upon a constant composition of the atmosphere and an isothermal temperature which are the same as standard conditions at 65,000 feet. This tentative extended isothermal region ends at 32 kilometers (approximately 105,000 ft). It is possible that as results of higher altitude temperature soundings become available and the standard atmosphere is extended to very high altitudes the present recommendation may be modified.

The Subcommittee also recommended that the values of temperature given in the following table be considered as maximum and minimum values occurring for the given altitudes with the variations between the specified points to be linear:

Altitude (km)	Temperature (°C abs.)	
	Minimum	Maximum
20	180	250
25	---	250
45	200	380

A tentative extension of the standard atmosphere computed from the equations given in appendix B using the recommended isothermal temperature is given in table VIII for altitudes from 65,000 to 100,000 feet. All quantities given in table VII are included in table VIII.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *July 17, 1946.*

APPENDIX A

SUMMARY OF EQUATIONS RELATING AIRSPEED QUANTITIES

The equations relating the various airspeed quantities, which are given in the present paper, are as follows:

$$q_c=p\left[\left(1+\frac{\gamma-1}{2\gamma}\frac{\rho}{p}V^2\right)^{\frac{\gamma}{\gamma-1}}-1\right]\text{ for }V<a \tag{A1}$$

$$q_c=p_0\left[\left(1+\frac{\gamma-1}{2\gamma}\frac{\rho_0}{p_0}V_c^2\right)^{\frac{\gamma}{\gamma-1}}-1\right]\text{ for }V<a \tag{A2}$$

$$q=\frac{1}{2}\rho V^2 \tag{A3}$$

$$q=f^2q_c \tag{A4}$$

$$q=\frac{\gamma}{2}pM^2 \tag{A5}$$

$$\rho=\rho_0\frac{p}{p_0}\frac{T_0}{T} \tag{A6}$$

$$f=\sqrt{\frac{\gamma}{\gamma-1}\frac{p}{q_c}\left[\left(\frac{q_c}{p}+1\right)^{\frac{\gamma-1}{\gamma}}-1\right]} \tag{A7}$$

$$f_0=\sqrt{\frac{\gamma}{\gamma-1}\frac{p_0}{q_c}\left[\left(\frac{q_c}{p_0}+1\right)^{\frac{\gamma-1}{\gamma}}-1\right]} \tag{A8}$$

$$M=\left\{5\left[\left(\frac{q_c}{p}+1\right)^{2/7}-1\right]\right\}^{1/2} \tag{A9}$$

$$a=\sqrt{\gamma\frac{p}{\rho}} \tag{A10}$$

If a is in miles per hour and T is in degrees Fahrenheit absolute

$$a=33.42\sqrt{T} \tag{A11}$$

If a is in knots and T is in degrees Fahrenheit absolute

$$a=29.02\sqrt{T} \tag{A12}$$

If a is in miles per hour and T is in degrees Centigrade absolute

$$a=44.84\sqrt{T} \tag{A13}$$

If a is in knots and T is in degrees Centigrade absolute

$$a=38.94\sqrt{T} \tag{A14}$$

$$V=Ma \tag{A15}$$

$$V=f\sqrt{\frac{2q_c}{\rho}} \tag{A16}$$

$$V_c=f_0\sqrt{\frac{2q_c}{\rho_0}} \tag{A17}$$

$$V_e=V\sigma^{1/2}=V\sqrt{\frac{\rho}{\rho_0}} \tag{A18}$$

$$V_e(\text{mph})=760.9M\sqrt{\frac{p}{p_0}} \tag{A19}$$

APPENDIX B

CONSTANTS AND EQUATIONS FOR USE IN COMPUTATIONS OF STANDARD ATMOSPHERE

The values of the standard atmosphere given herein are based on the following values:

Sea-level pressure $p_0 = 29.921$ in. Hg
$= 407.1$ in. H_2O
$= 2116.2$ lb/ft^2

Sea-level temperature $t_0 = 59°$ F

Sea-level absolute temperature $T_0 = 518.4°$ F

Sea-level density $\rho_0 = 0.002378$ slug/ft^3

Gravity $g = 32.1740$ ft/sec^2

Temperature gradient $\frac{dT}{dh} = 0.00356617°$ F/ft

The altitude of the lower limit of the isothermal atmosphere 35,332 ft

Specific weight of mercury at 32° F=848.7149 lb/ft^3

Specific weight of water at 59° F=62.3724 lb/ft^3

Up to the lower limit of the isothermal atmosphere (−67° F corresponding to 35,332 ft) the temperature is assumed to decrease linearly according to the equation

$$T = T_0 - \frac{dT}{dh} h \qquad \text{(B1)}$$

Further, the atmosphere is assumed to be a dry perfect gas that obeys the laws of Charles and Boyle, so that the mass density corresponding to the pressure and temperature is

$$\rho = \rho_0 \frac{p}{p_0} \frac{T_0}{T} \qquad \text{(B2)}$$

In reference 5 the pressure and altitude are related by

$$h = \frac{p_0}{\rho_0 g m} \frac{T_m}{T_0} \log_{10} \frac{p_0}{p} \qquad \text{(B3)}$$

where m is the modulus for common logarithms, that is,

$$m = \log_{10} e = 0.434294 \qquad \text{(B4)}$$

The harmonic mean temperature T_m is given by

$$T_m = \frac{\Sigma \Delta h}{\Sigma \frac{\Delta h}{T_{av}}} = \frac{\Delta h_1 + \Delta h_2 + \dots}{\frac{\Delta h_1}{T_{av_1}} + \frac{\Delta h_2}{T_{av_2}} + \dots} \qquad \text{(B5)}$$

where T_{av_1}, T_{av_2}, . . . are the average temperatures for the altitude increments Δh_1, Δh_2, ...

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TABLE I

IMPACT PRESSURE q_c IN POUNDS PER SQUARE FOOT FOR VARIOUS VALUES OF CALIBRATED AIRSPEED V_c IN MILES PER HOUR

Calibrated airspeed, V_c (mph)	0	1	2	3	4	5	6	7	8	9
0	0	0.002558	0.01023	0.02302	0.04093	0.06396	0.09208	0.1253	0.1637	0.2072
10	.2558	.3095	.3683	.4323	.5014	.5756	.6549	.7393	.8288	.9235
20	1.023	1.128	1.238	1.353	1.474	1.599	1.730	1.865	2.006	2.152
30	2.303	2.459	2.620	2.787	2.958	3.135	3.317	3.504	3.696	3.893
40	4.095	4.303	4.515	4.733	4.956	5.184	5.417	5.655	5.899	6.147
50	6.401	6.660	6.925	7.193	7.467	7.747	8.032	8.320	8.614	8.915
60	9.222	9.533	9.848	10.17	10.50	10.83	11.16	11.50	11.85	12.20
70	12.56	12.92	13.29	13.66	14.04	14.42	14.81	15.20	15.60	16.00
80	16.41	16.83	17.25	17.67	18.10	18.54	18.98	19.42	19.87	20.33
90	20.79	21.26	21.72	22.20	22.68	23.17	23.66	24.16	24.67	25.17
100	25.69	26.21	26.73	27.26	27.80	28.34	28.88	29.43	29.98	30.54
110	31.11	31.68	32.26	32.84	33.43	34.02	34.62	35.22	35.83	36.44
120	37.06	37.69	38.32	38.96	39.59	40.24	40.88	41.54	42.20	42.87
130	[illegible]	44.22	44.90	45.59	46.28	46.98	47.69	48.40	49.11	49.84
140	50.56	51.30	52.03	52.78	53.52	54.27	55.02	55.79	56.56	57.34
150	58.11	58.90	59.69	60.48	61.28	62.09	62.90	63.72	64.54	65.38
160	66.21	67.05	67.89	68.74	69.60	70.46	71.32	72.20	73.07	73.96
170	74.85	75.74	76.64	77.55	78.46	79.38	80.30	81.23	82.16	83.10
180	84.04	84.99	85.94	86.90	87.87	88.84	89.82	90.80	91.79	92.78
190	93.78	94.79	95.80	96.82	97.84	98.87	99.90	101.0	102.0	103.0
200	104.1	105.2	106.2	107.3	108.3	109.4	110.5	111.6	112.8	113.9
210	115.0	116.1	117.2	118.4	119.5	120.6	121.8	122.9	124.1	125.2
220	126.4	127.6	128.8	129.9	131.1	132.3	133.5	134.7	136.0	137.2
230	138.4	139.6	140.9	142.1	143.4	144.6	145.9	147.2	148.4	149.7
240	151.0	152.3	153.6	154.9	156.2	157.5	158.8	160.2	161.5	162.9
250	164.2	165.6	166.9	168.3	169.6	171.0	172.4	173.8	175.2	176.6
260	178.0	179.4	180.8	182.3	183.7	185.1	186.6	188.0	189.5	190.9
270	192.4	193.9	195.4	196.8	198.3	199.8	201.3	202.8	204.4	205.9
280	207.4	208.9	210.5	212.0	213.6	215.1	216.7	218.3	219.8	221.4
290	223.0	224.6	226.2	227.9	229.5	231.1	232.7	234.4	236.0	237.7
300	239.3	241.0	242.7	244.3	246.0	247.7	249.4	251.1	252.8	254.5
310	256.2	257.9	259.6	261.4	263.1	264.8	266.6	268.4	270.1	271.9
320	273.7	275.5	277.3	279.1	280.9	282.7	284.5	286.4	288.2	290.1
330	291.9	293.8	295.6	297.5	299.3	301.2	303.1	305.0	306.9	308.8
340	310.7	312.6	314.6	316.5	318.5	320.4	322.4	324.3	326.3	328.2
350	330.2	332.2	334.2	336.2	338.2	340.2	342.2	344.3	346.3	348.4
360	350.4	352.5	354.6	356.6	358.7	360.8	362.9	365.0	367.1	369.2
370	371.3	373.4	375.6	377.7	379.9	382.0	384.2	386.4	388.5	390.7
380	392.9	395.1	397.3	399.6	401.8	404.0	406.2	408.5	410.7	413.0
390	415.2	417.5	419.8	422.1	424.4	426.7	429.0	431.3	433.7	436.0
400	438.3	440.7	443.0	445.4	447.7	450.1	452.5	454.9	457.3	459.7
410	462.1	464.5	466.9	469.4	471.8	474.2	476.7	479.2	481.6	484.1
420	486.6	489.1	491.6	494.1	496.6	499.1	501.7	504.2	506.8	509.3
430	511.9	514.5	517.1	519.6	522.2	524.8	527.4	530.1	532.7	535.4
440	538.0	540.7	543.3	546.0	548.6	551.3	554.0	556.7	559.4	562.1
450	564.8	567.5	570.3	573.0	575.8	578.5	581.3	584.1	586.8	589.6
460	592.4	595.2	598.1	600.9	603.8	606.6	609.5	612.3	615.2	618.0
470	620.9	623.8	626.7	629.7	632.6	635.5	638.4	641.4	644.3	647.3
480	650.2	653.2	656.2	659.2	662.2	665.2	668.2	671.3	674.3	677.4
490	680.4	683.5	686.6	689.6	692.7	695.8	698.9	702.0	705.2	708.3
500	711.4	714.6	717.8	720.9	724.1	727.3	730.5	733.7	737.0	740.2
510	743.4	746.6	749.9	753.1	756.4	759.6	762.9	766.2	769.5	772.8
520	776.1	779.5	782.8	786.2	789.5	792.9	796.3	799.7	803.0	806.4
530	809.8	813.2	816.7	820.1	823.6	827.0	830.5	834.0	837.5	841.0
540	844.5	848.0	851.6	855.1	858.7	862.2	865.8	869.4	872.9	876.5
550	880.1	883.7	887.3	891.0	894.6	898.2	901.9	905.6	909.2	912.9
560	916.6	920.3	924.1	927.8	931.6	935.3	939.1	942.9	946.6	950.4
570	954.2	958.0	961.8	965.7	969.5	973.3	977.2	981.1	984.9	988.8
580	992.7	996.6	1001	1004	1008	1012	1016	1020	1024	1028
590	1032	1036	1040	1044	1048	1052	1056	1060	1065	1069
600	1073	1077	1081	1086	1090	1094	1098	1102	1107	1111
610	1115	1119	1123	1128	1132	1136	1140	1144	1149	1153
620	1157	1161	1166	1170	1175	1179	1183	1188	1192	1197
630	1201	1206	1210	1215	1219	1224	1228	1233	1237	1242
640	1246	1251	1255	1260	1264	1269	1274	1278	1283	1287
650	1292	1297	1302	1306	1311	1316	1321	1326	1330	1335
660	1340	1345	1350	1354	1359	1364	1369	1374	1378	1383
670	1388	1393	1398	1403	1408	1413	1418	1423	1428	1433
680	1438	1443	1448	1453	1458	1463	1468	1473	1479	1484
690	1489	1494	1499	1505	1510	1515	1520	1525	1531	1536
700	1541	1546	1552	1557	1563	1568	1573	1579	1584	1590
710	1595	1600	1606	1611	1617	1622	1628	1633	1639	1644
720	1650	1656	1661	1667	1672	1678	1684	1689	1695	1700
730	1706	1712	1718	1723	1729	1735	1741	1747	1752	1758
740	1764	1770	1776	1781	1787	1793	1799	1805	1811	1817
750	1823	1829	1835	1841	1847	1853	1859	1865	1871	1877
760	1883	1889								

TABLE II

IMPACT PRESSURE q_c IN POUNDS PER SQUARE FOOT FOR VARIOUS VALUES OF CALIBRATED AIRSPEED V_c IN KNOTS

Calibrated airspeed, V_c (knots)	0	1	2	3	4	5	6	7	8	9
0	0	0.003386	0.01356	0.03053	0.05428	0.08479	0.1221	0.1662	0.2171	0.2747
10	.3392	.4105	.4884	.5732	.6648	.7632	.8684	.9803	1.099	1.225
20	1.357	1.496	1.642	1.795	1.954	2.120	2.294	2.474	2.660	2.854
30	3.054	3.261	3.475	3.696	3.923	4.158	4.399	4.647	4.902	5.163
40	5.432	5.707	5.989	6.278	6.574	6.876	7.186	7.502	7.824	8.154
50	8.491	8.835	9.185	9.542	9.906	10.28	10.66	11.04	11.43	11.83
60	12.24	12.65	13.07	13.49	13.92	14.36	14.81	15.26	15.72	16.19
70	16.66	17.15	17.63	18.13	18.63	19.14	19.65	20.18	20.71	21.24
80	21.78	22.34	22.89	23.46	24.03	24.61	25.19	25.78	26.38	26.99
90	27.60	28.22	28.85	29.48	30.12	30.77	31.42	32.08	32.75	33.43
100	34.11	34.80	35.50	36.20	36.91	37.63	38.35	39.08	39.82	40.57
110	41.32	42.08	42.85	43.63	44.41	45.20	45.99	46.80	47.60	48.42
120	49.24	50.08	50.91	51.76	52.61	53.48	54.34	55.22	56.09	56.98
130	57.87	58.78	59.69	60.61	61.53	62.46	63.40	64.35	65.30	66.26
140	67.22	68.20	69.18	70.18	71.17	72.18	73.18	74.20	75.22	76.26
150	77.30	78.35	79.40	80.46	81.53	82.61	83.69	84.79	85.89	87.00
160	88.11	89.24	90.36	91.50	92.63	93.78	94.94	96.11	97.28	98.46
170	99.65	100.8	102.0	103.2	104.5	105.7	106.9	108.2	109.4	110.6
180	111.9	113.2	114.5	115.8	117.1	118.4	119.7	121.0	122.3	123.6
190	125.0	126.4	127.7	129.1	130.4	131.8	133.2	134.6	136.0	137.4
200	138.8	140.2	141.6	143.1	144.5	146.0	147.4	148.9	150.4	151.9
210	153.4	154.9	156.4	157.9	159.4	161.0	162.5	164.1	165.6	167.2
220	168.8	170.4	172.0	173.5	175.1	176.7	178.4	180.0	181.6	183.2
230	184.9	186.6	188.2	189.9	191.6	193.3	195.0	196.7	198.4	200.2
240	201.9	203.6	205.4	207.2	208.9	210.7	212.4	214.2	216.0	217.8
250	219.6	221.5	223.3	225.2	227.0	228.8	230.7	232.6	234.5	236.4
260	238.3	240.2	242.2	244.1	246.0	248.0	249.9	251.8	253.8	255.8
270	257.8	259.7	261.7	263.7	265.8	267.8	269.8	271.8	273.9	276.0
280	278.0	280.1	282.2	284.3	286.4	288.5	290.6	292.8	294.9	297.1
290	299.2	301.4	303.6	305.8	308.0	310.2	312.4	314.6	316.8	319.1
300	321.3	323.6	325.9	328.1	330.4	332.7	335.0	337.3	339.6	342.0
310	344.3	346.6	349.0	351.4	353.8	356.1	358.5	360.9	363.3	365.7
320	368.1	370.6	373.0	375.4	377.9	380.4	382.9	385.4	387.9	390.4
330	393.0	395.5	398.0	400.6	403.2	405.7	408.3	410.9	413.5	416.1
340	418.7	421.4	424.0	426.6	429.3	432.0	434.6	437.3	440.0	442.7
350	445.4	448.2	450.9	453.6	456.4	459.2	461.9	464.7	467.5	470.3
360	473.1	476.0	478.8	481.6	484.5	487.4	490.2	493.1	496.0	498.9
370	501.8	504.8	507.7	510.7	513.6	516.6	519.6	522.6	525.6	528.6
380	531.6	534.6	537.7	540.8	543.8	546.9	550.0	553.0	556.1	559.2
390	562.4	565.5	568.6	571.8	575.0	578.1	581.3	584.5	587.8	591.0
400	594.2	597.4	600.7	604.0	607.2	610.5	613.8	617.1	620.4	623.8
410	627.1	630.4	633.8	637.2	640.6	644.0	647.4	650.8	654.3	657.8
420	661.2	664.7	668.2	671.6	675.1	678.6	682.2	685.7	689.2	692.8
430	696.4	700.0	703.5	707.1	710.8	714.4	718.0	721.6	725.3	729.0
440	732.6	736.3	740.0	743.8	747.5	751.3	755.0	758.8	762.6	766.4
450	770.2	774.0	777.8	781.6	785.5	789.4	793.2	797.1	801.0	805.0
460	808.9	812.8	816.8	820.8	824.7	828.7	832.7	836.7	840.7	844.8
470	848.8	852.9	857.0	861.1	865.2	869.3	873.4	877.6	881.7	885.8
480	890.0	894.2	898.4	902.6	906.8	911.1	915.4	919.6	923.9	928.2
490	932.6	936.9	941.2	945.6	949.9	954.2	958.6	963.0	967.4	971.9
500	976.3	980.8	985.2	989.7	994.2	998.7	1003	1008	1012	1017
510	1022	1026	1031	1036	1040	1044	1049	1054	1058	1063
520	1068	1073	1078	1082	1087	1092	1096	1101	1106	1111
530	1116	1121	1126	1131	1136	1140	1145	1150	1155	1160
540	1165	1170	1175	1180	1185	1190	1196	1201	1206	1211
550	1216	1221	1226	1231	1236	1242	1247	1252	1258	1263
560	1268	1274	1279	1284	1290	1296	1301	1306	1312	1317
570	1322	1328	1333	1339	1344	1350	1356	1362	1367	1372
580	1378	1384	1389	1394	1400	1406	1412	1417	1423	1429
590	1435	1441	1447	1453	1458	1464	1470	1476	1482	1488
600	1494	1500	1506	1512	1518	1524	1530	1536	1542	1548
610	1554	1560	1566	1572	1578	1585	1591	1597	1604	1610
620	1616	1622	1629	1636	1642	1648	1654	1661	1667	1674
630	1680	1686	1693	1700	1706	1713	1720	1726	1733	1740
640	1746	1753	1760	1766	1773	1780	1786	1793	1800	1807
650	1814	1821	1828	1835	1842	1848	1855	1862	1869	1876
660	1883	1890								

TABLE III

STATIC PRESSURE p IN POUNDS PER SQUARE FOOT FOR VALUES OF PRESSURE ALTITUDE h_p FROM −1,000 TO 100,000 FEET

Pressure altitude, h_p	0	100	200	300	400	500	600	700	800	900
−1,000	2194									
−0	2116	2186	2178	2170	2162	2154	2147	2139	2131	2124
0	2116	2108	2101	2093	2086	2078	2070	2063	2056	2048
1,000	2041	2033	2026	2018	2011	2004	1996	1989	1982	1975
2,000	1968	1960	1953	1946	1939	1932	1924	1918	1910	1903
3,000	1896	1889	1882	1876	1868	1862	1855	1848	1841	1834
4,000	1828	1821	1814	1807	1800	1794	1787	1780	1774	1767
5,000	1760	1754	1747	1741	1734	1728	1721	1715	1708	1702
6,000	1696	1689	1683	1676	1670	1664	1658	1651	1645	1639
7,000	1633	1626	1620	1614	1608	1602	1596	1590	1584	1578
8,000	1572	1566	1560	1554	1548	1542	1536	1530	1524	1518
9,000	1512	1506	1501	1495	1489	1483	1478	1472	1466	1461
10,000	1455	1449	1444	1438	1432	1427	1421	1416	1410	1405
11,000	1399	1394	1388	1383	1378	1372	1367	1362	1356	1351
12,000	1346	1340	1335	1330	1324	1319	1314	1309	1304	1298
13,000	1293	1288	1283	1278	1273	1268	1263	1258	1253	1248
14,000	1243	1238	1233	1228	1223	1218	1213	1208	1203	1199
15,000	1194	1189	1184	1180	1175	1170	1165	1160	1156	1151
16,000	1146	1142	1137	1133	1128	1123	1119	1114	1110	1105
17,000	1101	1096	1092	1087	1083	1078	1074	1070	1065	1061
18,000	1056	1052	1048	1043	1039	1035	1030	1026	1022	1018
19,000	1014	1009	1005	1001	996.8	992.6	988.5	984.3	980.2	976.1
20,000	972.1	968.0	963.9	959.9	955.9	951.9	947.9	943.0	939.9	935.9
21,000	932.0	928.1	924.1	920.2	916.3	912.5	908.6	904.8	900.9	897.1
22,000	893.3	889.5	885.7	881.9	878.2	874.4	870.7	867.0	863.2	859.6
23,000	855.9	852.2	848.5	844.9	841.3	837.7	834.0	830.5	826.9	823.3
24,000	819.8	816.2	812.7	809.2	805.7	802.2	798.7	795.2	791.7	788.3
25,000	784.9	781.4	778.0	774.6	771.3	767.9	764.5	761.2	757.8	754.5
26,000	751.2	747.9	744.6	741.3	738.1	734.8	731.6	728.3	725.1	721.9
27,000	718.7	715.5	712.4	709.2	706.0	702.9	699.8	696.7	693.6	690.5
28,000	687.4	684.3	681.2	678.2	675.2	672.1	669.1	666.1	663.1	660.1
29,000	657.1	654.2	651.2	648.3	645.4	642.4	639.5	636.6	633.7	630.9
30,000	628.0	625.2	622.3	619.5	616.6	613.8	611.0	608.2	605.5	602.7
31,000	599.9	597.2	594.4	591.7	589.0	586.3	583.6	580.9	578.2	575.5
32,000	572.9	570.2	567.6	564.9	562.3	559.7	557.1	554.5	551.9	549.4
33,000	546.8	544.2	541.7	539.2	536.6	534.1	531.6	529.1	526.6	524.2
34,000	521.7	519.2	516.8	514.4	511.9	509.5	507.1	504.7	502.3	500.0
35,000	497.6	495.2	492.9	490.5	488.2	485.8	483.5	481.2	478.9	476.6
36,000	474.4	472.1	469.8	467.6	465.4	463.2	461.0	458.8	456.6	454.4
37,000	452.2	450.1	447.9	445.8	443.7	441.6	439.5	437.4	435.3	433.2
38,000	431.1	429.1	427.0	425.0	423.0	421.0	419.0	417.0	415.0	413.0
39,000	411.0	409.1	407.1	405.2	403.3	401.3	399.4	397.5	395.6	393.7
40,000	391.9	390.0	388.1	386.3	384.5	382.6	380.8	379.0	377.2	375.4
41,000	373.6	371.8	370.0	368.3	366.5	364.8	363.0	361.3	359.6	357.9
42,000	356.2	354.5	352.8	351.1	349.4	347.8	346.1	344.5	342.8	341.2
43,000	339.6	337.9	336.3	334.7	333.1	331.5	330.0	328.4	326.8	325.3
44,000	323.7	322.2	320.6	319.1	317.6	316.1	314.6	313.1	311.6	310.1
45,000	308.6	307.6	305.7	304.2	302.8	301.3	300.0	298.5	297.1	295.6
46,000	291.2	292.8	291.4	290.0	288.7	287.3	285.9	284.6	283.2	281.9
47,000	280.5	279.2	277.8	276.5	275.2	273.9	272.6	271.3	270.0	268.7
48,000	267.4	266.2	264.9	263.6	262.4	261.1	259.9	258.6	257.4	256.2
49,000	255.0	253.7	252.5	251.3	250.1	248.9	247.7	246.6	245.4	244.2
50,000	243.1	211.9	240.8	239.6	238.5	237.3	236.2	235.1	234.0	232.8
51,000	231.7	230.6	229.5	228.4	227.3	226.3	225.2	221.1	223.0	222.0
52,000	220.9	219.9	218.8	217.8	216.7	215.7	214.7	213.7	212.6	211.6
53,000	210.6	209.6	208.6	207.6	206.6	205.6	201.7	203.7	202.7	201.8
54,000	200.8	199.8	198.9	197.9	197.0	196.1	195.1	194.2	193.3	192.4
55,000	191.4	190.5	189.6	188.7	187.8	186.9	186.0	185.1	184.2	183.4
56,000	182.5	181.6	180.8	179.9	179.0	178.2	177.3	176.5	175.7	174.8
57,000	174.0	173.2	172.3	171.5	170.7	169.9	169.1	168.3	167.5	166.7
58,000	165.9	165.1	164.3	163.5	162.7	162.0	161.2	160.4	159.7	158.9
59,000	158.1	157.4	156.6	155.9	155.1	154.4	153.7	152.9	152.2	151.5
h_p	0	1000	2000	3000	4000	5000	6000	7030	8000	9000
60,000	150.8	143.8	137.1	130.7	124.6	118.7	113.2	107.9	102.9	98.10
70,000	93.53	89.17	85.00	81.04	77.26	73.66	70.23	66.95	63.82	60.86
80,000	58.01	55.31	52.72	50.26	47.92	45.08	43.55	41.52	39.59	37.74
90,000	35.97	31.30	32.70	31.17	29.72	28.33	27.01	25.75	24.54	23.40
100,000	22.31									

TABLE IV

MACH NUMBER FOR VARIOUS VALUES OF q_c/p

[For example: at $\frac{q_c}{p}=0.021$, $M=0.1725$; at $\frac{q_c}{p}=0.036$, $M=0.2254$]

$\frac{q_c}{p}$	0	1	2	3	4	5	6	7	8	9
0	0.0000	0.0377	0.0536	0.0656	0.0757	0.0846	0.0927	0.1001	0.1069	0.1133
.01	.1194	.1252	.1307	.1360	.1411	.1460	.1508	.1554	.1599	.1642
.02	.1684	.1725	.1765	.1804	.1843	.1881	.1918	.1954	.1990	.2025
.03	.2059	.2093	.2126	.2159	.2191	.2223	.2254	.2285	.2315	.2345
.04	.2374	.2403	.2432	.2460	.2488	.2516	.2543	.2570	.2597	.2623
.05	.2649	.2675	.2701	.2726	.2751	.2776	.2801	.2825	.2849	.2873
.06	.2897	.2921	.2944	.2967	.2990	.3013	.3036	.3058	.3080	.3102
.07	.3124	.3146	.3167	.3189	.3210	.3231	.3252	.3273	.3293	.3314
.08	.3334	.3354	.3374	.3394	.3414	.3434	.3453	.3473	.3492	.3511
.09	.3530	.3549	.3568	.3587	.3606	.3624	.3643	.3661	.3679	.3697
.10	.3715	.3733	.3751	.3769	.3786	.3804	.3821	.3839	.3856	.3873
.11	.3890	.3907	.3924	.3941	.3958	.3974	.3991	.4007	.4024	.4040
.12	.4056	.4072	.4089	.4105	.4121	.4137	.4153	.4168	.4184	.4199
.13	.4215	.4231	.4246	.4261	.4277	.4292	.4307	.4322	.4338	.4353
.14	.4367	.4382	.4397	.4412	.4427	.4441	.4456	.4470	.4484	.4499
.15	.4513	.4527	.4542	.4556	.4570	.4584	.4598	.4612	.4626	.4640
.16	.4654	.4668	.4682	.4695	.4709	.4723	.4736	.4750	.4763	.4777
.17	.4790	.4803	.4817	.4830	.4843	.4856	.4869	.4882	.4895	.4908
.18	.4921	.4934	.4947	.4960	.4972	.4985	.4998	.5010	.5023	.5035
.19	.5048	.5060	.5073	.5085	.5098	.5110	.5122	.5135	.5147	.5159
.20	.5171	.5183	.5195	.5207	.5219	.5231	.5243	.5255	.5266	.5278
.21	.5290	.5302	.5313	.5325	.5337	.5348	.5360	.5372	.5383	.5395
.22	.5406	.5417	.5429	.5440	.5452	.5463	.5474	.5485	.5497	.5508
.23	.5519	.5530	.5541	.5552	.5563	.5574	.5585	.5596	.5607	.5618
.24	.5629	.5640	.5651	.5662	.5673	.5683	.5694	.5705	.5716	.5726
.25	.5737	.5748	.5758	.5769	.5779	.5790	.5800	.5811	.5821	.5832
.26	.5842	.5852	.5863	.5873	.5884	.5894	.5904	.5914	.5925	.5935
.27	.5945	.5955	.5965	.5975	.5985	.5995	.6005	.6015	.6025	.6035
.28	.6045	.6055	.6065	.6075	.6084	.6094	.6104	.6114	.6124	.6133
.29	.6143	.6153	.6162	.6172	.6182	.6191	.6201	.6210	.6220	.6229
.30	.6239	.6248	.6258	.6267	.6277	.6286	.6296	.6305	.6314	.6324
.31	.6333	.6342	.6352	.6361	.6370	.6379	.6388	.6398	.6407	.6416
.32	.6425	.6434	.6443	.6452	.6461	.6470	.6479	.6488	.6497	.6506
.33	.6515	.6524	.6533	.6542	.6551	.6560	.6569	.6578	.6586	.6595
.34	.6604	.6613	.6622	.6630	.6639	.6648	.6656	.6665	.6674	.6682
.35	.6691	.6700	.6708	.6717	.6725	.6734	.6742	.6751	.6759	.6768
.36	.6776	.6784	.6793	.6801	.6810	.6818	.6827	.6835	.6843	.6852
.37	.6860	.6868	.6876	.6885	.6893	.6901	.6909	.6918	.6926	.6934
.38	.6942	.6950	.6958	.6966	.6975	.6983	.6991	.6999	.7007	.7015
.39	.7023	.7031	.7039	.7047	.7055	.7063	.7071	.7079	.7087	.7095
.40	.7103	.7111	.7119	.7127	.7135	.7143	.7151	.7159	.7166	.7174
.41	.7182	.7190	.7197	.7205	.7213	.7221	.7228	.7236	.7244	.7251
.42	.7259	.7267	.7274	.7282	.7290	.7297	.7305	.7312	.7320	.7327
.43	.7335	.7343	.7350	.7358	.7365	.7373	.7380	.7388	.7395	.7403
.44	.7410	.7417	.7425	.7432	.7439	.7446	.7454	.7461	.7468	.7476
.45	.7483	.7490	.7498	.7505	.7512	.7520	.7527	.7534	.7541	.7549
.46	.7556	.7563	.7571	.7578	.7585	.7592	.7599	.7607	.7614	.7621
.47	.7628	.7635	.7642	.7649	.7656	.7663	.7670	.7677	.7684	.7691
.48	.7698	.7705	.7712	.7719	.7726	.7733	.7740	.7747	.7754	.7761
.49	.7768	.7775	.7782	.7788	.7795	.7802	.7809	.7816	.7822	.7829
.50	.7836	.7843	.7850	.7857	.7863	.7870	.7877	.7884	.7890	.7897
.51	.7904	.7911	.7917	.7924	.7931	.7938	.7944	.7951	.7958	.7964
.52	.7971	.7978	.7984	.7991	.7998	.8004	.8011	.8017	.8024	.8030
.53	.8037	.8044	.8050	.8056	.8063	.8070	.8076	.8082	.8089	.8096
.54	.8102	.8109	.8115	.8122	.8128	.8135	.8141	.8148	.8154	.8161
.55	.8167	.8173	.8180	.8186	.8192	.8199	.8205	.8211	.8217	.8224
.56	.8230	.8236	.8243	.8249	.8255	.8262	.8268	.8274	.8280	.8287
.57	.8293	.8299	.8305	.8312	.8318	.8324	.8330	.8336	.8343	.8349
.58	.8355	.8361	.8368	.8374	.8380	.8386	.8392	.8399	.8405	.8411
.59	.8417	.8423	.8429	.8435	.8441	.8447	.8453	.8459	.8465	.8471
.60	.8477	.8483	.8489	.8495	.8501	.8507	.8513	.8519	.8525	.8531
.61	.8537	.8543	.8549	.8555	.8561	.8566	.8572	.8578	.8584	.8590
.62	.8596	.8602	.8608	.8614	.8620	.8626	.8632	.8637	.8643	.8649
.63	.8655	.8661	.8667	.8673	.8678	.8684	.8690	.8696	.8701	.8707
.64	.8713	.8719	.8724	.8730	.8736	.8742	.8747	.8753	.8759	.8764
.65	.8770	.8776	.8781	.8787	.8793	.8799	.8804	.8810	.8816	.8821
.66	.8827	.8833	.8838	.8844	.8850	.8855	.8861	.8866	.8872	.8877
.67	.8883	.8888	.8894	.8900	.8905	.8910	.8916	.8922	.8927	.8932
.68	.8938	.8944	.8949	.8955	.8960	.8966	.8971	.8977	.8982	.8988
.69	.8993	.8998	.9004	.9009	.9015	.9020	.9025	.9031	.9036	.9042
.70	.9047	.9052	.9058	.9063	.9069	.9074	.9080	.9085	.9090	.9096
.71	.9101	.9106	.9112	.9117	.9122	.9128	.9133	.9138	.9143	.9149
.72	.9154	.9159	.9165	.9170	.9175	.9181	.9186	.9191	.9196	.9202
.73	.9207	.9212	.9217	.9223	.9228	.9233	.9238	.9243	.9249	.9254
.74	.9259	.9264	.9269	.9275	.9280	.9285	.9290	.9296	.9301	.9306
.75	.9311	.9316	.9321	.9326	.9331	.9336	.9342	.9347	.9352	.9357
.76	.9362	.9367	.9372	.9377	.9383	.9388	.9393	.9398	.9403	.9408
.77	.9413	.9418	.9423	.9428	.9433	.9438	.9443	.9448	.9453	.9458
.78	.9463	.9468	.9473	.9478	.9483	.9488	.9493	.9498	.9503	.9508
.79	.9513	.9518	.9523	.9528	.9533	.9538	.9542	.9547	.9552	.9557
.80	.9562	.9567	.9572	.9577	.9582	.9587	.9592	.9596	.9601	.9606
.81	.9611	.9616	.9621	.9625	.9630	.9635	.9640	.9645	.9649	.9654
.82	.9659	.9664	.9669	.9673	.9678	.9683	.9688	.9693	.9697	.9702
.83	.9707	.9712	.9717	.9722	.9726	.9731	.9736	.9741	.9745	.9750
.84	.9755	.9760	.9764	.9769	.9774	.9778	.9783	.9788	.9793	.9797
.85	.9802	.9807	.9811	.9816	.9821	.9826	.9830	.9835	.9840	.9844
.86	.9849	.9854	.9858	.9863	.9867	.9872	.9877	.9881	.9886	.9890
.87	.9895	.9900	.9904	.9909	.9913	.9918	.9923	.9927	.9932	.9936
.88	.9941	.9946	.9950	.9955	.9960	.9964	.9969	.9973	.9979	.9982
.89	.9987	.9992	.9996	1.0000						

TABLE V

SPEED OF SOUND FOR VARIOUS VALUES OF FREE-AIR TEMPERATURE IN DEGREES FAHRENHEIT

t (°F)	0	1	2	3	4	5	6	7	8	9
Speed of sound, mph										
−70	659.5									
−60	667.9	667.1	666.2	665.4	664.5	663.7	662.9	662.0	661.2	660.3
−50	676.2	675.4	674.6	673.7	672.9	672.1	671.2	670.4	669.6	668.7
−40	684.4	683.6	682.8	682.0	681.1	680.3	679.5	678.7	677.9	677.0
−30	692.5	691.7	690.9	690.1	689.3	688.5	687.7	686.9	686.0	685.2
−20	700.5	699.7	698.9	698.1	697.3	696.5	695.7	694.9	694.1	693.3
−10	708.5	707.7	706.9	706.1	705.3	704.5	703.7	702.9	702.1	701.3
−0	716.3	715.5	714.8	714.0	713.2	712.4	711.6	710.8	710.0	709.2
0	716.3	717.1	717.9	718.6	719.4	720.2	721.0	721.7	722.5	723.3
10	724.1	724.8	725.6	726.4	727.1	727.9	728.7	729.4	730.2	731.0
20	731.7	732.5	733.3	734.0	734.8	735.5	736.3	737.1	737.8	738.6
30	739.3	740.1	740.8	741.6	742.3	743.1	743.8	744.6	745.3	746.1
40	746.8	747.6	748.3	749.1	749.8	750.6	751.3	752.1	752.8	753.5
50	754.3	755.0	755.8	756.5	757.2	758.0	758.7	759.4	760.2	760.9
60	761.6	762.4	763.1	763.8	764.6	765.3	766.0	766.8	767.5	768.2
70	769.0	769.7	770.4	771.1	771.8	772.6	773.3	744.0 774.	774.7	775.4
80	776.2	776.9	777.6	778.3	779.0	779.8	780.5	781.2	781.9	782.6
90	783.3	784.0	784.8	785.5	786.2	786.9	787.6	788.3	789.0	789.7
100	790.4	791.1	791.8	792.5	793.2	794.0	794.7	795.4	796.1	796.8
110	797.5	798.2	798.9	799.6	800.3	801.0	801.7	802.4	803.0	803.7
120	804.4									
Speed of sound, knots										
−70	572.6									
−60	580.0	579.2	578.5	577.8	577.0	576.3	575.6	574.9	574.1	573.4
−50	587.2	586.5	585.7	585.0	584.3	583.6	582.9	582.1	581.4	580.7
−40	594.3	593.6	592.9	592.2	591.5	590.8	590.0	589.3	588.6	587.9
−30	601.3	600.6	599.9	599.2	598.5	597.8	597.1	596.4	595.7	595.0
−20	608.3	607.6	606.9	606.2	605.5	604.8	604.1	603.4	602.7	602.0
−10	615.2	614.5	613.8	613.1	612.4	611.8	611.1	610.4	609.7	609.0
−0	622.0	621.3	620.6	620.0	619.3	618.6	617.9	617.2	616.6	615.9
0	622.0	622.7	623.4	624.0	624.7	625.4	626.0	626.7	627.4	628.1
10	628.7	629.4	630.1	630.7	631.4	632.1	632.7	633.4	634.1	634.7
20	635.4	636.1	636.7	637.4	638.0	638.7	639.4	640.0	640.7	641.3
30	642.0	642.6	643.3	644.0	644.6	645.3	645.9	646.6	647.2	647.9
40	648.5	649.2	649.8	650.5	651.1	651.8	652.4	653.0	653.7	654.3
50	655.0	655.6	656.3	656.9	657.5	658.2	658.8	659.5	660.1	660.7
60	661.4	662.0	662.6	663.3	663.9	664.6	665.2	665.8	666.4	667.1
70	667.7	668.3	669.0	669.6	670.2	670.8	671.5	672.1	672.7	673.4
80	674.0	674.6	675.2	675.9	676.5	677.1	677.7	678.3	679.0	679.6
90	680.2	680.8	681.4	682.1	682.7	683.3	683.9	684.5	685.1	685.8
100	686.4	687.0	687.6	688.2	688.8	689.4	690.0	690.6	691.3	691.9
110	692.5	693.1	693.7	694.3	694.9	695.5	696.1	696.7	697.3	697.9
120	698.5									

TABLE VI

SPEED OF SOUND FOR VARIOUS VALUES OF FREE-AIR TEMPERATURE IN DEGREES CENTIGRADE

t (°C)	0	1	2	3	4	5	6	7	8	9
Speed of sound, mph										
−60	654.4									
−50	669.6	668.1	666.6	665.1	663.6	662.0	660.5	659.0	657.5	656.0
−40	684.4	683.0	681.5	680.0	678.6	677.1	675.6	674.1	672.6	671.1
−30	699.0	697.5	696.1	694.6	693.2	691.8	690.3	688.8	687.4	685.9
−20	713.2	711.8	710.4	709.0	707.6	706.1	704.7	703.3	701.8	700.4
−10	727.2	725.8	724.4	723.0	721.6	720.2	718.8	717.4	716.0	714.6
−0	740.9	739.5	738.2	736.8	735.4	734.1	732.7	731.3	729.9	728.6
0	740.9	742.2	743.6	744.9	746.3	747.6	749.0	750.3	751.6	753.0
10	754.3	755.6	757.0	758.3	759.6	761.0	762.3	763.6	764.9	766.2
20	767.5	768.8	770.1	771.4	772.7	774.0	775.3	776.6	777.9	779.2
30	780.5	781.8	783.1	784.4	785.6	786.9	788.2	789.5	790.8	792.0
40	793.3	794.6	795.8	797.1	798.4	799.6	800.8	802.1	803.4	804.6
50	805.9									
Speed of sound, knots										
−60	568.3									
−50	581.5	580.2	578.9	577.6	576.2	574.9	573.6	572.3	571.0	569.6
−40	594.4	593.1	591.8	590.6	589.3	588.0	586.7	585.4	584.1	582.8
−30	607.0	605.8	604.5	603.2	602.0	600.7	599.5	598.2	596.9	595.7
−20	619.4	618.2	616.9	615.7	614.5	613.2	612.0	610.8	609.5	608.3
−10	631.5	630.3	629.1	627.9	626.7	625.5	624.2	623.0	621.8	620.6
−0	643.4	642.2	641.0	639.8	638.7	637.5	636.3	635.1	633.9	632.7
0	643.4	644.6	645.7	646.9	648.1	649.2	650.4	651.6	652.8	653.9
10	655.1	656.2	657.4	658.5	659.7	660.8	662.0	663.1	664.3	665.4
20	666.5	667.7	668.8	669.9	671.1	672.2	673.3	674.5	675.6	676.7
30	677.8	678.9	680.0	681.2	682.3	683.4	684.5	685.6	686.7	687.8
40	688.9	690.0	691.1	692.2	693.3	694.4	695.5	696.6	697.7	698.8
50	699.8									

TABLE VII

PROPERTIES OF THE STANDARD ATMOSPHERE

Altitude, h (ft)	Pressure, p			Density, ρ (slugs/ft^3)	Density ratio, $\sigma=\frac{\rho}{\rho_0}$	$\frac{1}{\sqrt{\sigma}}$	Temperature, T (°F abs.)	Speed of sound, a (mph)	Coefficient of viscosity, μ (slugs/ft-sec)	Kinematic viscosity, ν (ft^2/sec)
	(lb/ft^2)	(in. H_2O)	(in. Hg)							
0	2116	407.1	29.92	0.002378	1.0000	1.0000	518.4	760.9	3.725×10^{-7}	1.566×10^{-4}
500	2078	399.8	29.38	.002343	.9855	1.007	516.6	759.6	3.716	1.586
1,000	2041	392.6	28.86	.002309	.9710	1.015	514.8	758.3	3.705	1.604
1,500	2004	385.5	28.33	.002275	.9568	1.022	513.0	757.0	3.695	1.624
2,000	1968	378.5	27.82	.002242	.9428	1.030	511.2	755.7	3.685	1.644
2,500	1932	371.6	27.31	.002209	.9288	1.038	509.5	754.3	3.674	1.663
3,000	1896	364.8	26.81	.002176	.9151	1.045	507.7	753.0	3.664	1.684
3,500	1862	358.2	26.32	.002144	.9015	1.053	505.9	751.7	3.654	1.704
4,000	1828	351.6	25.84	.002112	.8881	1.061	504.1	750.4	3.644	1.725
4,500	1794	345.1	25.36	.002080	.8748	1.069	502.4	749.1	3.633	1.747
5,000	1760	338.7	24.89	.002049	.8616	1.077	500.6	747.7	3.623	1.768
5,500	1728	332.4	24.43	.002018	.8487	1.085	498.8	746.4	3.612	1.790
6,000	1696	326.2	23.98	.001988	.8358	1.094	497.0	745.1	3.602	1.812
6,500	1664	320.1	23.53	.001957	.8232	1.102	495.2	743.7	3.592	1.835
7,000	1633	314.1	23.09	.001928	.8106	1.111	493.4	742.3	3.581	1.857
7,500	1602	308.2	22.65	.001898	.7982	1.119	491.7	741.0	3.571	1.881
8,000	1572	302.4	22.22	.001869	.7859	1.128	489.9	739.7	3.561	1.905
8,500	1542	296.6	21.80	.001840	.7738	1.137	488.1	738.3	3.550	1.929
9,000	1512	291.0	21.38	.001812	.7619	1.146	486.3	737.0	3.540	1.954
9,500	1483	285.4	20.98	.001784	.7501	1.155	484.5	735.6	3.529	1.978
10,000	1455	279.9	20.58	.001756	.7384	1.164	482.7	734.3	3.519	2.004
10,500	1427	274.5	20.18	.001728	.7269	1.173	481.0	732.9	3.508	2.030
11,000	1399	269.2	19.79	.001702	.7154	1.182	479.2	731.6	3.498	2.055
11,500	1372	264.0	19.40	.001675	.7042	1.192	477.4	730.2	3.487	2.082
12,000	1346	258.9	19.03	.001648	.6931	1.201	475.6	728.8	3.476	2.109
12,500	1319	253.8	18.65	.001622	.6821	1.211	473.8	727.5	3.466	2.137
13,000	1293	248.8	18.29	.001596	.6712	1.220	472.0	726.1	3.455	2.165
13,500	1268	243.9	17.93	.001570	.6605	1.230	470.3	724.7	3.445	2.194
14,000	1243	239.1	17.57	.001545	.6499	1.240	468.5	723.4	3.434	2.223
14,500	1218	234.4	17.22	.001520	.6394	1.250	466.7	722.0	3.423	2.252
15,000	1194	229.7	16.88	.001496	.6291	1.261	464.9	720.6	3.413	2.281
15,500	1170	225.1	16.54	.001472	.6189	1.271	463.1	719.2	3.402	2.311
16,000	1146	220.6	16.21	.001448	.6088	1.282	461.3	717.8	3.391	2.342
16,500	1123	216.1	15.89	.001424	.5988	1.292	459.6	716.4	3.380	2.374
17,000	1101	211.8	15.56	.001401	.5891	1.303	457.8	715.0	3.370	2.405
17,500	1078	207.5	15.25	.001378	.5793	1.314	456.0	713.6	3.359	2.438
18,000	1056	203.2	14.94	.001355	.5698	1.325	454.2	712.2	3.348	2.471
18,500	1035	199.1	14.63	.001333	.5603	1.336	452.4	710.8	3.337	2.503
19,000	1014	195.0	14.33	.001311	.5509	1.347	450.6	709.4	3.325	2.537
19,500	992.6	191.0	14.04	.001289	.5418	1.358	448.9	708.0	3.316	2.572
20,000	972.1	187.0	13.75	.001267	.5327	1.370	447.1	706.6	3.305	2.608
20,500	951.9	183.1	13.46	.001246	.5237	1.382	445.3	705.2	3.294	2.644
21,000	932.0	179.3	13.18	.001225	.5148	1.394	443.5	703.8	3.283	2.680
21,500	912.5	175.6	12.90	.001204	.5061	1.406	441.7	702.4	3.272	2.718
22,000	893.3	171.9	12.63	.001183	.4974	1.418	439.9	701.0	3.261	2.756
22,500	874.4	168.2	12.36	.001163	.4889	1.430	438.2	699.6	3.250	2.794
23,000	855.9	164.7	12.10	.001143	.4805	1.443	436.4	698.1	3.239	2.834
23,500	837.7	161.2	11.84	.001123	.4721	1.455	434.6	696.7	3.228	2.874
24,000	819.8	157.7	11.59	.001103	.4640	1.468	432.8	695.3	3.217	2.916
24,500	802.2	154.3	11.34	.001085	.4559	1.481	431.0	693.8	3.206	2.955
25,000	784.9	151.0	11.10	.001065	.4480	1.494	429.2	692.4	3.195	3.000
25,500	767.9	147.7	10.86	.001046	.4401	1.507	427.5	691.0	3.184	3.044
26,000	751.2	144.5	10.62	.001028	.4323	1.521	425.7	689.5	3.173	3.086
26,500	734.8	141.4	10.39	.001010	.4247	1.534	423.9	688.1	3.162	3.131
27,000	718.7	138.3	10.16	.000992	.4171	1.548	422.1	686.6	3.150	3.175
27,500	702.9	135.2	9.939	.000974	.4097	1.562	420.3	685.2	3.139	3.223
28,000	687.4	132.2	9.720	.000957	.4023	1.577	418.5	683.7	3.128	3.268
28,500	672.1	129.3	9.504	.000940	.3951	1.591	416.8	682.3	3.117	3.316
29,000	657.1	126.4	9.293	.000922	.3879	1.606	415.0	680.8	3.106	3.369
29,500	642.4	123.6	9.085	.000906	.3809	1.620	413.2	679.3	3.094	3.415
30,000	628.0	120.8	8.880	.000889	.3740	1.635	411.4	677.9	3.083	3.468
30,500	613.8	118.0	8.680	.000873	.3671	1.650	409.6	676.4	3.072	3.519
31,000	599.9	115.4	8.483	.000857	.3603	1.666	407.8	674.9	3.060	3.570
31,500	586.3	112.8	8.290	.000842	.3537	1.682	406.1	673.4	3.049	3.621
32,000	572.9	110.2	8.101	.000826	.3472	1.697	404.3	672.0	3.038	3.678
32,500	559.7	107.6	7.915	.000810	.3406	1.713	402.5	670.5	3.026	3.736
33,000	546.8	105.2	7.732	.000795	.3343	1.730	400.7	669.0	3.015	3.792
33,500	534.1	102.8	7.554	.000780	.3280	1.746	399.0	667.5	3.004	3.851
34,000	521.7	100.4	7.377	.000765	.3218	1.763	397.2	666.0	2.992	3.911
34,500	509.5	98.03	7.205	.000750	.3158	1.779	395.4	664.5	2.981	3.975

TABLE VII

PROPERTIES OF THE STANDARD ATMOSPHERE—Concluded

Altitude, h (ft)	Pressure, p (lb/ft²)	Pressure, p (in. H_2O)	Pressure, p (in. Hg)	Density, ρ (slugs/ft³)	Density ratio, $\sigma=\frac{\rho}{\rho_0}$	$\frac{1}{\sqrt{\sigma}}$	Temperature, T (°F abs.)	Speed of sound, a (mph)	Coefficient of viscosity, μ (slugs/ft-sec)	Kinematic viscosity, ν (ft²/sec)
35, 000	497. 6	95. 75	7. 036	0. 000736	0. 3098	1. 797	393. 6	663. 0	2. 969 $\times 10^{-7}$	4. 034 $\times 10^{-4}$
35, 332	489. 8	94. 24	6. 926	. 000727	. 3058	1. 808	392. 4	662. 0	2. 962	4. 073
35, 500	485. 8	93. 51	6. 873	. 000721	. 3034	1. 816	392. 4	662. 0	2. 962	4. 105
36, 000	474. 4	91. 31	6. 711	. 000705	. 2963	1. 837	392. 4	662. 0	2. 962	4. 204
36, 500	463. 2	89. 15	6. 552	. 000688	. 2893	1. 859	392. 4	662. 0	2. 962	4. 306
37, 000	452. 2	87. 04	6. 397	. 000672	. 2824	1. 881	392. 4	662. 0	2. 962	4. 410
37, 500	441. 6	85. 00	6. 247	. 000656	. 2758	1. 904	392. 4	662. 0	2. 962	4. 516
38, 000	431. 1	82. 97	6. 098	. 000640	. 2692	1. 927	392. 4	662. 0	2. 962	4. 625
38, 500	421. 0	81. 01	5. 954	. 000625	. 2629	1. 950	392. 4	662. 0	2. 962	4. 737
39, 000	411. 0	79. 10	5. 813	. 000610	. 2567	1. 974	392. 4	662. 0	2. 962	4. 852
39, 500	401. 3	77. 23	5. 676	. 000596	. 2506	1. 998	392. 4	662. 0	2. 962	4. 969
40, 000	391. 9	75. 44	5. 544	. 000582	. 2448	2. 021	392. 4	662. 0	2. 962	5. 089
40, 500	382. 6	73. 64	5. 412	. 000568	. 2390	2. 045	392. 4	662. 0	2. 962	5. 212
41, 000	373. 6	71. 89	5. 284	. 000555	. 2333	2. 070	392. 4	662. 0	2. 962	5. 338
41, 500	364. 8	70. 18	5. 158	. 000542	. 2278	2. 095	392. 4	662. 0	2. 962	5. 467
42, 000	356. 2	68. 56	5. 038	. 000529	. 2225	2. 120	392. 4	662. 0	2. 962	5. 599
42, 500	347. 8	66. 93	4. 919	. 000516	. 2172	2. 146	392. 4	662. 0	2. 962	5. 735
43, 000	339. 6	65. 34	4. 802	. 000504	. 2120	2. 172	392. 4	662. 0	2. 962	5. 873
43, 500	331. 5	63. 79	4. 688	. 000492	. 2070	2. 198	392. 4	662. 0	2. 962	6. 015
44, 000	323. 7	62. 29	4. 578	. 000480	. 2021	2. 224	392. 4	662. 0	2. 962	6. 161
44, 500	316. 1	60. 82	4. 470	. 000469	. 1974	2. 251	392. 4	662. 0	2. 962	6. 310
45, 000	308. 6	59. 40	4. 365	. 000458	. 1927	2. 278	392. 4	662. 0	2. 962	6. 462
45, 500	301. 3	58. 01	4. 263	. 000448	. 1882	2. 305	392. 4	662. 0	2. 962	6. 618
46, 000	294. 2	56. 63	4. 162	. 000437	. 1838	2. 333	392. 4	662. 0	2. 962	6. 778
46, 500	287. 3	55. 28	4. 063	. 000427	. 1794	2. 361	392. 4	662. 0	2. 962	6. 942
47, 000	280. 5	53. 98	3. 967	. 000417	. 1752	2. 389	392. 4	662. 0	2. 962	7. 110
47, 500	273. 9	52. 72	3. 875	. 000407	. 1711	2. 418	392. 4	662. 0	2. 962	7. 282
48, 000	267. 4	51. 46	3. 782	. 000397	. 1670	2. 447	392. 4	662. 0	2. 962	7. 459
48, 500	261. 1	50. 24	3. 692	. 000388	. 1630	2. 477	392. 4	662. 0	2. 962	7. 640
49, 000	255. 0	49. 06	3. 605	. 000379	. 1592	2. 506	392. 4	662. 0	2. 962	7. 824
49, 500	248. 9	47. 92	3. 522	. 000370	. 1555	2. 536	392. 4	662. 0	2. 962	8. 012
50, 000	243. 1	46. 78	3. 438	. 000361	. 1518	2. 567	392. 4	662. 0	2. 962	8. 206
50, 500	237. 3	45. 67	3. 357	. 000352	. 1482	2. 598	392. 4	662. 0	2. 962	8. 404
51, 000	231. 7	44. 60	3. 276	. 000344	. 1447	2. 629	392. 4	662. 0	2. 962	8. 607
51, 500	226. 3	43. 54	3. 200	. 000336	. 1413	2. 660	392. 4	662. 0	2. 962	8. 815
52, 000	220. 9	42. 52	3. 124	. 000328	. 1379	2. 692	392. 4	662. 0	2. 962	9. 028
52, 500	215. 7	41. 51	3. 051	. 000320	. 1347	2. 725	392. 4	662. 0	2. 962	9. 246
53, 000	210. 6	40. 53	2. 979	. 000313	. 1315	2. 758	392. 4	662. 0	2. 962	9. 470
53, 500	205. 6	39. 57	2. 908	. 000305	. 1284	2. 791	392. 4	662. 0	2. 962	9. 699
54, 000	200. 8	38. 64	2. 840	. 000298	. 1254	2. 824	392. 4	662. 0	2. 962	9. 933
54, 500	196. 1	37. 73	2. 773	. 000291	. 1224	2. 858	392. 4	662. 0	2. 962	10. 17
55, 000	191. 4	36. 84	2. 707	. 000284	. 1195	2. 893	392. 4	662. 0	2. 962	10. 42
55, 500	186. 9	35. 97	2. 644	. 000278	. 1167	2. 927	392. 4	662. 0	2. 962	10. 67
56, 000	182. 5	35. 12	2. 581	. 000271	. 1140	2. 962	392. 4	662. 0	2. 962	10. 93
56, 500	178. 2	34. 29	2. 520	. 000264	. 1113	2. 997	392. 4	662. 0	2. 962	11. 19
57, 000	174. 0	33. 48	2. 461	. 000258	. 1087	3. 033	392. 4	662. 0	2. 962	11. 46
57, 500	169. 9	32. 69	2. 403	. 000252	. 1061	3. 070	392. 4	662. 0	2. 962	11. 74
58, 000	165. 9	31. 92	2. 346	. 000246	. 1036	3. 107	392. 4	662. 0	2. 962	12. 02
58, 500	162. 0	31. 17	2. 291	. 000240	. 1011	3. 145	392. 4	662. 0	2. 962	12. 32
59, 000	158. 1	30. 43	2. 236	. 000235	. 09875	3. 182	392. 4	662. 0	2. 962	12. 61
59, 500	154. 4	29. 71	2. 184	. 000229	. 09643	3. 220	392. 4	662. 0	2. 962	12. 92
60, 000	150. 8	29. 01	2. 132	. 000224	. 09415	3. 259	392. 4	662. 0	2. 962	13. 23
60, 500	147. 2	28. 33	2. 082	. 000218	. 09192	3. 298	392. 4	662. 0	2. 962	13. 55
61, 000	143. 8	27. 66	2. 033	. 000213	. 08976	3. 338	392. 4	662. 0	2. 962	13. 88
61, 500	140. 4	27. 01	1. 985	. 000208	. 08764	3. 378	392. 4	662. 0	2. 962	14. 21
62, 000	137. 1	26. 37	1. 938	. 000203	. 08557	3. 419	392. 4	662. 0	2. 962	14. 56
62, 500	133. 8	25. 74	1. 892	. 000199	. 08355	3. 460	392. 4	662. 0	2. 962	14. 91
63, 000	130. 7	25. 14	1. 848	. 000194	. 08158	3. 501	392. 4	662. 0	2. 962	15. 27
63, 500	127. 6	24. 54	1. 804	. 000189	. 07965	3. 543	392. 4	662. 0	2. 962	15. 64
64, 000	124. 6	23. 96	1. 761	. 000185	. 07777	3. 586	392. 4	662. 0	2. 962	16. 02
64, 500	121. 6	23. 40	1. 720	. 000180	. 07594	3. 629	392. 4	662. 0	2. 962	16. 40
65, 000	118. 7	22. 85	1. 679	. 000176	. 07414	3. 672	392. 4	662. 0	2. 962	16. 80

TABLE VIII

PROPERTIES OF THE TENTATIVE STANDARD-ATMOSPHERE EXTENSION

Altitude, h (ft)	Pressure, p (lb/ft²)	Pressure, p (in. H_2O)	Pressure, p (in. Hg)	Density, ρ (slugs/ft³)	Density ratio, $\sigma=\frac{\rho}{\rho_0}$	$\frac{1}{\sqrt{\sigma}}$	Temperature, T (°F abs.)	Speed of sound, a (mph)	Coefficient of viscosity, μ (slugs/ft-sec)	Kinematic viscosity, ν (ft²/sec)
65,000	118.7	22.85	1.679	0.000176	0.07414	3.672	392.4	662.0	2.962×10⁻⁷	16.80×10⁻⁴
65,500	116.0	22.31	1.640	.000172	.07240	3.716	392.4	662.0	2.962	17.20
66,000	113.2	21.78	1.601	.000168	.07069	3.761	392.4	662.0	2.962	17.62
66,500	110.5	21.27	1.563	.000164	.06901	3.807	392.4	662.0	2.962	18.05
67,000	107.9	20.77	1.526	.000160	.06739	3.852	392.4	662.0	2.962	18.48
67,500	105.4	20.28	1.490	.000156	.06580	3.898	392.4	662.0	2.962	18.93
68,000	102.9	19.80	1.455	.000153	.06424	3.945	392.4	662.0	2.962	19.39
68,500	100.5	19.33	1.421	.000149	.06272	3.993	392.4	662.0	2.962	19.86
69,000	98.10	18.87	1.387	.000146	.06125	4.041	392.4	662.0	2.962	20.34
69,500	95.79	18.43	1.354	.000142	.05981	4.089	392.4	662.0	2.962	20.83
70,000	93.53	17.99	1.322	.000139	.05839	4.138	392.4	662.0	2.962	21.33
70,500	91.33	17.57	1.291	.000136	.05702	4.188	392.4	662.0	2.962	21.85
71,000	89.17	17.16	1.261	.000132	.05567	4.238	392.4	662.0	2.962	22.38
71,500	87.05	16.75	1.231	.000129	.05435	4.289	392.4	662.0	2.962	22.92
72,000	85.00	16.35	1.202	.000126	.05307	4.341	392.4	662.0	2.962	23.47
72,500	82.99	15.97	1.173	.000123	.05181	4.393	392.4	662.0	2.962	24.04
73,000	81.04	15.59	1.146	.000120	.05060	4.446	392.4	662.0	2.962	24.62
73,500	79.14	15.22	1.119	.000117	.04941	4.499	392.4	662.0	2.962	25.21
74,000	77.26	14.86	1.092	.000115	.04823	4.554	392.4	662.0	2.962	25.82
74,500	75.44	14.51	1.067	.000112	.04710	4.608	392.4	662.0	2.962	26.45
75,000	73.66	14.17	1.042	.000109	.04599	4.663	392.4	662.0	2.962	27.09
75,500	71.92	13.84	1.017	.000107	.04490	4.719	392.4	662.0	2.962	27.74
76,000	70.23	13.51	.9930	.000104	.04385	4.775	392.4	662.0	2.962	28.41
76,500	68.58	13.19	.9694	.000102	.04280	4.833	392.4	662.0	2.962	29.10
77,000	66.95	12.88	.9467	.0000994	.04180	4.891	392.4	662.0	2.962	29.80
77,500	65.36	12.58	.9242	.0000970	.04081	4.950	392.4	662.0	2.962	30.52
78,000	63.82	12.28	.9024	.0000947	.03984	5.010	392.4	662.0	2.962	31.26
78,500	62.32	11.99	.8811	.0000925	.03891	5.070	392.4	662.0	2.962	32.01
79,000	60.86	11.71	.8605	.0000903	.03799	5.131	392.4	662.0	2.962	32.79
79,500	59.42	11.43	.8402	.0000882	.03710	5.192	392.4	662.0	2.962	33.58
80,000	58.01	11.16	.8202	.0000861	.03621	5.255	392.4	662.0	2.962	34.39
80,500	56.64	10.90	.8010	.0000841	.03536	5.317	392.4	662.0	2.962	35.22
81,000	55.31	10.64	.7821	.0000821	.03453	5.381	392.4	662.0	2.962	36.08
81,500	54.00	10.39	.7636	.0000802	.03371	5.446	392.4	662.0	2.962	36.95
82,000	52.72	10.14	.7456	.0000783	.03292	5.511	392.4	662.0	2.962	37.84
82,500	51.48	9.904	.7280	.0000764	.03214	5.578	392.4	662.0	2.962	38.76
83,000	50.26	9.670	.7106	.0000746	.03138	5.645	392.4	662.0	2.962	39.69
83,500	49.08	9.442	.6938	.0000729	.03064	5.713	392.4	662.0	2.962	40.65
84,000	47.92	9.210	.6776	.0000711	.02992	5.781	392.4	662.0	2.962	41.63
84,500	46.79	9.001	.6616	.0000695	.02921	5.851	392.4	662.0	2.962	42.64
85,000	45.68	8.789	.6460	.0000678	.02852	5.921	392.4	662.0	2.962	43.67
85,500	44.60	8.582	.6307	.0000662	.02785	5.992	392.4	662.0	2.962	44.73
86,000	43.55	8.379	.6158	.0000646	.02719	6.064	392.4	662.0	2.962	45.81
86,500	42.52	8.181	.6013	.0000631	.02655	6.137	392.4	662.0	2.962	46.92
87,000	41.52	7.988	.5871	.0000616	.02592	6.211	392.4	662.0	2.962	48.05
87,500	40.54	7.800	.5733	.0000602	.02531	6.286	392.4	662.0	2.962	49.21
88,000	39.59	7.617	.5598	.0000588	.02472	6.361	392.4	662.0	2.962	50.40
88,500	38.66	7.436	.5466	.0000574	.02414	6.437	392.4	662.0	2.962	51.62
89,000	37.74	7.260	.5335	.0000560	.02356	6.515	392.4	662.0	2.962	52.87
89,500	36.84	7.089	.5209	.0000547	.02300	6.593	392.4	662.0	2.962	54.14
90,000	35.97	6.921	.5086	.0000534	.02246	6.672	392.4	662.0	2.962	55.45
90,500	35.12	6.758	.4967	.0000521	.02193	6.752	392.4	662.0	2.962	56.79
91,000	34.30	6.599	.4850	.0000509	.02142	6.834	392.4	662.0	2.962	58.16
91,500	33.49	6.443	.4736	.0000497	.02091	6.916	392.4	662.0	2.962	59.57
92,000	32.70	6.291	.4624	.0000485	.02041	6.999	392.4	663.0	2.962	61.01
92,500	31.93	6.143	.4514	.0000474	.01993	7.083	392.4	662.0	2.962	62.49
93,000	31.17	5.998	.4407	.0000463	.01946	7.168	392.4	662.0	2.962	64.00
93,500	30.43	5.856	.4304	.0000452	.01900	7.254	392.4	662.0	2.962	65.54
94,000	29.72	5.718	.4202	.0000441	.01856	7.341	392.4	662.0	2.962	67.13
94,500	29.02	5.583	.4102	.0000431	.01812	7.429	392.4	662.0	2.962	68.75
95,000	28.33	5.451	.4006	.0000421	.01769	7.519	392.4	662.0	2.962	70.41
95,500	27.66	5.322	.3912	.0000411	.01727	7.609	392.4	662.0	2.962	72.11
96,000	27.01	5.197	.3819	.0000401	.01687	7.700	392.4	662.0	2.962	73.86
96,500	26.37	5.074	.3729	.0000391	.01647	7.792	392.4	662.0	2.962	75.64
97,000	25.75	4.954	.3641	.0000382	.01608	7.886	392.4	662.0	2.962	77.47
97,500	25.14	4.837	.3554	.0000373	.01570	7.981	392.4	662.0	2.962	79.34
98,000	24.54	4.723	.3471	.0000364	.01533	8.077	392.4	662.0	2.962	81.26
98,500	23.97	4.612	.3390	.0000356	.01497	8.174	392.4	662.0	2.962	83.22
99,000	23.40	4.503	.3309	.0000347	.01461	8.272	392.4	662.0	2.962	85.24
99,500	22.85	4.397	.3231	.0000339	.01427	8.371	392.4	662.0	2.962	87.30
100,000	22.31	4.293	.3156	.0000331	.01394	8.472	392.4	662.0	2.962	89.41

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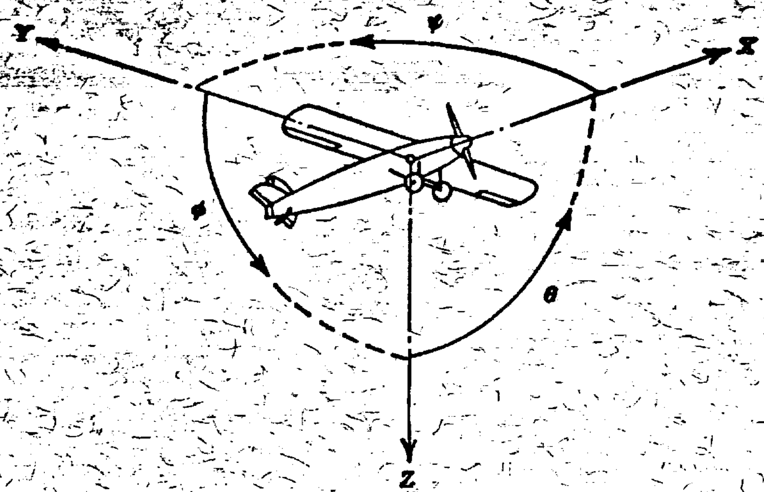

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l = \frac{L}{qbS}$ (rolling) $C_m = \frac{M}{qcS}$ (pitching) $C_n = \frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

- D Diameter
- p Geometric pitch
- p/D Pitch ratio
- V' Inflow velocity
- V_s Slipstream velocity
- T Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$
- Q Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$
- P Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$
- C_s Speed-power coefficient $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$
- η Efficiency
- n Revolutions per second, rps
- Φ Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg-m/s = 550 ft-lb/sec

1 metric horsepower = 0.9863 hp

1 mph = 0.4470 mps

1 mps = 2.2369 mph

1 lb = 0.4536 kg

1 kg = 2.2046 lb

1 mi = 1,609.35 m = 5,280 ft

1 m = 3.2808 ft