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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1200

TENTATIVE TABLES FOR THE PROPERTIES OF THE UPPER ATMOSPHERE

By Calvin N. Warfield

for the

NACA Special Subcommittee on the Upper Atmosphere

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

Washington

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SUMMARY

As a result of recent developments in aeronautics and ordnance, a need has arisen for tables of properties of the atmosphere at altitudes in excess of those covered by the existing standard tables (NACA Report No. 218). In order to satisfy this need, the National Advisory Committee for Aeronautics has adopted three temperature-height relationships and one composition-height relationship, and tables based upon them have been prepared for pertinent properties of the upper atmosphere (that is, from 20 to 120 kilometers in metric units, and from 65,000 to 393,700 feet in British units). In the absence of direct data, such as might be obtained by soundings with high-altitude rockets, the values adopted are based upon existing information obtained by indirect measurements of certain quantities. As a consequence, the tables are only tentative.

Two sets of tables based upon the adopted tentative standard specifications for the upper atmosphere are presented. One set of two tables is based upon the same arbitrary constant value for the acceleration of gravity as was used in the preparation of the existing standard tables for the lower levels (NACA Report No. 218). This set of tables for the upper levels of the atmosphere therefore constitutes a consistent extension of the existing standard tables. The other set of two tables takes into consideration the decrease in the acceleration of gravity with increasing altitude and therefore is more precise than the first set. Consequently, this set is presented only to satisfy the need for greater accuracy that may exist in some fields of research.

Each table is divided into separate parts for both day and night conditions at altitudes above 80 kilometers. The necessity for separate tables for day and night values is occasioned by the

In April 1946 this Panel was superseded by the Special Subcommittee on the Upper Atmosphere which was also appointed by the NACA.

The membership of this Special Subcommittee is as follows:

Dr. Harry Hall - Navy Dept.
Dr. Joseph Kaplan, C.I.T.
Dr. Harry Wexler, U. S. Weather Bureau, Chairman
Col. D. N. Yates, Chief, Air Weather Service
Col. Paul H. Dane, A. C., TSEAC, AAF Air Materiel Command
Capt. H. T. Orville, USN, Office of Chief of Naval Operations, Navy Department
Capt. Walter S. Diehl, USN, Bureau of Aeronautics, Navy Department
Dr. Calvin N. Warfield, Langley Memorial Aeronautical Laboratory
Dr. E. H. Krause, Naval Research Laboratory
Dr. W. G. Brombacher, National Bureau of Standards
Dr. L. V. Berkner, Carnegie Institution of Washington
Dr. B. Gutenberg, California Institute of Technology
Dr. Fred L. Whipple, Harvard Observatory, Harvard University
Dr. O. R. Wulf, Gates and Crellin Laboratories, California Institute of Technology.
Mr. Jerome Teplitz, NACA, Secretary.

This Subcommittee has considered the information available concerning temperature and composition in the upper atmosphere. On the basis of existing data obtained by balloons at altitudes up to about 32 kilometers (references 6 and 7), of indirect measurements obtained at greater heights such as those discussed in references 8 to 14, and of unpublished data resulting from similar indirect measurements, recommendations concerning temperature-height and composition-height relationships were made by the Subcommittee on June 24, 1946. The recommendations regarding temperature-height relationships cover three arbitrary sets of temperature: (1) tentative standard temperatures, (2) probable minimum temperatures, and (3) probable maximum temperatures. Also, recommendation was made that at this time no tables be prepared for altitudes in excess of 120 kilometers because of the uncertainty regarding the validity of the data in this region.

At a meeting of the executive committee of the National Advisory Committee for Aeronautics held on August 15, 1946, the previously mentioned recommendations of the Subcommittee were adopted. As a result of the adoption of the recommendations of the Subcommittee, two sets of tables for the upper atmosphere, based upon the tentative standard temperatures, have been prepared at the Langley Laboratory of the NACA.

The first set of tables provides a consistent extension of the present standard tables for the lower levels of the atmosphere (reference 1) because the same simplifying assumption of an arbitrary constant value for the acceleration of gravity is made in both cases. Because of this consistency with the present standard atmosphere tables, and in consideration of the fact that the present standard tables (reference 1) are widely used in evaluating performance characteristics of aircraft and for design purposes, it appears that this first set of tables may also be found useful in these same fields of aeronautical engineering. In addition, in order to be consistent with present practice in the use of the terms "pressure altitude" and "density altitude" (reference 15) it appears that it may be proper to use the term "tentative pressure altitude" to designate that altitude in this first set of tables which corresponds to a specified ambient-air pressure. Likewise, the term "tentative density altitude" can consistently be used with this set of tables in connection with ambient-air densities.

The second set of tables is more precise than the first because it takes into consideration the decrease in the acceleration of gravity with increasing altitude. This set is intended primarily for use in connection with research on the properties of the upper atmosphere. Values of still greater computational precision than those listed in this second set may be obtained by means of "latitude correction factors" which have been computed and tabulated in another table.

These two sets of tables for the upper atmosphere consist of two tables each, one in the metric system of units and the other in the British system of units. The altitude range covered is from 20 kilometers and 65,000 feet, respectively, to 120 kilometers and its British equivalent of about 393,700 feet. In addition to those quantities reported in references 1 to 5, there is included the mean free path of the air molecules. This quantity has been added because of its significance at high altitudes where the molecular mean free paths may be comparable to or larger than certain dimensions of the aircraft or missiles that may be flown there.

Acknowledgement is gratefully given for the contributions made by Dr. R. G. Stone, of the AAF Weather Service, who supplied valuable data concerning maximum and minimum temperatures over the entire world to altitudes of 32 kilometers, and for the thorough technical review and excellent suggestions offered by Mr. L. P. Harrison of the U. S. Weather Bureau.

SYMBOLS

a	speed of sound
c	most probable molecular speed
$\bar{c}$	average molecular speed
g	acceleration of gravity
h	altitude
K	volume gradient of oxygen dissociation $\left(\frac{\Delta v}{\Delta h}\right)$
L	temperature gradient $\left(\frac{\Delta T}{\Delta h}\right)$
M	molecular weight
m	mass of a molecule
N	number of molecules per unit volume
p	pressure
R	universal gas constant
r	radius of the earth
T	absolute temperature
t	temperature
v	volume of molecular oxygen in an initial unit volume of normal air, at the same temperature and pressure
w	specific weight $(g\rho)$
γ	ratio of specific heats

λ	mean free path of molecules
μ	coefficient of viscosity
ν	kinematic viscosity (μ/ρ)
ρ	density (mass per unit volume)
σ	molecular diameter; also density ratio (ρ/ρ_0)
$\bar{\sigma}$	average molecular diameter

The following subscripts are used to refer to the indicated conditions:

0	sea level
1	lower level
a	top of region of dissociation, where oxygen is all atomic
A	base of region with constant temperature and constant composition
B	base of region with constant temperature gradient and constant composition
C	base of region with constant temperature and constant volume gradient of dissociation
D	base of region with constant temperature gradient and constant volume gradient of dissociation
g	acceleration of gravity variable
m	base of region of dissociation, where oxygen is all molecular
n	nitrogen molecules
N	non-oxygen (i. e., all constituents other than oxygen)
o	oxygen
air	mixture of molecules in atmosphere
ϕ	latitude

ADOPTED SPECIFICATIONS FOR THE UPPER ATMOSPHERE

Tentative Temperatures

Three sets of tentative temperature-height relationships have been adopted. One set gives tentative standard temperatures and the other two list values of the probable minimum and the probable maximum temperatures for the entire world. These three sets of temperatures which were originally recommended by the Subcommittee on the Upper Atmosphere are given by linear variations with altitude between the points specified in the following tabulation of temperatures.

TEMPERATURES

Altitude (km)	Probable minimum (°K) (a)	Tentative standard (°K)	Probable maximum (°K) (a)
0	225	[b]288	320
10.76923		[b]218	-
11			250
17	180		
20		[b]218	
25			255
32		218	
45	200		380
50		350	
55	300		
60		350	
70			380
78		240	
80	170		300
83		240	
120	300	375	600

[a] The values of ambient air temperature listed in these two columns are not intended to represent extreme values for the entire world, and for all time, but rather values that bracket the temperatures over nearly all the earth most all the time.

[b] These values are standard, and have been used previously in references 1, 3, 4, and 5.

These temperature-altitude relationships are also shown in figure 1.

Tentative Composition

The tentative composition used in computing the tables was arrived at by taking into consideration the fact that, at altitudes below 80 kilometers in the day time and below 105 kilometers at night, the generally accepted variations in chemical composition are too small to affect appreciably the computed pressures and densities. However, it is believed that at levels above those just specified significant changes in composition result from the dissociation of oxygen molecules by solar radiation. It is furthermore known that the presence of water vapor in the atmosphere does not appreciably affect pressures and densities. As a result of such considerations, and in the interest of simplicity, the following tentative specifications for composition of the upper atmosphere were recommended by the Subcommittee and have been adopted for the purposes of computing the values in these tables:

(1) For day time, the dissociation of oxygen is such as to produce a linear volume gradient from all-molecular oxygen at 80 kilometers to all-atomic oxygen at 100 kilometers. Except for oxygen dissociation, the composition is the same as that at sea level.

(2) For night time, the dissociation of oxygen is such as to produce a linear volume gradient from all-molecular oxygen at 105 kilometers to all-atomic oxygen at 120 kilometers. Except for oxygen dissociation the composition is the same as that at sea level.

(3) At altitudes below the regions of oxygen dissociation the composition is the same as that at sea level.

(4) At altitudes above the regions in which both molecular and atomic oxygen exist, as stipulated in (1) and (2), and up to at least 120 kilometers, the composition is the same as that at sea level, except for oxygen which is in the atomic rather than in the molecular form.

The variation with altitude of the specified molecular oxygen content of the atmospheres is graphically portrayed in figure 2.

PHYSICAL RELATIONSHIPS

Basic Equations

In addition to the specifications for temperature and composition already listed, certain other assumptions are made and serve as the basis for deriving the various equations used in computing the properties of the upper atmosphere. These additional assumptions are:

(a) The air is dry

(b) The air behaves as a perfect gas and hence obeys the general gas law which may be written

$$\frac{\rho}{\rho_0} = \frac{p}{p_0} \frac{T_0}{T} \frac{M}{M_0} \tag{1}$$

(c) The air is at rest with respect to the earth and hence obeys the basic law for fluid statics

$$dp = -g\rho \, dh \tag{2}$$

By means of equations (1) and (2) and equations representing the adopted specifications for temperature and composition, relationships may be deduced between pressure and height. The equations representing the adopted specifications are

$$T = T_1 + L(h - h_1) \tag{3}$$

where L is the temperature gradient $\Delta T/\Delta h$, and

$$\frac{M}{M_0} = \frac{1}{1 - K(h - h_m)} \tag{4}$$

where K is the volume gradient of oxygen dissociation $\Delta v/\Delta h$. The derivation of equation (4) is given in appendix A.

In addition to the three assumptions just listed, it is necessary to make an assumption concerning the value of the acceleration of gravity. For the purpose of furnishing tables for the upper atmosphere that will be consistent with the present standard tables for the lower atmosphere (reference 1), it is necessary to make the same assumption concerning the acceleration of gravity as was used in preparing the standard tables. This assumption is

(d) For the tables based on a constant value of g the acceleration of gravity at all altitudes is the standard sea-level value; that is,

$$g = g_0 \tag{5}$$

For those instances in which closer conformity to actual conditions is required than is inherent in these tables it is necessary to make another assumption concerning the value of the acceleration of gravity. This assumption is

(e) For tables based on a variable value of g the acceleration of gravity varies inversely as the square of the distance from the center of the earth; that is,

$$g = g_0\left(\frac{r}{r + h}\right)^2 \tag{6}$$

Pressure-Height Relationships

By use of the foregoing basic equations and assumptions, other equations are derived which relate pressure to altitude. Two sets of equations are used, one set based on a constant value of g as specified in assumption (d), the other set based on the variation of g that is specified in assumption (e). The deductions for the first set are indicated in appendix B and for the second set in appendix C. The equations that are based on a constant value of g are as follows:

For combination A (constant temperature and constant composition):

$$\log_e\left(\frac{p}{p_A}\right) = C_A(h - h_A) \tag{7}$$

where

$$C_A = -\frac{g_0\rho_0}{p_0}\frac{T_0}{T}\frac{M}{M_0} \tag{8}$$

For combination B (constant temperature gradient and constant composition):

$$\log\left(\frac{p}{p_B}\right) = C_B \log\left(\frac{T}{T_B}\right) \tag{9}$$

where

$$C_B = -\frac{g_0\rho_0 T_0}{p_0 L}\frac{M}{M_0} \tag{10}$$

For combination C (constant temperature and constant volume gradient of dissociation):

$$\log\left(\frac{p}{p_C}\right) = C_C \log\left(\frac{M}{M_C}\right) \qquad (11)$$

where

$$C_C = -\frac{g_0 \rho_0 T_0}{p_0 K T} \qquad (12)$$

For combination D (constant temperature gradient and constant volume gradient of dissociation):

$$\log\left(\frac{p}{p_D}\right) = C_D \log\left(\frac{T}{T_D}\,\frac{M}{M_D}\right) \qquad (13)$$

where

$$C_D = \frac{-g_0 \rho_0 T_0 M_D}{p_0\left(l M_0 + M_D T_D K\right)} \qquad (14)$$

The equations derived in appendix C, based on a variable value of g, are more complex than those listed in the foregoing and consequently they are not reproduced here.

Speed of Sound

The speed of sound at any altitude relative to that at sea level is computed by the equation

$$\frac{a}{a_0} = \left(\frac{\gamma T M_0}{\gamma_0 T_0 M}\right)^{1/2} \qquad (15)$$

where the ratio of the specific heats γ, as derived in appendix A, is

$$\frac{\gamma}{\gamma_0} = 1 - \frac{128K(h - h_m)}{21M_0} \qquad (16)$$

The variation with altitude of the ratio of specific heats γ for the specified atmosphere is shown in figure 3(a).

Coefficient of Viscosity

Sutherland's equation for the variation of the coefficient of viscosity with temperature is used. It is

$$\frac{\mu}{\mu_0} = \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \qquad (17)$$

in which, according to reference 16,

$$S = 120$$

when the T's are in °K, and

$$S = 216$$

when the T's are in °F absolute.

A caution concerning the use of values obtained from equation (17) for the upper atmosphere is given in the section entitled "Discussion of Tables."

Molecular Mean Free Path

The ratio of the molecular mean free path at any altitude to the corresponding value at sea level is computed by

$$\frac{\lambda}{\lambda_0} = \frac{p_0 T g}{p T_0 g_0} \qquad (18)$$

This equation is justified in appendix D.

BASIC CONSTANTS

In the preceding section equations are given by means of which several properties of the upper atmosphere are computed. These computations involve numerical values of the several properties at sea level. Appendix E discusses the chosen sea-level values for each of several properties of the atmosphere and they are listed in table I in both metric and British engineering systems of units. Values are listed for each of the three specified atmospheres and in some instances the quantity is expressed in more than one unit in either the metric or British system.

The values listed in table I for the standard atmosphere at sea level are identical with those used in references 1 and 5 except in a few instances. The exceptions are noted and explained in appendix E.

DISCUSSION OF TABLES

The appropriate equation (equation (7), (9), (11) or (13) for the constant value of g, or (C3), (C6), (C10) or (C13) for the variable values of g) is used to compute the ratio of the pressure p at any height to the pressure at the base of the region to which that particular equation applies. These pressure ratios for each of the regions are then used to compute the ratio of the pressure p to the pressure p_0 at sea level. These ratios p/p_0 are given in tables II to V.

By use of the computed values of the pressure ratios p/p_0 and of the sea-level value of pressure p_0 as given in table I, the value of the pressure p is computed and then given in tables II to V. The pressures given in tables IV and V are also plotted against altitude in figure 3(b).

The remaining quantities given in tables II to V are similarly computed by means of the appropriate equation and the corresponding sea-level value given in table I. The values for these remaining quantities given in tables IV and V are also shown plotted against altitude in figures 3(c) to 3(h).

Attention is directed to the fact that all tables in this report are based on the engineering system (sometimes referred to as the gravitational system) in which the fundamental quantities are length, force, and time. The standard units for force used herein are, therefore, pounds for the British system and kilograms for the metric system.

Accuracy of Computed Tables II to V

In tables II to V all quantities except the mean free paths of the molecules are tabulated to four significant figures, and the mean free paths of the molecules are tabulated to three significant figures. All computations for table II were carried through to six significant figures and consequently the values given in this table are believed to be exact.

Most of the values for table IV were obtained from table II by use of suitable conversion factors evaluated by a graphical method described in appendix C. The errors resulting from the method, and therefore the errors in the values tabulated in table IV are believed not to exceed 0.01 of 1 percent.

A method of graphical interpolation was applied to obtain from tables II and IV the values for use at the intermediate levels tabulated in tables III and V. The accuracy of this method is such as to introduce an error of not over one-twentieth of 1 percent in the values listed in tables III and V. Consequently, whenever a discrepancy exists between the metric and British values, the metric values should govern.

Validity of Tabulated Values at the Higher Altitudes

Pressure, density, specific weight, and mean free path of molecules.- As was previously mentioned, the computations for tables II and III are based on a constant value for the acceleration of gravity g so that the values listed would be consistent with those appearing in the present standard tables for the lower levels of the atmosphere (reference 1). The errors in the computed values of pressure, density, specific weight and mean free path inherent in the assumption of a constant value for the acceleration of gravity become progressively greater with increasing altitude, being about 30 percent at 120 kilometers. However, a variation of 30 percent in pressure at 120 kilometers corresponds to a variation of less than 4 percent in altitude at this level, and at lower levels the change in altitude corresponding to the error in pressure rapidly approaches zero. It is apparent therefore that in at least some applications the values in tables II and III will be adequate and therefore useful. Furthermore, they represent an extension of the present standard tables (reference 1).

In order to satisfy the need that may exist for values that are not affected by the use of a constant value for the acceleration of gravity g, tables IV and V are presented. In these tables g is assumed to vary inversely as the square of the distance from the center of the earth. This assumption therefore takes into consideration the variation due to gravitational attraction, but it does not allow for the effect of centrifugal force. The centrifugal force due to the rotation of the earth is known to be only a small fraction of 1 percent of the gravitational force at an altitude of 120 kilometers, and consequently this omission does not result in a significant error.

The standard value used for the acceleration of gravity at sea level (and at all altitudes for tables II and III) is 9.80665 meters per second per second. This value corresponds rather closely to the true acceleration of gravity at sea level at latitude 45°. (More specifically, it corresponds to the theoretical acceleration of gravity at sea level and at latitude 45° 24' according to the International formula. See reference 17.) If still greater accuracy than is inherent in tables IV and V is required at latitudes far displaced from latitude 45°, an estimate of the latitude effect upon pressure and density may be obtained by use of the equation

$$\log \frac{p_\phi}{p_0} = \frac{g_{0\phi}}{g_0} \log \frac{p}{p_0} \tag{19}$$

where p_ϕ is the pressure at altitude h and at latitude ϕ, and $g_{0\phi}$ is the acceleration of gravity at sea level and at latitude ϕ. A similar equation (replacing p's with ρ's) applies to densities.

By means of equation (19) it can be shown that a latitude correction factor (L.C.F.) defined by

$$\text{L.C.F.} = \frac{p_\phi}{p} \tag{20}$$

can be computed by

$$\text{L.C.F.} = \left(\frac{p}{p_0}\right)^{\frac{g_{0\phi} - g_0}{g_0}} \tag{21}$$

If values of g_{0_ϕ} from reference 17 are used, the following values for the exponent $(g_{0_\phi} - g_0)/g_0$ are obtained:

Latitude (deg)	$\frac{g_{0_\phi} - g_0}{g_0}$	Latitude (deg)	$\frac{g_{0_\phi} - g_0}{g_0}$
0	-2.66758×10^{-3}	50	0.42175×10^{-3}
10	-2.50922	60	1.28372
20	-2.05299	70	1.98732
30	-1.35337	80	2.44701
40	-0.49405	90	2.60670

The foregoing exponents when applied to the values of pressure ratio p/p_0 tabulated in tables IV and V give the values of the latitude correction factor described by equations (20) and (21). For latitudes at increments of 10° and for altitudes at increments of 10 kilometers the latitude correction factors that are applicable to the pressures given in tables IV and V have been computed and are presented in table VI. By means of table VI it is therefore possible to obtain computed values of pressure which take into consideration the variation with latitude of the sea-level value of the acceleration of gravity g_0. This computation may be made by use of equation (20) which may be written $p_\phi = (\text{L.C.F.})p$.

Coefficient of viscosity and kinematic viscosity.- The Sutherland formula (equation (17)) is strictly applicable only to a gas of constant composition and to pressures which are not too small, and consequently the tabulated values for the coefficient of viscosity and for the kinematic viscosity are obviously not entirely reliable at the higher altitudes. However, the lack of data on the viscosity of oxygen in the atomic form does not permit at this time an estimation of the correction that is needed to allow for the specified dissociation. Furthermore, because of the fact that the effective value of the viscosity of a gas at very low pressure flowing over a body depends on the size and shape of the body, it is not practical to give a correction that will be applicable to more than one specific size and shape of a body. The values for viscosity at the higher altitudes should therefore be used with caution.

Speed of sound.- The tabulated values for the speed of sound are believed to be correct for all altitudes covered by the tables.

Caution should be exercised, however, in using the tabulated values for the upper altitudes in connection with Mach numbers because at high altitudes where the mean free paths of the air molecules are large in comparison with the dimensions of the body moving through them, the laws of fluid dynamics do not apply and the laws of particle dynamics must be used. When aerodynamic forces, for example, are computed for these conditions by use of the laws of particle dynamics the most probable speed of the air molecules is found to be the basic quantity rather than the speed of sound.

As in the case of viscosity, the altitude range in which the most probable speed of the air molecules replaces the speed of sound as the basic quantity depends upon the size of the body under consideration. It is consequently not possible to specify a single level at which the molecular speed becomes significant in aerodynamics. For this reason values for the speed of sound are listed to 120 kilometers.

In any case in which the most probable speed of the air molecules c is needed rather than the velocity of sound a it is possible to obtain the value of c from the value of a listed in the tables by use of the appropriate factor obtained from the following tabulation:

Altitude, h		Ratio of the most probable molecular speed to the speed of sound, $\frac{c}{a} = \sqrt{\frac{2}{\gamma}}$	
(m)	(ft)	Day	Night
80,000	262,467	1.195	1.195
85,000	278,871	1.189	1.195
90,000	295,275	1.183	1.195
95,000	311,679	1.176	1.195
100,000	328,083	1.170	1.195
105,000	344,487	1.170	1.195
110,000	360,892	1.170	1.187
115,000	377,296	1.170	1.179
120,000	393,700	1.170	1.170

CONCLUDING REMARKS

The fact should be emphasized that the values given in the tables for the upper atmosphere are only tentative and as such may become obsolete after a sufficient number of reliable direct measurements of certain quantities have been made available. In the meantime these tentative tables should be useful not only in serving as a basis for comparing performance characteristics and estimating limiting values of performance, but also in securing the additional data needed for revising these tentative tables for the upper atmosphere.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., December 6, 1946

APPENDIX A

VARIATION WITH ALTITUDE OF MOLECULAR WEIGHT AND RATIO OF SPECIFIC HEATS

Molecular Weight in the Region of Oxygen Dissociation

Consider an initial unit volume of normal air composed only of molecular gases, consisting of oxygen and other constituents. Let all the non-oxygen constituents be diatomic of average molecular weight M_N, and let the molecular weight of oxygen in the molecular form be M_m, and in the atomic form M_a. Then

$$M_a = \frac{1}{2}M_m \tag{A1}$$

Let the initial conditions be as follows:

v_0 volume of all-molecular oxygen at height h_m

$1 - v_0$ volume of non-oxygen components at height h_m

M_0 average molecular weight of the initial air mixture at height h_m

Then

$$M_0 = v_0 M_m + (1 - v_0)M_N \tag{A2}$$

At height h, between h_m and h_a (where h_m is height at base of region in which dissociation occurs, and h_a is height at top of the region, and where all the oxygen is in the atomic form) the volume of molecular oxygen v_m per unit initial volume of normal air is

$$v_m = v_0\left(\frac{h_a - h}{h_a - h_m}\right) \tag{A3}$$

and the volume of atomic oxygen v_a per unit initial volume of normal air is

$$v_a = 2v_0\left(\frac{h - h_m}{h_a - h_m}\right) \tag{A4}$$

Therefore, the average molecular weight M of the atmosphere at height h can be shown to be

$$M = \frac{M_0}{1 - K(h - h_m)} \qquad \text{(A5)}$$

where

$$K = -\frac{v_0}{h_a - h_m} \qquad \text{(A6)}$$

the volume gradient of molecular oxygen, $\Delta v/\Delta h$.

Ratio of Specific Heats in the Region of Oxygen Dissociation

The ratio of specific heats γ for diatomic gases is taken to be 7/5 and for monatomic gases, 5/3. If the ratio of the specific heats γ for the atmosphere is assumed to be given by a weighted average, according to relative masses, of the values of γ for diatomic and monatomic gases, it can be shown, by using equations (A1), (A2), (A3), and (A4) that for those regions of the atmosphere in which dissociation of oxygen occurs

$$\gamma = \frac{7}{5} + \frac{4}{15} v_0 \left(\frac{M_m}{M_0}\right)\left(\frac{h - h_m}{h_a - h_m}\right) \qquad \text{(A7)}$$

The standard value for γ_0, for the atmosphere at sea level, is 7/5, and for M_m the standard value is 32. Therefore

$$\frac{\gamma}{\gamma_0} = 1 - \frac{128K(h - h_m)}{21M_0} \qquad \text{(A8)}$$

It is estimated that in the tentative standard atmosphere the variation of γ due to pressure and temperature effects is only about 0.6 of 1 percent. For this reason the effect of pressure and temperature upon γ is ignored in computing these tentative tables.

APPENDIX B

VARIATION OF PRESSURE WITH ALTITUDE (ASSUMING THE ACCELERATION OF GRAVITY IS A CONSTANT g_0)

The equations relating atmospheric pressure to height for all altitude ranges in all three atmospheres (minimum, standard, and maximum temperatures) are only four in number. These four equations represent all possible combinations of the two types of temperature-height relationship and the two types of composition-height relationship. The deductions of the equations are based upon the familiar hydrostatic relation

$$dp = -g_0 \rho \, dh \tag{B1}$$

and upon the general gas equation

$$\frac{\rho}{\rho_0} = \frac{p}{p_0} \frac{M}{M_0} \frac{T_0}{T} \tag{B2}$$

These two equations, when combined, give

$$\frac{dp}{p} = -\frac{g_0 \rho_0 T_0 M \, dh}{p_0 T M_0} \tag{B3}$$

The differential equation (B3) is then used for deriving algebraic equations for pressure as a function of altitude, for each of the four combinations of temperature-height and composition-height relationships previously discussed. The derivations are indicated in the following paragraphs and the resulting equations are used in the preparation of tables II and III.

<u>Combination A (constant temperature and constant composition)</u>.- The type of atmosphere in which both the temperature and composition are constant may be represented algebraically by

$$T = \text{Constant}$$

and

$$M = \text{Constant}$$

Equation (B3) when integrated between the limits of height h_A and height h then becomes,

$$\log_e\left(\frac{p}{p_A}\right) = \frac{-g_0\rho_0 T_0 M}{p_0 T M_0}(h - h_A) \tag{B4}$$

where h_A is the base of the region in which type A conditions prevail.

<u>Combination B (constant temperature gradient and constant composition)</u>.- For the type of atmosphere having a constant temperature gradient and constant composition, let the temperature gradient be represented by

$$L = \text{Constant} = \frac{\Delta T}{\Delta h} \tag{B5}$$

and the temperature by

$$T = T_B + L(h - h_B) \tag{B6}$$

where T_B and h_B are the respective values at the base of the region to which combination B conditions prevail. Also M = Constant. Equation (B3) then becomes

$$\frac{dp}{p} = \left(\frac{-g_0\rho_0 T_0 M}{p_0 M_0}\right)\frac{dh}{T_B + L(h - h_B)} \tag{B7}$$

and when integrated between the limits of h_B and h this equation becomes

$$\log\left(\frac{p}{p_B}\right) = -\frac{g_0\rho_0 T_0 M}{p_0 L M_0}\log\left(\frac{T}{T_B}\right) \tag{B8}$$

<u>Combination C (constant temperature and constant volume gradient of dissociation)</u>.- In the type of atmosphere where both the temperature and volume gradient of dissociation are constant

$$T = \text{Constant}$$

and an expression for M as a function of h is derived in appendix A, and it is found to be

$$M = \frac{M_0}{1 - K(h - h_m)} \tag{B9}$$

where K is the volume gradient of molecular oxygen defined by

$$K = \frac{\Delta v}{\Delta h} = \text{Constant} \tag{B10}$$

Using these relationships with equation (B3) gives

$$\frac{dp}{p} = - \frac{g_0 \rho_0 T_0 \, dh}{p_0 T \left[1 - K(h - h_m)\right]} \tag{B11}$$

Integrating equation (B11) between the limits of h_C and h, where h_C is the height at the base of the region in which type C conditions prevail, gives

$$\log \left(\frac{p}{p_C}\right) = \frac{g_0 \rho_0 T_0}{p_0 T K} \log \left(\frac{M_C}{M}\right) \tag{B12}$$

Combination D (constant temperature gradient and constant volume gradient of dissociation).- The type of atmosphere having both the temperature gradient and the volume gradient of dissociation constant is referred to as combination D. For this combination, the expression for molecular weight given in equation (B9) and an appropriate modification of equation (B6) give, for equation (B3), the following equation:

$$\frac{dp}{p} = - \frac{g_0 \rho_0 T_0 \, dh}{p_0 \left[1 - K(h - h_m)\right] \left[T_D + L(h - h_D)\right]} \tag{B13}$$

Integrating the variable part of the right-hand member, between the limits of h_D and h, gives

$$\frac{1}{(1 + Kh_m)L + (T_D - Lh_D)K} \log \frac{T_D + L(h - h_D)}{1 - K(h - h_m)} \Bigg|_{h_D}^{h}$$

Therefore

$$\log\left(\frac{p}{p_D}\right) = \frac{-g_0\rho_0T_0M_D}{p_0\left(M_0L + M_DKT_D\right)} \log\left(\frac{TM}{T_DM_D}\right) \qquad \text{(B14)}$$

APPENDIX C

VARIATION OF PRESSURE WITH ALTITUDE (ASSUMING THE ACCELERATION OF GRAVITY VARIES INVERSELY AS THE SQUARE OF THE DISTANCE FROM THE CENTER OF THE EARTH)

The equations relating pressure and altitude derived herein are based upon the general differential equation derived from equation (B2) of appendix B, from the hydrostatic relation

$$dp = -g\rho \, dh \qquad \text{(C1)}$$

and from the equation representing the inverse square variation of the acceleration of gravity

$$g = g_0 \left(\frac{r}{r + h}\right)^2 \qquad \text{(C2)}$$

This general differential equation is

$$\frac{dp}{p} = \frac{-g_0 \rho_0 T_0 M r^2 \, dh}{p_0 T M_0 (r + h)^2} \qquad \text{(C3)}$$

As in appendix B four equations are deduced for use in each of the four possible combinations of specified temperature-altitude and composition-altitude relationships. The resulting algebraic equations are used in the preparation of tables IV and V. The deductions for each combination are indicated in the following paragraphs.

Combination A (constant temperature and constant composition).- For combination A (constant temperature and constant pressure) the algebraic equation relating pressure and altitude is obtained by integrating equation (C3) between the limits of altitude h_A and h. The result is

$$\log_e \left(\frac{p}{p_A}\right)_g = \frac{-g_0 \rho_0 T_0 M}{p_0 T M_0} \, \frac{r^2 (h - h_A)}{(r + h)(r + h_A)} \qquad \text{(C4)}$$

(Note that in this equation and succeeding equations the subscript g is used to indicate values computed with the variation in the acceleration of gravity that is specified by equation (C2).)

Combination B (constant temperature gradient and constant composition).- For combination B (constant temperature gradient and constant composition) the differential equation is obtained by substituting in equation (C3) the value for T given by

$$T = T_B + L(h - h_B) \tag{C5}$$

The differential equation is then

$$\frac{dp}{p} = \frac{-g_0 \rho_0 T_0 M r^2 \, dh}{p_0 M_0 \left[T_B + L(h - h_B)\right] (r + h)^2} \tag{C6}$$

The algebraic equation obtained by integrating equation (C6) between the appropriate limits is

$$\log_e \left(\frac{p}{p_B}\right)_g = C_{B_g} \left[\frac{r(h - h_B)}{(r + h)(r + h_B)} + \frac{rL}{rL + h_B L - T_B} \log_e \frac{(r + h)T_B}{(r + h_B)T}\right] \tag{C7}$$

where

$$C_{B_g} = \frac{g_0 \rho_0 T_0 M}{p_0 M_0 \left[L - \frac{1}{r}(T_B - L h_B)\right]} \tag{C8}$$

Combination C (constant temperature and constant volume gradient of dissociation).- For combination C (constant temperature and constant volume gradient of dissociation) the differential equation is obtained by substituting in equation (C3) the value of M given by

$$M = \frac{M_0}{1 - K(h - h_m)} \tag{C9}$$

The differential equation is then

$$\frac{dp}{p} = \frac{-g_0\rho_0 T_0 r^2\,dh}{p_0 T\left[1 - K(h - h_m)\right](r + h)^2} \qquad \text{(C10)}$$

The algebraic equation obtained by integrating equation (C10) between appropriate limits is

$$\log_e\left(\frac{p}{p_C}\right)_g = C_{C_g}\left\{\left[\frac{K}{K + \dfrac{1 + Kh_C}{r}}\log_e\frac{M(r + h)}{M_0(r + h_C)}\right] - \frac{r(h_C - h)}{(r + h)(r + h_C)}\right\} \qquad \text{(C11)}$$

where

$$C_{C_g} = \frac{-g_0\rho_0 T_0}{p_0 T\left(K + \dfrac{1 + Kh_C}{r}\right)} \qquad \text{(C12)}$$

Combination D (constant temperature gradient and constant volume gradient of dissociation).- For combination D (constant temperature gradient and constant volume gradient of dissociation) the differential equation is obtained by substituting in equation (C3) the values of T and M given by a slightly modified form of equation (C5) and by equation (C9), respectively. The resulting differential equation is then

$$\frac{dp}{p} = \frac{-g_0\rho_0 T_0 r^2\,dh}{p_0\left[T_D + L(h - h_D)\right]\left[1 - K(h - h_m)\right](r + h)^2} \qquad \text{(C13)}$$

The algebraic equation obtained by integrating equation (C13) between appropriate limits is

$$\log_e\left(\frac{p}{p_D}\right)_g = C_{Dg}\left[\frac{a(h - h_D)}{(1 + xh)(1 + xh_D)} + \frac{b}{x}\log_e\left(\frac{1 + xh}{1 + xh_D}\right)\right.$$

$$\left. + \frac{c}{y}\log_e\left(\frac{1 + yh}{1 + yh_D}\right) + \frac{d}{z}\log_e\left(\frac{1 + zh}{1 + zh_D}\right)\right] \qquad \text{(C14)}$$

where

$$C_{D_g} = \frac{-g_0 \rho_0 T_0}{p_0 (T_D - Lh_D)(1 + Kh_m)} \tag{C15}$$

$$x = \frac{1}{r}$$

$$y = \frac{L}{(T_D - Lh_D)}$$

$$z = \frac{-K}{(1 + kh_m)}$$

$$a = \frac{x^2(x^2 + yz - yx - zx)}{(z - x)^2(y - x)^2}$$

$$\frac{b}{x} = \frac{x(2yz - xy - xz)}{(z - x)^2(y - x)^2}$$

$$\frac{c}{y} = \frac{-y^2}{(y - x)^2(z - y)}$$

$$\frac{d}{z} = \frac{z^2}{(z - x)^2(z - y)}$$

Equations (C4), (C7), (C11), and (C14) were used to compute the pressure ratios at the transition levels only in the tentative standard atmosphere. By dividing these pressure ratios by the pressure ratios at the same transition levels obtained by use of the equations in appendix B based on a constant value for the acceleration of gravity, a conversion factor was obtained for each of the several transition altitudes. Since it was impractical to use these complex equations for directly computing the pressure ratios at all the levels recorded in tables IV and V, the values at these numerous intermediate levels were arrived at as follows:

(1) For each altitude a value for the conversion factor was computed by algebraic summation from the equation

$$\log_e\left(\frac{p_g}{p}\right) = \frac{\rho_0 T_0}{p_0 M_0} \sum_{0}^{h} (g_0 - g)\frac{M}{T}\Delta h \qquad \text{(C16)}$$

where p_g is the pressure based on the variable value of g, and p is the pressure based on a constant value for the acceleration of gravity. In equation (C16) the proper value of g, T, and of M was substituted for each region of the atmosphere, according to equation (C2), (C5), and (C9), respectively.

(2) The values of p_g/p so computed were plotted against altitude to define the shape of the curve relating pressure ratios to altitude.

(3) The accurate values for the pressure ratio computed by equations (C4), (C7), (C11), and (C14) and by equations (B4), (B8), (B12), and (B14) were also plotted and another curve was drawn through these points representing the accurately computed ratios and faired according to the curve drawn through the points obtained by use of equation (C16).

(4) The curve arrived at from step (3) was then used to obtain conversion factors for each of the altitudes recorded in tables IV and V.

APPENDIX D

MOLECULAR MEAN FREE PATHS

Ratio of the Mean Free Paths of Molecules

The conventional equation for the mean free path of the molecules λ of a gas (reference 18) is

$$\lambda = \frac{1}{\pi \sqrt{2}\, N\sigma^2} \tag{D1}$$

Therefore the ratio of the mean free path at any altitude to the value at sea level is

$$\frac{\lambda}{\lambda_0} = \frac{N_0}{N}\left(\frac{\sigma_0}{\sigma}\right)^2 \tag{D2}$$

But

$$Nm = \rho \tag{D3}$$

and

$$g\rho = \frac{pM}{RT} \tag{D4}$$

Therefore

$$\frac{N_0}{N} = \frac{p_0}{p}\,\frac{T}{T_0}\,\frac{g}{g_0} \tag{D5}$$

and

$$\frac{\lambda}{\lambda_0} = \frac{p_0}{p}\,\frac{T}{T_0}\,\frac{g}{g_0}\left(\frac{\sigma_0}{\sigma}\right)^2 \tag{D6}$$

For all constituents of the atmosphere except oxygen in the region of dissociation,

$$\sigma = \sigma_0$$

In the absence of available data on the diameter of atoms of oxygen relative to that of molecular oxygen, and in consideration of the fact that the small difference in these two diameters of oxygen has an even smaller effect upon the average diameter of all atmospheric constituents, and for reasons of simplicity it is herein assumed for oxygen also that $\sigma = \sigma_0$. For the purpose of computing these tables therefore equation (D6) is simplified to

$$\frac{\lambda}{\lambda_0} = \frac{p_0}{p} \cdot \frac{T}{T_0} \frac{g}{g_0} \tag{D7}$$

Furthermore, in those computations that are based on a constant value for the acceleration of gravity

$$g = g_0$$

whence equation (D7) is further simplified to

$$\frac{\lambda}{\lambda_0} = \frac{p_0}{p} \frac{T}{T_0} \tag{D8}$$

Mean Free Paths of Molecules at Sea Level

The values of the mean free path of the molecules at sea level given in table I are for nitrogen and oxygen molecules in a normal atmospheric mixture of nitrogen and oxygen. These mean free paths are designated λ_n and λ_o, respectively. A weighted average of the foregoing mean free paths, based upon the relative volumes of nitrogen and oxygen in air is also included and is designated λ_{air}.

The mean free path of the nitrogen molecules in the atmosphere at sea level was computed by the following formula (p. 99 of reference 18):

$$\lambda_n = \frac{1}{\pi\sqrt{2}\, N_n \sigma_n{}^2 + \pi N_o \bar{\sigma}^2 \dfrac{\sqrt{\bar{c}_n{}^2 + \bar{c}_o{}^2}}{\bar{c}_n}}$$

where

N_n	number of nitrogen molecules per unit volume of air
N_o	number of oxygen molecules per unit volume of air
σ_n	diameter of nitrogen molecules
σ_o	diameter of oxygen molecules
$\bar{\sigma}$	average diameter of nitrogen and oxygen molecules
$\bar{c}_n$	average speed of nitrogen molecules
$\bar{c}_o$	average speed of oxygen molecules

Similarly, the mean free path of the oxygen molecules at sea level was computed by

$$\lambda_o = \frac{1}{\pi\sqrt{2}\,N_o\sigma_o^{\,2} + \pi N_n\bar{\sigma}^{2}\frac{\sqrt{\bar{c}_n^{\,2} + \bar{c}_o^{\,2}}}{\bar{c}_o}} \tag{D9}$$

The values for the average speeds $\bar{c}_n$ and $\bar{c}_o$ were obtained from the formula $\bar{c} = \sqrt{\frac{3RT}{M}}$. The values for σ were taken from appendix III, column 4, of reference 18. Values of N_n and N_o, the number of molecules of nitrogen and oxygen, respectively, per unit volume were calculated from the Loschmidt number and the relative volume of the nitrogen and oxygen in air at sea level.

APPENDIX E

VALUES OF CERTAIN CONSTANTS

Tentative Standard Atmosphere at Sea Level

The standard sea-level values for various properties of the atmosphere have been listed in reference 1, and sea-level values for certain other properties are listed in reference 5. Most of these previously listed values are adopted for use in computing the tables herein, but a few changes have been made. The changes are as follows:

Speed of sound.- The values for the speed of sound have been altered slightly to avoid the discrepancy which existed between the values previously listed and the values computed by the conventional equation

$$a_0 = \sqrt{\frac{\gamma_0 p_0}{\rho_0}} \tag{E1}$$

The values for a_0 listed in table I are computed according to equation (E1) by using the appropriate values for γ_0, p_0, and ρ_0 that are also listed in table I.

Density.- The values for density in the British engineering system has been changed from 0.002378 to 0.0023779 slugs per cubic foot to avoid discrepancies resulting when computations are based either on the standardized value for specific weight, 1.2255 kilograms per cubic meter (reference 1), or on the derived value for density.

Molecular mean free paths and molecular weight.- In addition to the various quantities previously given in references 1 and 5, the present paper lists molecular mean free paths and the average molecular weight of normal sea-level air. Molecular mean free paths for the nitrogen molecules and oxygen molecules in the normal air mixture have been computed and a weighted average for air has been taken, as described in appendix D. The average molecular weight of normal sea-level air is taken as 28.966 in accordance with reference 19.

Pressure.- The value for pressure in the British engineering system has been changed from 407.1 or 407.2 inches of water at 15° C as used in reference 5 and reference 20, respectively, to 407.15 inches of water at 15° C. This value of 407.15 is the computed value corresponding to 760 millimeters of mercury based on the auxiliary constants and conversion factors listed in the last section of this appendix E.

Table of Sea-Level Values

The values for the various properties of the atmosphere at sea level corresponding to the adopted values for probable minimum and probable maximum temperatures are computed from the values corresponding to standard sea-level temperatures. All three sets of values used in both metric and British engineering systems of units are tabulated in table I. In some instances a quantity is listed in more than one unit, in either the metric or British system.

Auxiliary Constants and Conversion Factors

In addition to the atmospheric properties at sea level given in table I certain other basic constants and conversion factors are used in computing tables II to V. They are

Auxiliary constants:

Density of mercury at 0° C, gm/cm^3	13.5951
Standard acceleration of gravity, g_0, cm/sec^2	980.665
Density of water at 15° C, gm/ml	0.9991286
Radius of the earth at 45° latitude and at sea level, m	6,367,623

Conversion factors:

$$1 \text{ lb} = 453.5924 \text{ gm}$$

$$1 \text{ meter} = 3.280833 \text{ ft}$$

$$^{\circ}K = {}^{\circ}C + 273$$

$$^{\circ}F \text{ abs} = {}^{\circ}F + 459.4$$

$$1 \text{ ml} = 1.000027 \text{ cm}^3$$

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TABLE I.—PROPERTIES OF THE ATMOSPHERE AT SEA LEVEL

Quantity	Symbol	Metric engineering system				British engineering system			
		Unit	At probable minimum temperature	At standard temperature	At probable maximum temperature	Unit	At probable minimum temperature	At standard temperature	At probable maximum temperature
Temperature	t_0	°C	-48.0	15.0	47.0	°F	-54.5	59.0	116.6
Absolute temperature	T_0	°K	225.0	288.0	320.0	°F abs.	405.0	518.4	576.0
Pressure	p_0	mm Hg at 0°C	760	760	760	in.Hg at 32°F	29.9212	29.9212	29.9212
		kg/m^2	10332.3	10332.3	10332.3	in. water at 15°C	407.15	407.15	407.15
		dynes/cm^2	1.01325×10^6	1.01325×10^6	1.01325×10^6	lb/ft^2	2116.23	2116.23	2116.23
Specific weight	w_0	kg/m^3	1.5686	1.2255	1.1030	lb/ft^3	0.097928	0.076506	0.068855
		dynes/cm^3	1.5383	1.2018	1.0816				
Density	$\rho_0 = \frac{w_0}{g_0}$	kg-sec^2/m^4	0.15995	0.124966	0.11247	slugs/ft^3	0.0030437	0.0023779	0.0021401
Coefficient of viscosity	μ_0	kg-sec/m^2	1.4852×10^{-6}	1.8187×10^{-6}	1.9751×10^{-6}	lb-sec/ft^2	3.0420×10^{-7}	3.7250×10^{-7}	4.0455×10^{-7}
		poise (dyne-sec/cm^2)	14565×10^{-8}	17835×10^{-8}	19369×10^{-8}				
Kinematic viscosity	$\nu_0 = \frac{\mu_0}{\rho_0}$	m^2/sec	9.2848×10^{-6}	14.553×10^{-6}	17.561×10^{-6}	ft^2/sec	0.99944×10^{-4}	1.5665×10^{-4}	1.8903×10^{-4}
Speed of sound	a_0	m/sec	300.72	340.22	358.63	ft/sec	986.61	1116.22	1176.60
		km/hr	1082.6	1224.8	1291.1	mph	672.69	761.06	802.23
						knots	584.16	660.90	696.65
Mean free path of nitrogen molecules	λ_n	m	5.76×10^{-8}	7.38×10^{-8}	8.20×10^{-8}	ft	0.1891×10^{-6}	0.2421×10^{-6}	0.2690×10^{-6}
Mean free path of oxygen molecules	λ_o	m	5.75×10^{-8}	7.36×10^{-8}	8.18×10^{-8}	ft	0.1887×10^{-6}	0.2415×10^{-6}	0.2683×10^{-6}
Mean free path of air molecules	λ_{air}	m	5.76×10^{-8}	7.37×10^{-8}	8.19×10^{-8}	ft	0.1890×10^{-6}	0.2419×10^{-6}	0.2688×10^{-6}
Average molecular weight	M_0	----	28.966	28.966	28.966	----	28.966	28.966	28.966
Ratio of specific heats	γ_0	----	1.4	1.4	1.4	----	1.4	1.4	1.4
Relative volume of oxygen	r_0	----	0.2095	0.2095	0.2095	----	0.2095	0.2095	0.2095

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TABLES II AND III

PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE

The following set of two tables (tables II and III) constitutes a consistent extension of the standard tables for the lower atmosphere (NACA Rep. No. 218). Consequently, altitudes in this set of tables which correspond to specified ambient-air pressures may be referred to as "tentative pressure altitudes," and those which correspond to a specified ambient-air density may be referred to as "tentative density altitudes" (NACA Rep. No. 474).

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TABLE II.— PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE — METRIC ENGINEERING SYSTEM

(a) For both day and night

Altitude, h (m)	Absolute temperature, T (°K)	Pressure, p (kg/m²)	Pressure ratio, p/p_0	Density, ρ $\left(\frac{\text{kg-sec}^2}{\text{m}^4}\right)$	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific weight, $w = g\rho$ (kg/m³)	Coefficient of viscosity, μ $\left(\frac{\text{kg-sec}}{\text{m}^2}\right)$	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (m²/sec)	Speed of sound, a (m/sec)	Mean free path of molecules, λ (m)
20,000	218.0	563.0	5449×10^{-5}	8999×10^{-6}	7198×10^{-5}	8821×10^{-5}	1.446×10^{-6}	0.01607×10^{-2}	296.0	0.00102×10^{-3}
20,500	218.0	520.5	5038	8318	6655	8157	1.446	0.01738	296.0	0.00111
21,000	218.0	481.3	4658	7690	6154	7542	1.446	0.01880	296.0	0.00120
21,500	218.0	445.0	4307	7110	5690	6973	1.446	0.02033	296.0	0.00130
22,000	218.0	411.5	3983	6575	5261	6448	1.446	0.02199	296.0	0.00140
22,500	218.0	380.5	3683	6080	4865	5962	1.446	0.02378	296.0	0.00151
23,000	218.0	351.8	3405	5622	4498	5513	1.446	0.02572	296.0	0.00164
23,500	218.0	325.3	3148	5198	4159	5097	1.446	0.02782	296.0	0.00177
24,000	218.0	300.8	2911	4806	3846	4713	1.446	0.03008	296.0	0.00192
24,500	218.0	278.1	2692	4444	3556	4358	1.446	0.03254	296.0	0.00207
25,000	218.0	257.2	2489	4109	3288	4030	1.446	0.03518	296.0	0.00224
25,500	218.0	237.8	2301	3800	3040	3726	1.446	0.03805	296.0	0.00242
26,000	218.0	219.9	2128	3513	2811	3445	1.446	0.04115	296.0	0.00262
26,500	218.0	203.3	1968	3248	2599	3186	1.446	0.04451	296.0	0.00284
27,000	218.0	188.0	1819	3004	2404	2946	1.446	0.04813	296.0	0.00307
27,500	218.0	173.8	1682	2777	2222	2724	1.446	0.05206	296.0	0.00332
28,000	218.0	160.7	1555	2568	2055	2518	1.446	0.05630	296.0	0.00359
28,500	218.0	148.6	1438	2375	1900	2329	1.446	0.06089	296.0	0.00388
29,000	218.0	137.4	1330	2196	1757	2153	1.446	0.06585	296.0	0.00419
29,500	218.0	127.1	1230	2030	1625	1991	1.446	0.07122	296.0	0.00454
30,000	218.0	117.5	1137	1878	1503	1841	1.446	0.07700	296.0	0.00490
30,500	218.0	108.6	1051	1736	1389	1702	1.446	0.08330	296.0	0.00531
31,000	218.0	100.4	972.1	1605	1284	1574	1.446	0.09009	296.0	0.00574
31,500	218.0	92.87	898.9	1484	1187	1455	1.446	0.09743	296.0	0.00621
32,000	218.0	85.87	831.1	1372	1098	1346	1.446	0.1054	296.0	0.00671
32,500	221.7	79.45	769.0	1249	999.1	1224	1.467	0.1175	298.5	0.00738
33,000	225.3	73.61	712.4	1138	910.5	1116	1.487	0.1307	300.9	0.00809
33,500	229.0	68.28	660.8	1039	831.0	1018	1.508	0.1452	303.4	0.00887
34,000	232.7	63.41	613.7	949.3	759.6	930.9	1.528	0.1610	305.8	0.00970
34,500	236.3	58.95	570.6	868.9	695.3	852.1	1.548	0.1782	308.2	0.0106
35,000	240.0	54.87	531.1	796.4	637.3	781.0	1.568	0.1969	310.6	0.0116
35,500	243.7	51.13	494.9	731.0	584.9	716.9	1.588	0.2172	312.9	0.0126
36,000	247.3	47.69	461.6	671.7	537.5	658.7	1.608	0.2393	315.3	0.0137
36,500	251.0	44.53	431.0	618.0	494.6	606.1	1.627	0.2633	317.6	0.0149
37,000	254.7	41.62	402.9	569.4	455.6	558.3	1.647	0.2893	319.9	0.0162
37,500	258.3	38.94	376.9	525.1	420.2	515.0	1.666	0.3173	322.2	0.0175
38,000	262.0	36.47	353.0	484.9	388.0	475.5	1.685	0.3476	324.5	0.0190
38,500	265.7	34.18	330.8	448.2	358.6	439.5	1.705	0.3803	326.8	0.0206
39,000	269.3	32.07	310.4	414.8	331.9	406.7	1.724	0.4156	329.0	0.0222
39,500	273.0	30.10	291.4	384.2	307.4	376.8	1.743	0.4535	331.2	0.0240
40,000	276.7	28.30	273.9	356.3	285.1	349.4	1.764	0.4944	333.5	0.0259
40,500	280.3	26.61	257.6	330.7	264.6	324.3	1.778	0.5383	335.7	0.0278
41,000	284.0	25.05	242.4	307.3	245.9	301.3	1.799	0.5854	337.8	0.0300
41,500	287.7	23.60	228.4	285.7	228.7	280.2	1.817	0.6359	340.0	0.0322
42,000	291.3	22.25	215.3	266.0	212.8	260.8	1.835	0.6900	342.2	0.0346
42,500	295.0	20.99	203.1	247.8	198.3	243.0	1.854	0.7480	344.3	0.0372
43,000	298.7	19.81	191.8	231.1	184.9	226.6	1.872	0.8100	346.5	0.0399
43,500	302.3	18.72	181.2	215.7	172.6	211.5	1.890	0.8763	348.6	0.0427
44,000	306.0	17.70	171.3	201.4	161.2	197.5	1.908	0.9470	350.7	0.0457
44,500	309.7	16.74	162.0	188.3	150.7	184.7	1.926	1.022	352.8	0.0489
45,000	313.3	15.85	153.4	176.2	141.0	172.8	1.943	1.103	354.9	0.0523
45,500	317.0	15.01	145.3	165.0	132.0	161.8	1.961	1.189	356.9	0.0558
46,000	320.7	14.23	137.7	154.6	123.7	151.6	1.978	1.280	359.0	0.0596
46,500	324.3	13.50	130.6	144.9	116.0	142.1	1.996	1.377	361.0	0.0636
47,000	328.0	12.81	123.9	136.0	108.8	133.4	2.013	1.480	363.1	0.0677
47,500	331.7	12.16	117.7	127.7	102.2	125.2	2.030	1.590	365.1	0.0721
48,000	335.3	11.55	111.8	120.0	96.03	117.7	2.047	1.706	367.1	0.0767
48,500	339.0	10.98	106.3	112.9	90.31	110.7	2.065	1.829	369.1	0.0816
49,000	342.7	10.45	101.1	106.2	84.97	104.1	2.081	1.960	371.1	0.0867
49,500	346.3	9.942	96.22	99.99	80.01	98.05	2.098	2.099	373.1	0.0921
50,000	350.0	9.465	91.60	94.20	75.38	92.37	2.115	2.245	375.1	0.0978
50,500	350.0	9.014	87.24	89.71	71.79	87.97	2.115	2.358	375.1	0.103
51,000	350.0	8.585	83.09	85.44	68.37	83.78	2.115	2.476	375.1	0.108
51,500	350.0	8.176	79.13	81.37	65.11	79.80	2.115	2.599	375.1	0.113
52,000	350.0	7.786	75.36	77.49	62.01	75.99	2.115	2.729	375.1	0.119
52,500	350.0	7.416	71.77	73.80	59.06	72.37	2.115	2.866	375.1	0.125
53,000	350.0	7.062	68.35	70.29	56.24	68.93	2.115	3.009	375.1	0.131
53,500	350.0	6.726	65.10	66.94	53.57	65.64	2.115	3.160	375.1	0.138
54,000	350.0	6.406	62.00	63.75	51.01	62.52	2.115	3.318	375.1	0.144
54,500	350.0	6.101	59.04	60.72	48.58	59.54	2.115	3.484	375.1	0.152
55,000	350.0	5.810	56.23	57.82	46.27	56.70	2.115	3.658	375.1	0.159
55,500	350.0	5.533	53.55	55.07	44.07	54.00	2.115	3.841	375.1	0.167
56,000	350.0	5.270	51.00	52.45	41.97	51.43	2.115	4.033	375.1	0.176
56,500	350.0	5.019	48.57	49.95	39.97	48.98	2.115	4.235	375.1	0.184
57,000	350.0	4.780	46.26	47.57	38.07	46.65	2.115	4.446	375.1	0.194
57,500	350.0	4.552	44.06	45.30	36.25	44.43	2.115	4.669	375.1	0.203
58,000	350.0	4.335	41.96	43.15	34.53	42.31	2.115	4.902	375.1	0.213
58,500	350.0	4.129	39.96	41.09	32.88	40.30	2.115	5.148	375.1	0.224
59,000	350.0	3.932	38.06	39.14	31.32	38.38	2.115	5.405	375.1	0.235
59,500	350.0	3.745	36.24	37.27	29.82	36.55	2.115	5.675	375.1	0.247
60,000	350.0	3.567	34.52	35.50	28.40	34.81	2.115	3.959	375.1	0.259
60,500	346.9	3.396	32.87	34.10	27.28	33.44	2.101	6.163	373.4	0.270
61,000	343.9	3.232	31.28	32.74	26.20	32.11	2.087	6.375	371.8	0.281
61,500	340.8	3.075	29.76	31.43	25.15	30.82	2.073	6.597	370.1	0.293
62,000	337.8	2.924	28.30	30.15	24.13	29.57	2.059	6.828	368.5	0.305
62,500	334.7	2.779	26.90	28.92	23.14	28.36	2.045	7.070	366.8	0.318
63,000	331.7	2.640	25.55	27.73	22.19	27.19	2.030	7.322	365.1	0.332
63,500	328.6	2.507	24.27	26.58	21.27	26.06	2.016	7.586	363.4	0.347
64,000	325.6	2.380	23.03	25.46	20.37	24.97	2.002	7.861	361.7	0.362
64,500	322.5	2.257	21.85	24.38	19.51	23.91	1.987	8.150	360.0	0.378
65,000	319.4	2.140	20.72	23.34	18.68	22.89	1.973	8.452	358.3	0.395
65,500	316.4	2.028	19.63	22.33	17.87	21.90	1.958	8.767	356.6	0.412
66,000	313.3	1.921	18.60	21.36	17.09	20.95	1.943	9.098	354.9	0.431
66,500	310.3	1.819	17.60	20.42	16.34	20.03	1.928	9.444	353.1	0.451
67,000	307.2	1.721	16.66	19.51	15.61	19.14	1.914	9.807	351.4	0.472
67,500	304.2	1.628	15.75	18.64	14.91	18.28	1.899	10.19	349.6	0.494
68,000	301.1	1.538	14.89	17.79	14.24	17.45	1.884	10.59	347.9	0.518
68,500	298.1	1.453	14.06	16.98	13.59	16.65	1.869	11.01	346.1	0.542
69,000	295.0	1.372	13.28	16.20	12.96	15.88	1.854	11.44	344.3	0.569
69,500	291.9	1.294	12.52	15.44	12.36	15.14	1.838	11.91	342.5	0.596
70,000	288.9	1.220	11.81	14.71	11.77	14.43	1.823	12.39	340.7	0.626
71,000	282.8	1.083	10.48	13.34	10.67	13.08	1.792	13.44	337.1	0.691
72,000	276.7	0.9583	9.275	12.06	9.654	11.83	1.761	14.60	333.5	0.763
73,000	270.6	0.8458	8.186	10.89	8.713	10.68	1.730	15.89	329.8	0.846
74,000	264.4	0.7444	7.205	9.806	7.846	9.616	1.698	17.32	326.0	0.939
75,000	258.3	0.6532	6.322	8.808	7.048	8.637	1.666	18.92	322.2	1.05
76,000	252.2	0.5714	5.530	7.891	6.314	7.738	1.634	20.70	318.4	1.17
77,000	246.1	0.4982	4.822	7.051	5.642	6.915	1.601	22.71	314.5	1.31
78,000	240.0	0.4328	4.189	6.282	5.027	6.161	1.568	24.96	310.6	1.47
79,000	240.0	0.3754	3.634	5.449	4.360	5.343	1.568	28.78	310.6	1.69
80,000	240.0	0.3256	3.151	4.726	3.782	4.635	1.568	33.18	310.6	1.95

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TABLE II.—PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE — METRIC ENGINEERING SYSTEM — Concluded

Altitude, h (m)	Absolute temperature, T (°K)	Pressure, p (kg/m^2)	Pressure ratio, p/p_0	Density, ρ $\left(\frac{\text{kg-sec}^2}{\text{m}^4}\right)$	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific weight, $w = g\rho$ (kg/m^3)	Coefficient of viscosity, μ $\left(\frac{\text{kg-sec}}{\text{m}^2}\right)$ (1)	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (m^2/sec) (1)	Speed of sound, a (m/sec)	Mean free path of molecules, λ (m)
(b) For day only										
80,000	240.0	0.3256	3151×10^{-8}	4726×10^{-9}	3782×10^{-8}	4635×10^{-8}	1.568×10^{-6}	0.3318	310.6	1.95×10^{-3}
81,000	240.0	0.2826	2735	4060	3248	3981	1.568	0.3863	312.5	2.25
82,000	240.0	0.2457	2378	3493	2795	3426	1.568	0.4489	314.5	2.58
83,000	240.0	0.2139	2070	3009	2408	2951	1.568	0.5211	316.5	2.97
84,000	243.6	0.1866	1806	2561	2049	2512	1.588	0.6200	320.8	3.45
85,000	247.3	0.1634	1582	2188	1751	2145	1.607	0.7348	325.2	4.00
86,000	250.9	0.1435	1389	1874	1500	1838	1.627	0.8682	329.6	4.62
87,000	254.6	0.1265	1224	1612	1290	1581	1.646	1.021	333.9	5.32
88,000	258.2	0.1118	1082	1391	1113	1364	1.666	1.197	338.3	6.11
89,000	261.9	0.09908	959.0	1204	963.7	1181	1.685	1.400	342.7	6.99
90,000	265.5	0.08810	852.7	1046	837.1	1026	1.704	1.629	347.1	7.97
91,000	269.2	0.07850	759.7	910.9	728.9	893.2	1.723	1.892	351.5	9.07
92,000	272.8	0.07016	679.0	795.7	636.7	780.3	1.742	2.189	355.9	10.3
93,000	276.5	0.06285	608.3	697.0	557.8	683.6	1.760	2.526	360.4	11.6
94,000	280.1	0.05643	546.1	611.9	489.7	600.1	1.779	2.907	364.8	13.1
95,000	283.8	0.05079	491.6	638.8	431.1	528.4	1.797	3.336	369.2	14.8
96,000	287.4	0.04584	443.7	475.8	380.7	466.6	1.816	3.816	373.7	16.6
97,000	291.1	0.04144	401.1	421.0	336.9	412.9	1.834	4.357	378.1	18.6
98,000	294.7	0.03756	363.5	373.5	298.9	366.3	1.852	4.960	382.6	20.7
99,000	298.4	0.03410	330.1	332.0	265.7	325.6	1.870	5.633	387.1	23.1
100,000	302.0	0.03102	300.2	295.8	236.7	290.1	1.888	6.383	391.5	25.7
101,000	305.7	0.02827	273.6	266.3	213.1	261.2	1.906	7.157	393.9	28.6
102,000	309.3	0.02579	249.6	240.1	192.1	235.5	1.924	8.013	396.2	31.7
103,000	313.0	0.02355	227.9	216.7	173.4	212.5	1.941	8.959	398.6	35.1
104,000	316.6	0.02153	208.4	195.8	156.7	192.0	1.959	10.00	400.9	38.9
105,000	320.3	0.01970	190.7	177.2	141.8	173.7	1.976	11.16	403.2	43.0
106,000	323.9	0.01805	174.7	160.5	128.4	157.4	1.994	12.42	405.5	47.5
107,000	327.6	0.01655	160.2	145.5	116.4	142.7	2.011	13.82	407.7	52.3
108,000	331.2	0.01519	147.0	132.1	105.7	129.5	2.028	15.36	410.0	57.7
109,000	334.9	0.01395	135.1	120.0	96.03	117.7	2.045	17.04	412.3	63.5
110,000	338.5	0.01283	124.2	109.2	87.35	107.1	2.060	18.89	414.5	69.8
111,000	342.2	0.01181	114.3	99.40	79.54	97.48	2.079	20.92	416.7	76.8
112,000	345.8	0.01088	105.3	90.60	72.50	88.85	2.096	23.13	418.9	84.0
113,000	349.5	0.01003	97.08	82.66	66.14	81.06	2.113	25.56	421.1	92.1
114,000	353.1	0.009255	89.58	75.49	60.40	74.02	2.129	28.21	423.3	101
115,000	356.8	0.008548	82.73	69.00	55.21	67.66	2.146	31.10	425.5	110
116,000	360.4	0.007900	76.46	63.13	50.51	61.91	2.162	34.25	427.7	121
117,000	364.1	0.007308	70.73	57.81	46.26	56.69	2.179	37.69	429.8	132
118,000	367.7	0.006765	65.47	52.98	42.40	51.96	2.195	41.43	432.0	144
119,000	371.4	0.006267	60.66	48.60	38.89	47.66	2.211	45.50	434.1	157
120,000	375.0	0.005810	56.24	44.62	35.71	43.76	2.227	49.92	436.3	171
(c) For night only										
80,000	240.0	0.3256	3151×10^{-8}	4726×10^{-9}	3782×10^{-8}	4635×10^{-8}	1.568×10^{-6}	0.3318	310.6	1.95×10^{-3}
81,000	240.0	0.2824	2733	4099	3280	4020	1.568	0.3825	310.6	2.25
82,000	240.0	0.2450	2371	3555	2845	3486	1.568	0.4411	310.6	2.59
83,000	240.0	0.2125	2056	3084	2467	3024	1.568	0.5085	310.6	2.99
84,000	243.6	0.1845	1785	2637	2110	2586	1.588	0.6021	312.9	3.49
85,000	247.3	0.1605	1553	2261	1809	2217	1.607	0.7110	315.3	4.07
86,000	250.9	0.1399	1354	1943	1554	1905	1.627	0.8376	317.6	4.74
87,000	254.6	0.1222	1183	1673	1338	1640	1.645	0.9834	319.9	5.51
88,000	258.2	0.1070	1036	1443	1155	1415	1.666	1.154	322.2	6.38
89,000	261.9	0.09383	908.1	1248	998.6	1224	1.685	1.350	324.4	7.38
90,000	265.5	0.08243	797.8	1081	865.3	1060	1.704	1.576	326.7	8.52
91,000	269.2	0.07254	702.1	938.8	751.2	920.6	1.723	1.835	328.9	9.81
92,000	272.8	0.06395	618.9	816.5	653.3	800.6	1.742	2.133	331.1	11.3
93,000	276.5	0.05647	546.6	711.5	569.3	697.7	1.760	2.474	333.4	12.9
94,000	280.1	0.04995	483.4	621.1	497.0	609.1	1.779	2.864	335.5	14.8
95,000	283.8	0.04425	428.3	543.2	434.6	532.7	1.798	3.309	337.7	17.0
96,000	287.4	0.03926	380.0	475.8	380.7	466.6	1.816	3.816	339.9	19.4
97,000	291.1	0.03489	337.7	417.5	334.1	409.4	1.834	4.393	342.0	22.1
98,000	294.7	0.03105	300.5	367.0	293.6	359.9	1.852	5.048	344.2	25.1
99,000	298.4	0.02767	267.8	323.0	258.5	316.8	1.870	5.790	346.3	28.5
100,000	302.0	0.02469	239.0	284.8	227.9	279.3	1.888	6.630	348.4	32.3
101,000	305.7	0.02207	213.6	251.5	201.2	246.6	1.906	7.579	350.5	36.6
102,000	309.3	0.01975	191.1	222.4	178.0	218.1	1.924	8.651	352.6	41.4
103,000	313.0	0.01770	171.3	197.0	157.6	193.1	1.942	9.859	354.7	46.8
104,000	316.6	0.01588	153.6	174.7	139.8	171.3	1.959	11.22	356.7	52.7
105,000	320.3	0.01426	138.0	155.1	124.1	152.1	1.976	12.74	358.8	59.4
106,000	323.9	0.01284	124.2	136.2	109.0	133.5	1.994	14.64	363.9	66.7
107,000	327.6	0.01158	112.1	119.8	95.89	117.5	2.011	16.78	369.0	74.8
108,000	331.2	0.01048	101.4	105.8	84.62	103.7	2.028	19.18	374.1	83.6
109,000	334.9	0.009501	91.95	93.60	74.90	91.79	2.045	21.85	379.2	93.2
110,000	338.5	0.008636	83.58	83.06	66.47	81.46	2.062	24.83	384.3	104
111,000	342.2	0.007867	76.14	73.90	59.13	72.47	2.079	28.14	389.4	115
112,000	345.8	0.007183	69.52	65.91	52.74	64.63	2.096	31.80	394.6	127
113,000	349.5	0.006573	63.62	58.93	47.16	57.79	2.113	35.85	399.8	141
114,000	353.1	0.006026	58.32	52.80	42.25	51.78	2.129	40.33	404.9	155
115,000	356.8	0.005534	53.56	47.41	37.94	46.49	2.146	45.26	410.1	170
116,000	360.4	0.005091	49.28	42.66	34.13	41.83	2.162	50.69	415.3	187
117,000	364.1	0.004695	45.44	38.47	30.78	37.73	2.179	56.63	420.6	205
118,000	367.7	0.004336	41.97	34.77	27.82	34.09	2.195	63.14	425.8	224
119,000	371.4	0.004011	38.82	31.47	25.18	30.86	2.211	70.27	431.0	245
120,000	375.0	0.003718	35.98	28.55	22.85	28.00	2.227	78.01	436.3	267

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[1] The values for viscosity listed in these columns are not applicable at the higher altitudes where the mean free paths of the molecules are comparable to or longer than the dimensions of the body being considered. Furthermore, the values listed are based on the conventional Sutherland formula for normal air and, consequently, no allowance has been made for the effect of dissociated oxygen in the atmosphere at the higher levels.

TABLE III.– PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE— BRITISH ENGINEERING SYSTEM

Altitude, h (ft)	Absolute temperature, T (°F abs.)	Pressure, p (lb/ft²)	Pressure ratio, p/p₀	Density, ρ (slugs/ft³)	Density ratio, σ = ρ/ρ₀	Specific weight, w = ρg (lb/ft³)	Coefficient of viscosity, μ (lb-sec/ft²)	Kinematic viscosity, ν = μ/ρ (ft²/sec)	Speed of sound, a (ft/sec)	Mean free path of molecules, λ (ft)
(a) For both day and night										
65,000	392.4	118.8	5612×10^{-5}	1763×10^{-7}	7414×10^{-5}	5672×10^{-6}	2.961×10^{-7}	0.001680	971.1	0.00326×10^{-3}
66,000	392.4	113.2	5350	1681	7068	5407	2.961	0.001761	971.1	0.00342
67,000	392.4	107.9	5100	1602	6738	5155	2.961	0.001848	971.1	0.00359
68,000	392.4	102.9	4862	1527	6423	4914	2.961	0.001939	971.1	0.00377
69,000	392.4	98.09	4635	1456	6123	4684	2.961	0.002034	971.1	0.00395
70,000	392.4	93.52	4419	1388	5838	4466	2.961	0.002133	971.1	0.00414
71,000	392.4	89.16	4213	1324	5566	4258	2.961	0.002236	971.1	0.00435
72,000	392.4	85.01	4017	1262	5307	4060	2.961	0.002346	971.1	0.00456
73,000	392.4	81.05	3830	1203	5060	3871	2.961	0.002461	971.1	0.00478
74,000	392.4	77.26	3651	1147	4823	3690	2.961	0.002582	971.1	0.00502
75,000	392.4	73.67	3481	1094	4599	3519	2.961	0.002710	971.1	0.00527
76,000	392.4	70.22	3318	1042	4383	3353	2.961	0.002844	971.1	0.00553
77,000	392.4	66.94	3163	993.7	4179	3197	2.961	0.002985	971.1	0.00580
78,000	392.4	63.80	3015	947.1	3983	3047	2.961	0.003127	971.1	0.00608
79,000	392.4	60.84	2875	903.1	3798	2906	2.961	0.003279	971.1	0.00637
80,000	392.4	58.01	2741	861.0	3621	2770	2.961	0.003439	971.1	0.00668
81,000	392.4	55.30	2613	820.9	3452	2641	2.961	0.003607	971.1	0.00701
82,000	392.4	52.72	2491	782.6	3291	2518	2.961	0.003784	971.1	0.00735
83,000	392.4	50.26	2375	746.2	3138	2401	2.961	0.003968	971.1	0.00771
84,000	392.4	47.91	2264	711.2	2991	2288	2.961	0.004163	971.1	0.00809
85,000	392.4	45.69	2159	678.2	2852	2182	2.961	0.004366	971.1	0.00848
86,000	392.4	43.55	2058	646.6	2719	2080	2.961	0.004579	971.1	0.00890
87,000	392.4	41.54	1963	616.6	2593	1984	2.961	0.004802	971.1	0.00933
88,000	392.4	39.59	1871	587.8	2472	1891	2.961	0.005037	971.1	0.00979
89,000	392.4	37.73	1783	560.2	2356	1802	2.961	0.005286	971.1	0.0103
90,000	392.4	35.95	1699	533.8	2245	1718	2.961	0.005547	971.1	0.0108
91,000	392.4	34.28	1620	508.9	2140	1637	2.961	0.005818	971.1	0.0113
92,000	392.4	32.70	1545	485.3	2041	1561	2.961	0.006101	971.1	0.0119
93,000	392.4	31.17	1473	462.7	1946	1489	2.961	0.006399	971.1	0.0124
94,000	392.4	29.71	1404	441.1	1855	1419	2.961	0.006713	971.1	0.0130
95,000	392.4	28.34	1339	420.7	1769	1353	2.961	0.007038	971.1	0.0137
96,000	392.4	27.02	1277	401.2	1687	1291	2.961	0.007380	971.1	0.0143
97,000	392.4	25.75	1217	382.4	1608	1230	2.961	0.007743	971.1	0.0150
98,000	392.4	24.55	1160	364.3	1532	1172	2.961	0.008128	971.1	0.0158
99,000	392.4	23.41	1106	347.4	1461	1118	2.961	0.008523	971.1	0.0166
100,000	392.4	22.31	1054	331.0	1392	1065	2.961	0.008946	971.1	0.0174
102,000	392.4	20.39	958.6	301.0	1266	968.6	2.961	0.009837	971.1	0.0191
104,000	392.4	18.44	871.3	273.7	1151	880.6	2.961	0.01082	971.1	0.0210
104,987	392.4	17.59	831.1	261.1	1098	840.0	2.961	0.01134	971.1	0.0220
106,000	396.5	16.76	792.2	246.4	1036	792.6	2.987	0.01212	976.2	0.0234
108,000	404.5	15.26	721.2	219.8	924.2	707.1	3.039	0.01383	986.0	0.0262
110,000	412.6	13.92	658.0	196.6	826.8	632.6	3.090	0.01572	995.8	0.0293
112,000	420.6	12.73	601.4	176.2	741.2	567.1	3.141	0.01783	1005	0.0326
114,000	428.7	11.65	550.6	158.3	665.9	509.5	3.191	0.02016	1015	0.0363
116,000	436.7	10.69	505.0	142.6	599.5	458.7	3.241	0.02273	1025	0.0404
118,000	444.8	9.817	463.9	128.6	540.9	413.8	3.290	0.02558	1034	0.0447
120,000	452.8	9.026	426.5	116.1	488.3	373.6	3.339	0.02876	1043	0.0495
122,000	460.9	8.315	392.9	105.1	442.0	338.2	3.388	0.03224	1052	0.0547
124,000	468.9	7.671	362.5	95.31	400.8	306.6	3.436	0.03605	1062	0.0604
126,000	476.9	7.089	335.0	86.58	364.1	278.6	3.484	0.04024	1071	0.0664
128,000	485.0	6.556	309.8	78.73	331.1	253.3	3.531	0.04485	1080	0.0731
130,000	493.0	6.071	286.9	71.74	301.7	230.8	3.579	0.04989	1089	0.0802
132,000	501.1	5.631	266.1	65.46	275.3	210.6	3.625	0.05538	1097	0.0879
134,000	509.1	5.229	247.1	59.83	251.6	192.5	3.672	0.06137	1106	0.0961
136,000	517.2	4.859	229.6	54.72	230.1	176.0	3.718	0.06795	1115	0.105
138,000	525.2	4.522	213.7	50.15	210.9	161.4	3.764	0.07505	1124	0.115
140,000	533.3	4.213	199.1	46.01	193.5	148.0	3.809	0.08279	1132	0.125
142,000	541.3	3.930	185.7	42.28	177.8	136.0	3.854	0.09115	1141	0.136
144,000	549.4	3.670	173.4	38.90	163.6	125.2	3.899	0.1002	1149	0.148
146,000	557.4	3.428	162.0	35.83	150.7	115.3	3.944	0.1101	1157	0.161
148,000	565.5	3.208	151.6	33.05	139.0	106.3	3.988	0.1207	1166	0.174
150,000	573.5	3.003	141.9	30.51	128.3	98.16	4.032	0.1322	1174	0.189
152,000	581.6	2.815	133.0	28.20	118.6	90.74	4.076	0.1445	1182	0.204
154,000	589.6	2.639	124.7	26.06	109.6	83.85	4.119	0.1581	1190	0.221
156,000	597.6	2.478	117.1	24.16	101.6	77.73	4.163	0.1723	1199	0.238
158,000	605.7	2.328	110.0	22.39	94.15	72.03	4.205	0.1878	1207	0.257
160,000	613.7	2.190	103.5	20.79	87.42	66.88	4.247	0.2043	1215	0.277
162,000	621.8	2.061	97.37	19.30	81.15	62.13	4.289	0.2222	1222	0.298
164,000	629.8	1.941	91.72	17.95	75.49	57.72	4.331	0.2413	1230	0.320
164,042	630.0	1.938	91.60	17.92	75.38	57.66	4.332	0.2417	1231	0.321
166,000	630.0	1.829	86.42	16.91	71.11	54.40	4.332	0.2562	1231	0.340
168,000	630.0	1.723	81.43	15.93	67.01	51.27	4.332	0.2719	1231	0.361
170,000	630.0	1.624	76.73	15.01	63.14	48.31	4.332	0.2886	1231	0.383
172,000	630.0	1.530	72.29	14.14	59.48	45.51	4.332	0.3064	1231	0.407
174,000	630.0	1.441	68.11	13.33	56.04	42.87	4.332	0.3250	1231	0.432
176,000	630.0	1.358	64.19	12.55	52.82	40.41	4.332	0.3449	1231	0.458
178,000	630.0	1.280	60.48	11.83	49.77	38.08	4.332	0.3662	1231	0.486
180,000	630.0	1.206	56.98	11.15	46.89	35.87	4.332	0.3885	1231	0.516
182,000	630.0	1.136	53.69	10.51	44.18	33.80	4.332	0.4122	1231	0.548
184,000	630.0	1.071	50.59	9.899	41.63	31.85	4.332	0.4376	1231	0.581
186,000	630.0	1.009	47.67	9.329	39.23	30.01	4.332	0.4644	1231	0.617
188,000	630.0	0.9506	44.92	8.789	36.96	28.28	4.332	0.4929	1231	0.655
190,000	630.0	0.8956	42.32	8.280	34.82	26.64	4.332	0.5232	1231	0.695
192,000	630.0	0.8442	39.89	7.802	32.81	25.10	4.332	0.5552	1231	0.737
194,000	630.0	0.7953	37.58	7.352	30.92	23.66	4.332	0.5892	1231	0.782
196,000	630.0	0.7491	35.40	6.927	29.13	22.29	4.332	0.6254	1231	0.830
196,850	630.0	0.7305	34.52	6.756	28.40	21.74	4.332	0.6412	1231	0.852
198,000	626.1	0.7060	33.36	6.568	27.62	21.13	4.312	0.6565	1227	0.876
200,000	619.4	0.6645	31.40	6.249	26.28	20.11	4.277	0.6844	1220	0.929
202,000	612.7	0.6253	29.55	5.945	25.00	19.13	4.242	0.7135	1214	0.968
204,000	606.0	0.5881	27.79	5.652	23.77	18.19	4.206	0.7442	1207	1.02
206,000	599.3	0.5528	26.12	5.372	22.59	17.28	4.171	0.7764	1200	1.07
208,000	592.6	0.5189	24.52	5.101	21.45	16.41	4.135	0.8106	1193	1.13
210,000	585.9	0.4869	23.01	4.841	20.36	15.58	4.099	0.8467	1187	1.19
212,000	579.2	0.4567	21.58	4.592	19.31	14.77	4.063	0.8848	1180	1.25
214,000	572.5	0.4279	20.22	4.354	18.31	14.01	4.026	0.9247	1173	1.32
216,000	565.8	0.4006	18.93	4.123	17.34	13.27	3.990	0.9677	1166	1.39
218,000	559.1	0.3748	17.71	3.905	16.42	12.56	3.953	1.012	1159	1.47
220,000	552.4	0.3504	16.56	3.695	15.54	11.89	3.916	1.060	1152	1.56
222,000	545.7	0.3272	15.46	3.493	14.69	11.24	3.879	1.111	1145	1.65
224,000	539.0	0.3054	14.43	3.301	13.88	10.62	3.841	1.164	1138	1.74
226,000	532.3	0.2846	13.45	3.115	13.10	10.02	3.804	1.221	1131	1.85
228,000	525.6	0.2652	12.53	2.939	12.36	9.456	3.766	1.281	1124	1.96
230,000	518.9	0.2470	11.67	2.773	11.66	8.921	3.727	1.344	1117	2.07
232,000	512.1	0.2296	10.85	2.611	10.98	8.400	3.689	1.413	1109	2.20
234,000	505.4	0.2133	10.08	2.459	10.34	7.911	3.651	1.485	1102	2.34
236,000	498.7	0.1979	9.351	2.311	9.720	7.436	3.612	1.563	1095	2.49
238,000	492.0	0.1835	8.671	2.172	9.136	6.990	3.573	1.645	1087	2.65
240,000	485.3	0.1699	8.029	2.039	8.576	6.561	3.533	1.733	1080	2.82
242,000	478.6	0.1572	7.426	1.913	8.045	6.155	3.494	1.826	1073	3.01
244,000	471.9	0.1453	6.865	1.793	7.541	5.769	3.454	1.926	1065	3.21
246,000	465.2	0.1341	6.337	1.679	7.062	5.403	3.414	2.033	1057	3.43
248,000	458.5	0.1237	5.844	1.571	6.607	5.055	3.373	2.148	1050	3.66
250,000	451.8	0.1139	5.382	1.468	6.175	4.724	3.333	2.270	1042	3.92
252,000	445.1	0.1048	4.950	1.371	5.795	4.411	3.292	2.401	1034	4.20
254,000	438.4	0.09625	4.548	1.279	5.378	4.114	3.251	2.542	1026	4.50
255,905	432.0	0.08865	4.189	1.195	5.027	3.846	3.212	2.688	1019	4.81
256,000	432.0	0.08829	4.172	1.190	5.006	3.831	3.212	2.697	1019	4.83
258,000	432.0	0.08095	3.825	1.091	4.590	3.512	3.212	2.944	1019	5.27
260,000	432.0	0.07422	3.507	1.001	4.208	3.219	3.212	3.209	1019	5.75
262,000	432.0	0.06806	3.216	0.9176	3.859	2.952	3.212	3.500	1019	6.27
262,457	432.0	0.06669	3.151	0.8993	3.782	2.893	3.212	3.572	1019	6.40

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TABLE III.—PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE — BRITISH ENGINEERING SYSTEM — Continued

Altitude, h (ft)	Absolute temperature, T (°F abs.)	Pressure, p (lb/ft²)	Pressure ratio, p/p_0	Density, ρ (slugs/ft³)	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific weight, $w = g\rho$ (lb/ft³)	Coefficient of viscosity, μ (lb sec/ft²) (1)	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (ft²/sec) (1)	Speed of sound, a (ft/sec)	Mean free path of molecules, λ (ft)
(b) For day only										
262,467	432.0	0.06669	3.151×18^{-5}	89.93×10^{-9}	3.782×10^{-5}	2.893×10^{-6}	3.212×10^{-7}	3.572	1019	6.40×10^{-3}
264,000	432.0	0.06241	2.949	83.75	3.522	2.695	3.212	3.835	1022	6.84
266,000	432.0	0.05724	2.705	76.33	3.210	2.456	3.212	4.208	1026	7.45
268,000	432.0	0.05257	2.484	69.65	2.929	2.241	3.212	4.612	1030	8.12
270,000	432.0	0.04829	2.282	63.59	2.674	2.046	3.212	5.051	1034	8.83
272,000	432.0	0.04438	2.097	58.07	2.442	1.868	3.212	5.531	1038	9.61
272,309	432.0	0.04381	2.070	57.26	2.408	1.842	3.212	5.610	1038	9.74
274,000	435.4	0.04082	1.929	52.67	2.215	1.695	3.232	6.136	1046	10.5
276,000	439.4	0.03760	1.776	47.77	2.009	1.537	3.257	6.818	1054	11.5
278,000	443.4	0.03469	1.638	43.42	1.826	1.397	3.282	7.559	1063	12.6
280,000	447.4	0.03200	1.512	39.45	1.659	1.269	3.306	8.380	1072	13.8
282,000	451.4	0.02956	1.397	35.91	1.510	1.155	3.331	9.273	1081	15.1
284,000	455.4	0.02736	1.293	32.74	1.377	1.053	3.355	10.25	1089	16.4
286,000	459.4	0.02535	1.198	29,89	1.257	0.9616	3.379	11.30	1098	17.9
288,000	463.4	0.02351	1.111	27.32	1.149	0.8791	3.403	12.46	1107	19.5
290,000	467.4	0.02184	1.032	25.02	1.052	0.8048	3.427	13.70	1116	21.1
292,000	471.4	0.02029	0.9588	22.91	0.9635	0.7371	3.451	15.06	1124	22.9
294,000	475.4	0.01888	0.8920	21.01	0.8837	0.6761	3.475	16.54	1133	24.9
296,000	479.4	0.01759	0.8310	19.30	0.8117	0.6210	3.499	18.13	1142	26.9
298,000	483.4	0.01639	0.7746	17.74	0.7460	0.5707	3.523	19.86	1151	29.1
300,000	487.4	0.01530	0.7228	16.32	0.6865	0.5252	3.546	21.73	1160	31.5
302,000	491.4	0.01428	0.6750	15.03	0.6322	0.4837	3.569	23.75	1169	34.0
304,000	495.4	0.01336	0.6314	13.87	0.5833	0.4463	3.593	25.90	1177	36.6
306,000	499.4	0.01250	0.5908	12.80	0.5384	0.4119	3.616	28.25	1186	39.4
308,000	503.4	0.01170	0.5531	11.82	0.4972	0.3804	3.639	30.79	1195	42.5
310,000	507.4	0.01098	0.5185	10.94	0.4599	0.3519	3.662	33.47	1204	45.7
312,000	511.5	0.01030	0.4866	10.13	0.4259	0.3258	3.685	36.38	1213	49.0
314,000	515.5	0.009671	0.4570	9.386	0.3947	0.3020	3.708	39.51	1222	52.6
316,000	519.5	0.009091	0.4296	8.705	0.3661	0.2801	3.731	42.86	1231	56.4
318,000	523.5	0.008550	0.4040	8.082	0.3399	0.2600	3.754	46.45	1240	60.5
320,000	527.5	0.008050	0.3804	7.509	0.3158	0.2416	3.777	50.30	1248	64.7
322,000	531.5	0.007585	0.3584	6.984	0.2937	0.2247	3.799	54.40	1257	69.2
324,000	535.5	0.007153	0.3380	6.504	0.2735	0.2092	3.822	58.75	1266	73.9
326,000	539.5	0.006744	0.3187	6.054	0.2546	0.1948	3.844	63.50	1275	79.0
328,000	543.5	0.006368	0.3009	5.645	0.2374	0.1816	3.867	68.48	1284	84.3
328,083	543.6	0.006353	0.3002	5.628	0.2367	0.1811	3.867	68.71	1285	84.5
330,000	547.5	0.006012	0.2841	5.288	0.2224	0.1701	3.889	73.54	1289	89.9
332,000	551.5	0.005686	0.2687	4.965	0.2088	0.1597	3.911	78.77	1294	95.8
334,000	555.5	0.005377	0.2541	4.661	0.1960	0.1500	3.933	84.38	1298	102
336,000	559.5	0.005087	0.2404	4.380	0.1842	0.1409	3.955	90.30	1303	109
338,000	563.5	0.004812	0.2274	4.114	0.1730	0.1324	3.977	96.67	1308	116
340,000	567.5	0.004556	0.2153	3,866	0.1626	0.1244	3.999	103.4	1312	123
342,000	571.5	0.004315	0.2039	3.636	0.1529	0.1170	4.021	110.5	1317	131
344,000	575.5	0.004091	0.1933	3.424	0.1440	0.1102	4.043	118.1	1322	139
346,000	579.5	0.003875	0.1831	3.220	0.1354	0.1036	4.065	126.2	1326	148
348,000	583.5	0.003674	0.1736	3.032	0.1275	0.09755	4.086	134.8	1331	157
350,000	587.5	0.003485	0.1647	2.858	0.1202	0.09196	4.108	143.7	1335	167
352,000	591.5	0.003306	0.1562	2.692	0.1132	0.08660	4.129	153.4	1340	177
354,000	595.5	0.003136	0.1482	2.537	0.1067	0.08163	4.151	163.6	1344	188
356,000	599.5	0.002978	0.1407	2.392	0.1006	0.07697	4.172	174.4	1349	199
358,000	603.5	0.002829	0.1337	2.258	0.09495	0.07264	4.193	185.7	1353	211
360,000	607.5	0.002690	0.1271	2.132	0.08967	0.06860	4.214	197.7	1358	223
362,000	611.5	0.002556	0.1208	2.013	0.08466	0.06477	4.236	210.4	1362	236
364,000	615.5	0.002429	0.1148	1.901	0.07994	0.06116	4.257	223.9	1367	250
366,000	619.6	0.002311	0.1092	1.796	0.07554	0.05779	4.278	238.2	1371	265
368,000	623.6	0.002199	0.1039	1.698	0.07142	0.05464	4.299	253.2	1376	280
370,000	627.6	0.002092	0.09887	1.606	0.06753	0.05166	4.319	268.9	1380	296
372,000	631.6	0.001992	0.09411	1.519	0.06387	0.04886	4.340	285.7	1384	313
374,000	635.6	0.001897	0.08962	1.437	0.06044	0.04624	4.361	303.5	1389	331
376,000	639.6	0.001806	0.08536	1.360	0.05720	0.04376	4.382	322.2	1393	350
378,000	643.6	0.001721	0.08133	1.288	0.05416	0.04144	4.402	341.8	1398	370
380,000	647.6	0.001640	0.07751	1.220	0.05130	0.03925	4.423	362.5	1402	390
382,000	651.6	0.001564	0.07390	1.156	0.04861	0.03719	4.443	384.3	1406	411
384,000	655.6	0.001492	0.07049	1.096	0.04609	0.03526	4.464	407.3	1411	434
386,000	659.6	0.001423	0.06724	1.039	0.04369	0.03343	4.484	431.6	1415	458
388,000	663.6	0.001358	0.06417	0.9856	0.04145	0.03171	4.504	457.0	1419	483
390,000	667.6	0.001296	0.06126	0.9352	0.03933	0.03009	4.525	483.9	1423	509
392,000	671.6	0.001237	0.05847	0.8872	0.03731	0.02854	4.545	512.3	1428	536
393,700	675.0	0.001190	0.05624	0.8491	0.03571	0.02732	4.562	537.3	1431	560

[1] The values for viscosity listed in these columns are not applicable at the higher altitudes where the mean free paths of the molecules are comparable to or longer than the dimensions of the body being considered. Furthermore, the values listed are based on the conventional Sutherland formula for normal air and, consequently, no allowance has been made for the effect of dissociated oxygen in the atmosphere at the higher levels.

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TABLE III.— PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE — BRITISH ENGINEERING SYSTEM — Concluded

Altitude, h (ft)	Absolute temperature, T (°F abs.)	Pressure, p (lb/ft^2)	Pressure ratio, p/p_0	Density, ρ (slugs/ft^3)	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific Weight, $w = g\rho$ (lb/ft^3)	Coefficient of viscosity μ (lb-sec/ft^2) (1)	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (ft^2/sec) (1)	Speed of sound, a (ft/sec)	Mean free path of molecules, λ (ft)
(c) For night only										
262,467	432.0	0.06669	3.151×10^{-5}	89.93×10^{-9}	3.782×10^{-5}	2.893×10^{-6}	3.212×10^{-7}	3.572	1019	6.40×10^{-3}
264,000	432.0	0.06239	2.948	84.13	3.538	2.707	3.212	3.818	1019	6.84
266,000	432.0	0.05720	2.703	77.14	3.244	2.482	3.212	4.164	1019	7.46
268,000	432.0	0.05246	2.479	70.74	2.975	2.276	3.212	4.541	1019	8.13
270,000	432.0	0.04810	2.273	64.87	2.728	2.087	3.212	4.951	1019	8.87
272,000	432.0	0.04410	2.084	59.47	2.501	1.913	3.212	5.401	1019	9.67
272,309	432.0	0.04351	2.056	58.67	2.467	1.887	3.212	5.475	1019	9.80
274,000	435.4	0.04044	1.911	54.10	2.275	1.741	3.232	5.974	1023	10.6
276,000	439.4	0.03712	1.754	49.20	2.069	1.583	3.257	6.620	1028	11.7
278,000	443.4	0.03408	1.611	44.80	1.884	1.441	3.282	7.326	1032	12.8
280,000	447.4	0.03134	1.481	40.80	1.716	1.313	3.306	8.103	1037	14.1
282,000	451.4	0.02884	1.363	37.24	1.566	1.198	3.331	8.945	1042	15.5
284,000	455.4	0.02656	1.255	33.98	1.429	1.093	3.355	9.873	1046	16.9
286,000	459.4	0.02446	1.156	31.01	1.304	0.9976	3.379	10.90	1051	18.5
288,000	463.4	0.02256	1.066	28.34	1.192	0.9120	3.403	12.01	1055	20.3
290,000	467.4	0.02081	0.9832	25.92	1.090	0.8339	3.427	13.22	1060	22.2
292,000	471.4	0.01921	0.9079	23.74	0.9984	0.7638	3.451	14.54	1064	24.2
294,000	475.4	0.01774	0.8384	21.74	0.9142	0.6994	3.475	15.98	1069	26.5
296,000	479.4	0.01640	0.7748	19.92	0.8378	0.6410	3.499	17.57	1073	28.9
298,000	483.4	0.01517	0.7168	18.28	0.7687	0.5881	3.523	19.27	1078	31.5
300,000	487.4	0.01406	0.6643	16.80	0.7065	0.5405	3.546	21.11	1082	34.2
302,000	491.4	0.01302	0.6151	15.43	0.6489	0.4964	3.569	23.13	1087	37.3
304,000	495.4	0.01206	0.5699	14.18	0.5963	0.4562	3.593	25.34	1091	40.6
306,000	499.4	0.01119	0.5286	13.05	0.5487	0.4198	3.616	27.71	1096	44.1
308,000	503.4	0.01038	0.4906	12.01	0.5052	0.3865	3.639	30.30	1100	47.9
310,000	507.4	0.009642	0.4556	11.07	0.4654	0.3561	3.662	33.08	1104	52.0
312,000	511.5	0.008958	0.4233	10.20	0.4290	0.3282	3.685	36.13	1109	56.4
314,000	515.5	0.008327	0.3935	9.409	0.3957	0.3027	3.708	39.41	1113	61.1
316,000	519.5	0.007745	0.3660	8.686	0.3653	0.2795	3.731	42.95	1117	66.2
318,000	523.5	0.007210	0.3407	8.023	0.3374	0.2581	3.754	46.79	1122	71.7
320,000	527.5	0.006711	0.3171	7.410	0.3116	0.2384	3.777	50.97	1126	77.6
322,000	531.5	0.006253	0.2955	6.853	0.2882	0.2205	3.799	55.44	1130	83.9
324,000	535.5	0.005826	0.2753	6.337	0.2665	0.2039	3.822	60.31	1134	90.8
326,000	539.5	0.005437	0.2569	5.871	0.2469	0.1889	3.844	65.47	1139	98.0
328,000	543.5	0.005073	0.2397	5.436	0.2286	0.1749	3.867	71.14	1143	106
330,000	547.5	0.004736	0.2238	5.039	0.2119	0.1621	3.889	77.18	1147	114
332,000	551.5	0.004423	0.2090	4.673	0.1965	0.1503	3.911	83.69	1151	123
334,000	555.5	0.004133	0.1953	4.335	0.1823	0.1395	3.933	90.73	1155	133
336,000	559.5	0.003864	0.1826	4.023	0.1692	0.1294	3.955	98.31	1160	143
338,000	563.5	0.003617	0.1709	3.738	0.1572	0.1203	3.977	106.4	1164	154
340,000	567.5	0.003384	0.1599	3.474	0.1461	0.1118	3.999	115.1	1168	166
342,000	571.5	0.003166	0.1496	3.227	0.1357	0.1038	4.021	124.6	1172	178
344,000	575.5	0.002967	0.1402	3.003	0.1263	0.09663	4.043	134.6	1176	192
344,487	576.5	0.002920	0.1380	2.951	0.1241	0.09494	4.048	137.2	1177	195
346,000	579.5	0.002781	0.1314	2.777	0.1168	0.08936	4.065	146.4	1185	206
348,000	583.5	0.002611	0.1234	2.568	0.1080	0.08263	4.086	159.1	1195	221
350,000	587.5	0.002453	0.1159	2.376	0.09992	0.07644	4.108	172.9	1205	237
352,000	591.5	0.002305	0.1089	2.199	0.09248	0.07075	4.129	187.8	1215	253
354,000	595.5	0.002169	0.1025	2.039	0.08575	0.06560	4.151	203.6	1226	271
356,000	599.5	0.002041	0.09646	1.891	0.07951	0.06083	4.172	220.6	1236	290
358,000	603.5	0.001924	0.09090	1.756	0.07383	0.05748	4.193	238.8	1246	310
360,000	607.5	0.001815	0.08576	1.632	0.06864	0.05251	4.214	258.2	1256	331
362,000	611.5	0.001714	0.08098	1.519	0.06388	0.04887	4.236	278.9	1267	353
364,000	615.5	0.001618	0.07648	1.414	0.05947	0.04550	4.257	301.1	1277	376
366,000	619.6	0.001531	0.07235	1.319	0.05546	0.04243	4.278	324.3	1287	400
368,000	623.6	0.001449	0.06848	1.231	0.05175	0.03959	4.299	349.2	1297	425
370,000	627.6	0.001373	0.06488	1.149	0.04834	0.03698	4.319	375.9	1308	451
372,000	631.6	0.001302	0.06151	1.075	0.04520	0.03458	4.340	403.7	1318	479
374,000	635.6	0.001235	0.05836	1.006	0.04229	0.03235	4.361	433.5	1328	508
376,000	639.6	0.001172	0.05537	0.9409	0.03957	0.03027	4.382	465.7	1339	539
378,000	643.6	0.001113	0.05260	0.8817	0.03708	0.02837	4.402	499.3	1349	571
380,000	647.6	0.001058	0.05000	0.8268	0.03477	0.02660	4.423	535.0	1359	604
382,000	651.6	0.001007	0.04757	0.7761	0.03264	0.02497	4.443	572.5	1370	639
384,000	655.6	0.0009582	0.04528	0.7288	0.03065	0.02345	4.464	612.5	1381	676
386,000	659.6	0.0009127	0.04313	0.6851	0.02881	0.02204	4.484	654.5	1391	714
388,000	663.6	0.0008702	0.04112	0.6444	0.02710	0.02073	4.504	698.9	1401	754
390,000	667.6	0.0008296	0.03920	0.6064	0.02550	0.01951	4.525	746.2	1412	795
392,000	671.6	0.0007917	0.03741	0.5712	0.02402	0.01838	4.545	795.7	1422	838
393,700	675.0	0.0007614	0.03598	0.5434	0.02285	0.01748	4.562	839.5	1431	875

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[1] The values for viscosity listed in these columns are not applicable at the higher altitudes where the mean free paths of the molecules are comparable to or longer than the dimensions of the body being considered. Furthermore, the values listed are based on the conventional Sutherland formula for normal air and, consequently, no allowance has been made for the effect of dissociated oxygen in the atmosphere at the higher levels.

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TABLES IV AND V

PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE

The following set of two tables (tables IV and V) does not constitute a consistent extension of the standard tables for the lower atmosphere (NACA Rep. No. 218) but takes into account the inverse square law of gravitational attraction and, consequently, the values in these tables are more accurate than those in tables II and III.

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TABLE IV.– PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE — METRIC ENGINEERING SYSTEM

(a) For both day and night

Altitude, h (m)	Absolute temperature, T (°K)	Pressure, p (kg/m²)	Pressure ratio, p/p_0	Density, ρ $\left(\frac{\text{kg-sec}^2}{\text{m}^4}\right)$	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific weight, $w = g\rho$ (kg/m³)	Coefficient of viscosity, μ $\left(\frac{\text{kg-sec}}{\text{m}^2}\right)$	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (m²/sec)	Speed of sound, a (m/sec)	Mean free path of molecules, λ (m)
20,000	218.0	568.4	5501×10^{-5}	9082×10^{-6}	7268×10^{-5}	8851×10^{-5}	1.446×10^{-6}	0.01592×10^{-2}	296.0	0.00101×10^{-3}
20,500	218.0	525.8	5089	8402	6723	8186	1.446	0.01721	296.0	0.00109
21,000	218.0	486.4	4708	7771	6218	7572	1.446	0.01860	296.0	0.00118
21,500	218.0	449.9	4355	7189	5750	7003	1.446	0.02011	296.0	0.00127
22,000	218.0	416.3	4029	6651	5322	6478	1.446	0.02173	296.0	0.00138
22,500	218.0	385.1	3727	6153	4923	5993	1.446	0.02349	296.0	0.00149
23,000	218.0	356.3	3448	5693	4556	5543	1.446	0.02539	296.0	0.00161
23,500	218.0	329.6	3190	5266	4214	5128	1.446	0.02745	296.0	0.00174
24,000	218.0	305.0	2952	4873	3899	4743	1.446	0.02967	296.0	0.00188
24,500	218.0	282.2	2731	4508	3607	4388	1.446	0.03207	296.0	0.00203
25,000	218.0	261.0	2526	4171	3338	4059	1.446	0.03466	296.0	0.00219
25,500	218.0	241.5	2337	3859	3088	3755	1.446	0.03746	296.0	0.00237
26,000	218.0	223.4	2163	3570	2857	3474	1.446	0.04048	296.0	0.00256
26,500	218.0	206.7	2001	3303	2643	3213	1.446	0.04376	296.0	0.00276
27,000	218.0	191.3	1851	3056	2446	2972	1.446	0.04730	296.0	0.00299
27,500	218.0	177.0	1713	2828	2263	2750	1.446	0.05111	296.0	0.00323
28,000	218.0	163.8	1585	2617	2094	2544	1.446	0.05525	296.0	0.00349
28,500	218.0	151.5	1466	2421	1937	2353	1.446	0.05971	296.0	0.00377
29,000	218.0	140.2	1357	2240	1793	2177	1.446	0.06454	296.0	0.00407
29,500	218.0	129.7	1255	2073	1659	2014	1.446	0.06975	296.0	0.00440
30,000	218.0	120.1	1162	1918	1535	1864	1.446	0.07536	296.0	0.00476
30,500	218.0	111.1	1075	1775	1420	1724	1.446	0.08147	296.0	0.00514
31,000	218.0	102.8	994.6	1642	1314	1595	1.446	0.08805	296.0	0.00555
31,500	218.0	95.09	920.4	1519	1216	1475	1.446	0.09515	296.0	0.00600
32,000	218.0	87.99	851.6	1406	1125	1365	1.446	0.1028	296.0	0.00649
32,500	221.7	81.47	788.5	1280	1025	1243	1.467	0.1146	298.5	0.00712
33,000	225.3	75.54	731.1	1168	934.4	1133	1.487	0.1274	300.9	0.00781
33,500	229.0	70.12	678.6	1067	853.4	1035	1.508	0.1414	303.4	0.00854
34,000	232.7	65.16	630.7	975.6	780.7	946.5	1.528	0.1566	305.8	0.00934
34,500	236.3	60.63	586.8	893.6	713.1	867.0	1.548	0.1733	308.2	0.0102
35,000	240.0	56.48	546.6	819.7	655.9	795.1	1.568	0.1913	310.6	0.0111
35,500	243.7	52.67	509.8	752.9	602.4	730.2	1.588	0.2109	312.9	0.0121
36,000	247.3	49.17	475.9	692.4	554.1	671.5	1.608	0.2322	315.3	0.0132
36,500	251.0	45.94	444.7	637.6	510.2	618.2	1.627	0.2553	317.6	0.0143
37,000	254.7	42.98	415.9	587.8	470.4	569.9	1.647	0.2802	319.9	0.0155
37,500	258.3	40.24	389.4	542.5	434.1	526.0	1.666	0.3072	322.2	0.0168
38,000	262.0	37.71	365.0	501.1	401.1	486.0	1.685	0.3362	324.5	0.0182
38,500	265.7	35.37	342.3	463.7	371.1	449.5	1.705	0.3676	326.8	0.0196
39,000	269.3	33.21	321.4	429.4	343.6	416.2	1.724	0.4014	329.0	0.0212
39,500	273.0	31.21	302.0	398.2	318.6	385.8	1.743	0.4377	331.2	0.0228
40,000	276.7	29.35	284.0	369.5	295.6	358.0	1.761	0.4767	333.5	0.0246
40,500	280.3	27.62	267.4	343.2	274.6	332.5	1.779	0.5187	335.7	0.0265
41,000	284.0	26.02	251.8	319.1	255.4	309.1	1.799	0.5636	337.8	0.0285
41,500	287.7	24.53	237.4	297.0	237.7	287.6	1.817	0.6117	340.0	0.0306
42,000	291.3	23.14	224.0	276.7	221.4	267.9	1.835	0.6633	342.2	0.0329
42,500	295.0	21.85	211.5	258.0	206.4	249.8	1.854	0.7185	344.3	0.0352
43,000	298.7	20.64	199.8	240.7	192.6	233.0	1.872	0.7774	346.5	0.0377
43,500	302.3	19.52	188.9	224.9	179.9	217.6	1.890	0.8403	348.6	0.0404
44,000	306.0	18.46	178.7	210.2	168.2	203.4	1.908	0.9075	350.7	0.0432
44,500	309.7	17.48	169.2	196.7	157.4	190.3	1.926	0.9790	352.8	0.0462
45,000	313.3	16.56	160.3	184.1	147.3	178.1	1.943	1.055	354.9	0.0493
45,500	317.0	15.70	151.9	172.5	138.1	166.9	1.961	1.136	356.9	0.0526
46,000	320.7	14.89	144.1	161.8	129.5	156.5	1.978	1.223	359.0	0.0561
46,500	324.3	14.13	136.8	151.8	121.5	146.8	1.996	1.315	361.0	0.0598
47,000	328.0	13.42	129.9	142.6	114.1	137.8	2.013	1.412	363.1	0.0637
47,500	331.7	12.76	123.4	134.0	107.2	129.5	2.030	1.515	365.1	0.0677
48,000	335.3	12.13	117.4	126.0	100.8	121.8	2.047	1.625	367.1	0.0720
48,500	339.0	11.54	111.7	118.6	94.89	114.6	2.065	1.741	369.1	0.0765
49,000	342.7	10.98	106.3	111.7	89.37	107.9	2.081	1.864	371.1	0.0812
49,500	346.3	10.46	101.2	105.2	84.21	101.6	2.098	1.994	373.1	0.0862
50,000	350.0	9.770	96.50	99.23	79.40	95.80	2.115	2.132	375.1	0.0914
50,500	350.0	9.496	91.91	94.57	75.68	91.29	2.115	2.237	375.1	0.0959
51,000	350.0	9.052	87.61	90.12	72.11	87.00	2.115	2.346	375.1	0.101
51,500	350.0	8.628	83.50	85.89	68.73	82.91	2.115	2.462	375.1	0.106
52,000	350.0	8.223	79.59	81.86	65.51	79.01	2.115	2.583	375.1	0.111
52,500	350.0	7.838	75.86	78.03	62.44	75.29	2.115	2.710	375.1	0.116
53,000	350.0	7.471	72.30	74.37	59.51	71.75	2.115	2.844	375.1	0.122
53,500	350.0	7.121	68.92	70.88	56.72	68.38	2.115	2.984	375.1	0.128
54,000	350.0	6.787	65.69	67.55	54.05	65.17	2.115	3.130	375.1	0.134
54,500	350.0	6.470	62.62	64.39	51.52	62.11	2.115	3.284	375.1	0.141
55,000	350.0	6.167	59.68	61.37	49.11	59.19	2.115	3.446	375.1	0.148
55,500	350.0	5.878	56.89	58.50	46.81	56.41	2.115	3.615	375.1	0.155
56,000	350.0	5.603	54.23	55.76	44.62	53.76	2.115	3.793	375.1	0.162
56,500	350.0	5.341	51.69	53.15	42.53	51.23	2.115	3.979	375.1	0.170
57,000	350.0	5.091	49.27	50.66	40.54	48.82	2.115	4.174	375.1	0.179
57,500	350.0	4.853	46.97	48.30	38.65	46.53	2.115	4.379	375.1	0.187
58,000	350.0	4.626	44.77	46.03	36.84	44.35	2.115	4.595	375.1	0.196
58,500	350.0	4.410	42.68	43.88	35.11	42.27	2.115	4.820	375.1	0.206
59,000	350.0	4.204	40.68	41.83	33.47	40.28	2.115	5.056	375.1	0.216
59,500	350.0	4.007	38.78	39.88	31.91	38.39	2.115	5.303	375.1	0.227
60,000	350.0	3.820	36.97	38.02	30.42	36.59	2.115	5.560	375.1	0.238
60,500	346.9	3.641	35.24	36.55	29.25	35.17	2.101	5.748	373.4	0.247
61,000	343.9	3.468	33.57	35.13	28.11	33.80	2.087	5.940	371.8	0.257
61,500	340.8	3.303	31.97	33.75	27.01	32.47	2.073	6.140	370.1	0.268
62,000	337.8	3.144	30.43	32.41	25.94	31.19	2.059	6.350	368.5	0.279
62,500	334.7	2.991	28.95	31.12	24.90	29.94	2.045	6.569	366.8	0.290
63,000	331.7	2.844	27.53	29.86	23.90	28.73	2.030	6.796	365.1	0.302
63,500	328.6	2.704	26.17	28.64	22.92	27.56	2.016	7.034	363.4	0.315
64,000	325.6	2.569	24.86	27.49	21.99	26.43	2.002	7.282	361.7	0.329
64,500	322.5	2.439	23.61	26.35	21.08	25.33	1.987	7.542	360.0	0.343
65,000	319.4	2.315	22.41	25.25	20.20	24.27	1.973	7.813	358.3	0.357
65,500	316.4	2.197	21.26	24.19	19.35	23.25	1.958	8.095	356.6	0.373
66,000	313.3	2.083	20.16	23.15	18.53	22.26	1.943	8.392	354.9	0.390
66,500	310.3	1.974	19.11	22.16	17.73	21.30	1.928	8.702	353.1	0.407
67,000	307.2	1.870	18.10	21.20	16.97	20.38	1.914	9.026	351.4	0.425
67,500	304.2	1.771	17.14	20.28	16.23	19.48	1.899	9.366	349.6	0.445
68,000	301.1	1.675	16.21	19.38	15.51	18.62	1.884	9.723	347.9	0.465
68,500	298.1	1.584	15.33	18.52	14.82	17.79	1.869	10.09	346.1	0.487
69,000	295.0	1.498	14.49	17.68	14.15	16.98	1.854	10.48	344.3	0.510
69,500	291.9	1.414	13.69	16.88	13.50	16.21	1.838	10.89	342.5	0.534
70,000	288.9	1.335	12.92	16.10	12.88	15.46	1.823	11.32	340.7	0.560
71,000	282.8	1.188	11.50	14.64	11.71	14.05	1.792	12.25	337.1	0.615
72,000	276.7	1.054	10.20	13.28	10.62	12.74	1.761	13.27	333.5	0.678
73,000	270.6	0.9332	9.032	12.02	9.615	11.52	1.730	14.40	329.8	0.749
74,000	264.4	0.8238	7.973	10.85	8.682	10.40	1.698	15.65	326.0	0.829
75,000	258.3	0.7250	7.017	9.777	7.823	9.368	1.666	17.04	322.2	0.920
76,000	252.2	0.6362	6.157	8.787	7.031	8.415	1.634	18.60	318.4	1.02
77,000	246.1	0.5565	5.386	7.876	6.302	7.541	1.601	20.33	314.5	1.14
78,000	240.0	0.4851	4.695	7.041	5.634	6.739	1.568	22.27	310.6	1.28
79,000	240.0	0.4222	4.087	6.127	4.903	5.863	1.568	25.59	310.6	1.47
80,000	240.0	0.3675	3.557	5.334	4.268	5.102	1.568	29.40	310.6	1.68

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TABLE IV.– PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE — METRIC ENGINEERING SYSTEM — Concluded

Altitude, h (m)	Absolute temperature, T (°K)	Pressure, p (kg/m²)	Pressure ratio, p/p_0	Density, ρ $\left(\frac{kg\text{-}sec^2}{m^4}\right)$	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific weight, $w = g\rho$ (kg/m³)	Coefficient of viscosity, μ $\left(\frac{kg\text{-}sec}{m^2}\right)$ (1)	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (m²/sec) (1)	Speed of sound, a (m/sec)	Mean free path of molecules, λ (m)
					(b) For day only					
80,000	240.0	0.3675	3557×10^{-8}	5334×10^{-9}	4268×10^{-8}	5102×10^{-8}	1.568×10^{-6}	0.2940	310.6	1.68×10^{-3}
81,000	240.0	0.3201	3098	4598	3680	4395	1.568	0.3411	312.5	1.93
82,000	240.0	0.2793	2703	3970	3177	3795	1.568	0.3950	314.5	2.22
83,000	240.0	0.2439	2361	3432	2747	3280	1.568	0.4568	316.5	2.54
84,000	243.6	0.2136	2067	2931	2346	2800	1.588	0.5415	320.8	2.94
85,000	247.3	0.1877	1817	2513	2011	2399	1.607	0.6394	325.2	3.39
86,000	250.9	0.1653	1600	2160	1729	2062	1.627	0.7529	329.6	3.91
87,000	254.6	0.1462	1415	1864	1492	1779	1.646	0.8827	333.9	4.48
88,000	258.2	0.1297	1255	1614	1292	1540	1.666	1.031	338.3	5.12
89,000	261.9	0.1153	1116	1402	1122	1337	1.685	1.202	342.7	5.84
90,000	265.5	0.1029	995.6	1222	977.5	1165	1.704	1.395	347.1	6.64
91,000	269.2	0.09195	890.0	1067	853.8	1017	1.723	1.614	351.5	7.52
92,000	272.8	0.08244	797.9	935.1	748.3	891.0	1.742	1.862	355.9	8.50
93,000	276.5	0.07408	717.0	821.5	657.3	782.8	1.760	2.143	360.4	9.59
94,000	280.1	0.06666	645.7	723.6	579.0	689.2	1.779	2.459	364.8	10.8
95,000	283.8	0.06023	583.0	638.9	511.3	608.5	1.797	2.814	369.2	12.1
96,000	287.4	0.05453	527.8	565.8	452.8	538.8	1.816	3.208	373.7	13.5
97,000	291.1	0.04945	478.6	502.2	401.9	478.0	1.834	3.652	378.1	15.1
98,000	294.7	0.04494	435.0	446.9	357.6	425.1	1.852	4.145	382.6	16.8
99,000	298.4	0.04093	396.1	398.5	318.8	378.9	1.870	4.694	387.1	18.7
100,000	302.0	0.03734	361.4	356.0	284.9	338.4	1.888	5.303	391.5	20.7
101,000	305.7	0.03412	330.2	321.4	257.2	305.5	1.906	5.928	393.9	23.0
102,000	309.3	0.03122	302.1	290.6	232.6	276.1	1.924	6.616	396.2	25.4
103,000	313.0	0.02859	276.7	263.1	210.5	249.9	1.941	7.375	398.5	28.0
104,000	316.6	0.02621	253.7	238.4	190.8	226.4	1.959	8.210	400.9	30.9
105,000	320.3	0.02406	232.8	216.3	173.1	205.3	1.976	9.129	403.2	34.1
106,000	323.9	0.02210	213.9	196.5	157.2	186.4	1.994	10.14	405.5	37.5
107,000	327.6	0.02032	196.7	178.7	143.0	169.5	2.011	11.24	407.7	41.2
108,000	331.2	0.01870	181.0	162.7	130.2	154.2	2.028	12.46	410.0	45.3
109,000	334.9	0.01723	166.8	148.2	118.6	140.5	2.045	13.79	412.3	49.7
110,000	338.5	0.01589	153.8	135.2	108.2	128.1	2.062	15.24	414.5	54.4
111,000	342.2	0.01466	141.9	123.5	98.79	117.0	2.079	16.83	416.7	59.6
112,000	345.8	0.01355	131.1	112.8	90.29	106.9	2.096	18.56	418.9	65.2
113,000	349.5	0.01252	121.2	103.2	82.62	97.75	2.113	20.45	421.1	71.2
114,000	353.1	0.01159	112.2	94.55	75.66	89.49	2.129	22.51	423.3	77.8
115,000	356.8	0.01074	103.9	86.66	69.34	82.00	2.146	24.75	425.5	84.8
116,000	360.4	0.009947	96.27	79.50	63.62	75.21	2.162	27.19	427.7	92.4
117,000	364.1	0.009227	89.30	73.00	58.41	69.03	2.179	29.83	429.8	101
118,000	367.7	0.008565	82.90	67.10	53.69	63.43	2.195	32.71	432.0	109
119,000	371.4	0.007958	77.02	61.72	49.38	58.33	2.211	35.82	434.1	119
120,000	375.0	0.007398	71.60	56.82	45.46	53.67	2.227	39.20	436.3	129
					(c) For night only					
80,000	240.0	0.3675	3557×10^{-8}	5334×10^{-9}	4268×10^{-8}	5102×10^{-8}	1.568×10^{-6}	0.2940	310.6	1.68×10^{-3}
81,000	240.0	0.3198	3096	4641	3713	4439	1.568	0.3377	310.6	1.93
82,000	240.0	0.2784	2695	4041	3233	3863	1.568	0.3879	310.6	2.22
83,000	240.0	0.2424	2346	3518	2815	3361	1.568	0.4458	310.6	2.55
84,000	243.6	0.2112	2044	3020	2416	2885	1.588	0.5259	312.9	2.97
85,000	247.3	0.1844	1785	2598	2079	2481	1.607	0.6189	315.3	3.45
86,000	250.9	0.1613	1562	2240	1793	2138	1.627	0.7265	317.6	4.00
87,000	254.6	0.1415	1369	1936	1549	1847	1.645	0.8499	319.9	4.63
88,000	258.2	0.1243	1203	1675	1341	1599	1.666	0.9939	322.2	5.34
89,000	261.9	0.1094	1058	1455	1164	1387	1.685	1.158	324.4	6.16
90,000	265.5	0.09640	933.0	1265	1012	1206	1.704	1.347	326.7	7.08
91,000	269.2	0.08515	824.1	1101	881.1	1050	1.723	1.564	328.9	8.12
92,000	272.8	0.07533	729.1	961.8	769.6	916.4	1.742	1.811	331.1	9.31
93,000	276.5	0.06676	646.1	841.1	673.1	801.2	1.760	2.093	333.4	10.6
94,000	280.1	0.05926	573.5	737.0	589.7	701.8	1.779	2.414	335.5	12.1
95,000	283.8	0.05269	509.9	646.7	517.5	615.6	1.798	2.780	337.7	13.8
96,000	287.4	0.04691	454.0	568.5	454.9	541.1	1.816	3.195	339.9	15.7
97,000	291.1	0.04183	404.9	500.6	400.5	476.3	1.834	3.664	342.0	17.9
98,000	294.7	0.03736	361.6	441.5	353.3	420.0	1.852	4.196	344.2	20.2
99,000	298.4	0.03341	323.3	390.0	312.1	370.9	1.870	4.795	346.3	22.9
100,000	302.0	0.02992	289.5	345.0	276.1	328.0	1.888	5.472	348.4	25.9
101,000	305.7	0.02683	259.7	305.8	244.7	290.6	1.906	6.233	350.5	29.2
102,000	309.3	0.02409	233.2	271.3	217.1	257.8	1.924	7.090	352.6	32.9
103,000	313.0	0.02166	209.7	241.1	192.9	229.0	1.942	8.052	354.7	37.0
104,000	316.6	0.01950	188.8	214.5	171.6	203.7	1.959	9.130	356.7	41.6
105,000	320.3	0.01758	170.2	191.2	153.0	181.5	1.976	10.34	358.8	46.6
106,000	324.0	0.01588	153.7	168.4	134.8	159.8	1.994	11.84	363.9	52.2
107,000	327.6	0.01438	139.1	148.7	119.0	141.0	2.011	13.52	369.0	58.3
108,000	331.2	0.01305	126.3	131.7	105.4	124.8	2.028	15.41	374.1	64.9
109,000	334.9	0.01187	114.9	116.9	93.57	110.8	2.045	17.49	379.2	72.1
110,000	338.5	0.01082	104.8	104.1	83.30	98.63	2.062	19.81	384.3	79.9
111,000	342.2	0.009890	95.72	92.90	74.33	87.98	2.079	22.38	389.4	88.4
112,000	345.8	0.009059	87.68	83.11	66.50	78.70	2.096	25.22	394.6	97.5
113,000	349.5	0.008315	80.47	74.55	59.65	70.56	2.113	28.34	399.8	107
114,000	353.1	0.007646	74.00	66.99	53.60	63.40	2.129	31.78	404.9	118
115,000	356.8	0.007042	68.15	60.33	48.28	57.09	2.146	35.57	410.1	129
116,000	360.4	0.006499	62.90	54.44	43.56	51.49	2.162	39.72	415.3	141
117,000	364.1	0.006009	58.16	49.24	39.40	46.55	2.179	44.25	420.6	154
118,000	367.7	0.005567	53.88	44.63	35.71	42.18	2.195	49.18	425.8	168
119,000	371.4	0.005164	49.98	40.50	32.41	38.28	2.211	54.58	431.0	183
120,000	375.0	0.004800	46.45	36.86	29.50	34.82	2.227	60.42	436.3	199

[1] The values for viscosity listed in these columns are not applicable at the higher altitudes where the mean free paths of the molecules are comparable to or longer than the dimensions of the body being considered. Furthermore, the values listed are based on the conventional Sutherland formula for normal air and, consequently, no allowance has been made for the effect of dissociated oxygen in the atmosphere at the higher levels.

TABLE V.- PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE — BRITISH ENGINEERING SYSTEM

Altitude, h (ft)	Absolute temperature, T (°F abs.)	Pressure, p (lb/ft²)	Pressure ratio, p/p_0	Density, ρ (slugs/ft³)	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific weight, $\gamma = g\rho$ (lb/ft³)	Coefficient of viscosity, μ (lb-sec/ft²)	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (ft²/sec)	Speed of sound, a (ft/sec)	Mean free path of molecules, λ (ft)
(a) For both day and night										
65,000	392.4	119.9	5664×10^{-5}	1779×10^{-7}	7483×10^{-5}	5690×10^{-6}	2.961×10^{-7}	0.001664	971.1	0.00321×10^{-3}
66,000	392.4	114.3	5402	1697	7137	5426	2.961	0.001745	971.1	0.00337
67,000	392.4	109.0	5151	1618	6805	5173	2.961	0.001830	971.1	0.00353
68,000	392.4	104.0	4913	1543	6491	4934	2.961	0.001919	971.1	0.00370
69,000	392.4	99.12	4684	1471	6188	4705	2.961	0.002013	971.1	0.00388
70,000	392.4	94.53	4467	1405	5901	4485	2.961	0.002110	971.1	0.00407
71,000	392.4	90.17	4261	1339	5629	4277	2.961	0.002211	971.1	0.00427
72,000	392.4	85.98	4063	1276	5368	4079	2.961	0.002321	971.1	0.00448
73,000	392.4	82.00	3875	1217	5119	3889	2.961	0.002433	971.1	0.00469
74,000	392.4	78.19	3695	1161	4881	3708	2.961	0.002550	971.1	0.00492
75,000	392.4	74.58	3524	1107	4656	3537	2.961	0.002675	971.1	0.00516
76,000	392.4	71.13	3361	1056	4440	3372	2.961	0.002804	971.1	0.00541
77,000	392.4	67.83	3205	1007	4234	3216	2.961	0.002940	971.1	0.00567
78,000	392.4	64.67	3056	960.0	4037	3066	2.961	0.003084	971.1	0.00594
79,000	392.4	61.69	2915	915.7	3851	2924	2.961	0.003234	971.1	0.00623
80,000	392.4	58.83	2780	873.4	3673	2789	2.961	0.003390	971.1	0.00654
81,000	392.4	56.10	2651	832.7	3502	2659	2.961	0.003556	971.1	0.00686
82,000	392.4	53.50	2528	794.2	3340	2535	2.961	0.003728	971.1	0.00719
83,000	392.4	51.04	2412	757.6	3186	2418	2.961	0.003908	971.1	0.00753
84,000	392.4	48.67	2300	722.6	3039	2306	2.961	0.004098	971.1	0.00790
85,000	392.4	46.43	2194	689.1	2898	2199	2.961	0.004297	971.1	0.00828
86,000	392.4	44.27	2092	657.3	2764	2097	2.961	0.004505	971.1	0.00868
87,000	392.4	42.24	1996	627.1	2637	2001	2.961	0.004722	971.1	0.00910
88,000	392.4	40.27	1903	597.8	2514	1907	2.961	0.004953	971.1	0.00954
89,000	392.4	38.41	1815	570.2	2398	1819	2.961	0.005193	971.1	0.0100
90,000	392.4	36.61	1730	543.6	2286	1734	2.961	0.005447	971.1	0.0105
91,000	392.4	34.92	1650	518.4	2180	1653	2.961	0.005712	971.1	0.0110
92,000	392.4	33.31	1574	494.4	2079	1577	2.961	0.005989	971.1	0.0115
93,000	392.4	31.79	1502	471.8	1984	1504	2.961	0.006276	971.1	0.0121
94,000	392.4	30.30	1432	449.9	1892	1435	2.961	0.006584	971.1	0.0127
95,000	392.4	28.89	1365	428.7	1803	1367	2.961	0.006907	971.1	0.0133
96,000	392.4	27.57	1303	409.2	1721	1305	2.961	0.007236	971.1	0.0139
97,000	392.4	26.30	1243	390.5	1642	1245	2.961	0.007583	971.1	0.0146
98,000	392.4	25.10	1186	372.6	1567	1188	2.961	0.007947	971.1	0.0153
99,000	392.4	23.91	1130	355.0	1493	1131	2.961	0.008341	971.1	0.0161
100,000	392.4	22.81	1078	338.6	1424	1079	2.961	0.008745	971.1	0.0168
102,000	392.4	20.76	980.9	308.2	1296	981.9	2.961	0.009607	971.1	0.0185
104,000	392.4	18.89	892.4	280.4	1179	893.1	2.961	0.01056	971.1	0.0203
104,987	392.4	18.02	851.6	267.5	1125	852.1	2.961	0.01107	971.1	0.0213
106,000	396.5	17.19	812.1	252.5	1062	804.3	2.988	0.01183	976.2	0.0226
108,000	404.5	15.66	740.0	225.5	948.3	718.1	3.039	0.01348	986.0	0.0252
110,000	412.6	14.30	675.8	201.9	849.1	642.8	3.090	0.01530	995.8	0.0282
112,000	420.6	13.06	618.2	181.2	761.9	576.7	3.141	0.01733	1005	0.0314
114,000	428.7	11.99	566.5	162.9	685.1	518.5	3.191	0.01959	1015	0.0349
116,000	436.7	11.01	520.1	146.8	617.4	467.1	3.241	0.02208	1025	0.0388
118,000	444.8	10.12	478.2	132.5	557.4	421.7	3.290	0.02485	1034	0.0429
120,000	452.8	9.311	440.0	119.8	503.7	381.0	3.339	0.02787	1043	0.0475
122,000	460.9	8.588	405.8	108.6	456.5	345.2	3.388	0.03120	1052	0.0524
124,000	468.9	7.930	374.7	98.52	414.3	313.2	3.436	0.03488	1062	0.0577
126,000	476.9	7.335	346.6	89.58	376.7	284.8	3.484	0.03889	1071	0.0634
128,000	485.0	6.789	320.8	81.54	342.9	259.2	3.532	0.04332	1080	0.0697
130,000	493.0	6.294	297.4	74.31	312.7	236.3	3.579	0.04816	1089	0.0764
132,000	501.1	5.843	276.1	67.91	285.6	215.8	3.624	0.05336	1097	0.0836
134,000	509.1	5.430	256.6	62.13	261.3	197.4	3.671	0.05909	1106	0.0914
136,000	517.2	5.049	238.6	56.88	239.2	180.6	3.718	0.06537	1115	0.0998
138,000	525.2	4.704	222.3	52.17	219.4	165.7	3.764	0.07215	1124	0.109
140,000	533.3	4.387	207.3	47.91	201.5	152.1	3.809	0.07950	1132	0.118
142,000	541.3	4.097	193.6	44.09	185.4	139.9	3.854	0.08741	1141	0.129
144,000	549.4	3.828	180.9	40.59	170.7	128.8	3.899	0.09606	1149	0.140
146,000	557.4	3.581	169.2	37.42	157.4	118.8	3.944	0.1054	1157	0.152
148,000	565.5	3.352	158.4	34.53	145.2	109.5	3.988	0.1155	1166	0.164
150,000	573.5	3.140	148.4	31.89	134.1	101.1	4.032	0.1264	1174	0.178
152,000	581.6	2.948	139.3	29.53	124.2	93.65	4.075	0.1380	1182	0.192
154,000	589.6	2.766	130.7	27.32	114.9	86.62	4.119	0.1508	1190	0.207
156,000	597.6	2.599	122.8	25.32	106.5	80.28	4.162	0.1644	1199	0.224
158,000	605.7	2.444	115.5	23.51	98.85	74.50	4.205	0.1789	1207	0.241
160,000	613.7	2.302	108.8	21.85	91.90	69.24	4.247	0.1944	1215	0.259
162,000	621.8	2.167	102.4	20.30	85.37	64.31	4.289	0.2113	1222	0.279
164,000	629.8	2.045	96.56	18.90	79.48	59.86	4.331	0.2292	1230	0.300
164,042	630.0	2.042	96.50	18.88	79.41	59.81	4.332	0.2294	1231	0.300
166,000	630.0	1.927	91.08	17.82	74.95	56.44	4.332	0.2431	1231	0.318
168,000	630.0	1.818	85.89	16.81	70.68	53.22	4.332	0.2577	1231	0.337
170,000	630.0	1.714	81.01	15.85	66.66	50.18	4.332	0.2733	1231	0.357
172,000	630.0	1.617	76.40	14.95	62.87	47.32	4.332	0.2898	1231	0.379
174,000	630.0	1.525	72.05	14.10	59.29	44.61	4.332	0.3073	1231	0.401
176,000	630.0	1.438	67.97	13.30	55.93	42.08	4.332	0.3257	1231	0.425
178,000	630.0	1.357	64.11	12.54	52.75	39.68	4.332	0.3455	1231	0.451
180,000	630.0	1.279	60.46	11.83	49.75	37.41	4.332	0.3662	1231	0.478
182,000	630.0	1.207	57.03	11.16	46.93	35.29	4.332	0.3882	1231	0.507
184,000	630.0	1.139	53.80	10.53	44.27	33.28	4.332	0.4114	1231	0.537
186,000	630.0	1.074	50.77	9.935	41.78	31.40	4.332	0.4360	1231	0.569
188,000	630.0	1.013	47.87	9.367	39.39	29.60	4.332	0.4625	1231	0.603
190,000	630.0	0.9555	45.15	8.834	37.15	27.91	4.332	0.4904	1231	0.639
192,000	630.0	0.9017	42.61	8.337	35.06	26.34	4.332	0.5196	1231	0.677
194,000	630.0	0.8503	40.18	7.862	33.06	24.83	4.332	0.5510	1231	0.718
196,000	630.0	0.8021	37.90	7.417	31.19	23.42	4.332	0.5841	1231	0.761
196,850	630.0	0.7824	36.97	7.254	30.42	22.84	4.332	0.5988	1231	0.780
198,000	626.1	0.7563	35.74	7.036	29.59	22.22	4.312	0.6128	1227	0.802
200,000	619.4	0.7132	33.70	6.706	28.20	21.17	4.277	0.6379	1220	0.842
202,000	612.7	0.6719	31.75	6.388	26.86	20.16	4.242	0.6641	1214	0.883
204,000	606.0	0.6325	29.89	6.080	25.57	19.17	4.206	0.6918	1207	0.928
206,000	599.3	0.5953	28.13	5.785	24.33	18.25	4.171	0.7210	1200	0.975
208,000	592.6	0.5595	26.44	5.500	23.13	17.35	4.135	0.7518	1193	1.03
210,000	585.9	0.5257	24.84	5.227	21.98	16.48	4.099	0.7843	1187	1.08
212,000	579.2	0.4935	23.32	4.963	20.87	15.65	4.063	0.8187	1180	1.14
214,000	572.5	0.4630	21.88	4.711	19.81	14.85	4.026	0.8546	1173	1.20
216,000	565.8	0.4340	20.51	4.468	18.79	14.08	3.990	0.8930	1166	1.26
218,000	559.1	0.4067	19.22	4.237	17.82	13.35	3.955	0.9330	1159	1.33
220,000	552.4	0.3807	17.99	4.014	16.88	12.65	3.916	0.9755	1152	1.40
222,000	545.7	0.3562	16.83	3.802	15.99	11.98	3.879	1.020	1145	1.48
224,000	539.0	0.3329	15.73	3.598	15.13	11.33	3.841	1.068	1138	1.57
226,000	532.3	0.3109	14.69	3.403	14.31	10.71	3.804	1.118	1131	1.66
228,000	525.6	0.2899	13.70	3.213	13.51	10.11	3.766	1.172	1124	1.75
230,000	518.9	0.2702	12.77	3.034	12.76	9.551	3.727	1.228	1117	1.85
232,000	512.1	0.2518	11.90	2.865	12.05	9.018	3.689	1.288	1109	1.96
234,000	505.4	0.2343	11.07	2.699	11.35	8.492	3.651	1.352	1102	2.08
236,000	498.7	0.2178	10.29	2.544	10.70	8.004	3.612	1.420	1095	2.21
238,000	492.0	0.2021	9.551	2.392	10.06	7.524	3.573	1.493	1087	2.35
240,000	485.3	0.1876	8.863	2.251	9.467	7.079	3.533	1.570	1080	2.50
242,000	478.6	0.1738	8.211	2.115	8.893	6.649	3.494	1.652	1073	2.66
244,000	471.9	0.1609	7.605	1.987	8.354	6.245	3.454	1.738	1065	2.83
246,000	465.2	0.1488	7.033	1.864	7.837	5.857	3.414	1.832	1057	3.02
248,000	458.5	0.1375	6.498	1.747	7.347	5.490	3.373	1.931	1050	3.22
250,000	451.8	0.1269	5.996	1.636	6.880	5.140	3.333	2.037	1042	3.43
252,000	445.1	0.1169	5.525	1.530	6.435	4.807	3.292	2.152	1034	3.67
254,000	438.4	0.1077	5.087	1.430	6.015	4.492	3.251	2.273	1026	3.92
255,905	432.0	0.09936	4.695	1.340	5.634	4.207	3.212	2.397	1019	4.19
256,000	432.0	0.09895	4.676	1.334	5.611	4.189	3.212	2.408	1019	4.21
258,000	432.0	0.09091	4.296	1.226	5.155	3.848	3.212	2.620	1019	4.58
260,000	432.0	0.08353	3.947	1.126	4.736	3.535	3.212	2.852	1019	4.98
262,000	432.0	0.07678	3.628	1.035	4.354	3.249	3.212	3.102	1019	5.42
262,467	432.0	0.07527	3.557	1.015	4.268	3.185	3.212	3.165	1019	5.53

TABLE V .- PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE — BRITISH ENGINEERING SYSTEM — Continued

Altitude, h (ft)	Absolute temperature, T (°F abs.)	Pressure, p (lb/ft^2)	Pressure ratio, p/p_0	Density, ρ (slugs/ft^3)	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific weight, $w = g\rho$ (lb/ft^3)	Coefficient of viscosity, μ (lb-sec/ft^2) (1)	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (ft^2/sec) (1)	Speed of sound, a (ft/sec)	Mean free path of molecules, λ (ft)
(b) For day only										
262,467	432.0	0.07527	3.557×10^{-5}	101.5×10^{-9}	4.268×10^{-5}	3.185×10^{-6}	3.212×10^{-7}	3.165	1019	5.53×10^{-3}
264,000	432.0	0.07056	3.334	94.66	3.981	2.970	3.212	3.392	1022	5.90
266,000	432.0	0.06484	3.064	86.46	3.636	2.712	3.212	3.715	1026	6.42
268,000	432.0	0.05968	2.820	79.07	3.325	2.480	3.212	4.062	1030	6.97
270,000	432.0	0.05494	2.596	72.34	3.042	2.268	3.212	4.440	1034	7.57
272,000	432.0	0.05060	2.391	66.20	2.784	2.076	3.212	4.852	1038	8.22
272,309	432.0	0.04996	2.361	65.32	2.747	2.048	3.212	4.917	1038	8.32
274,000	435.4	0.04664	2.204	60.18	2.531	1.887	3.232	5.371	1046	8.98
276,000	439.4	0.04302	2.033	54.67	2.299	1.713	3.257	5.958	1054	9.82
278,000	443.4	0.03972	1.877	49.72	2.091	1.558	3.282	6.601	1063	10.7
280,000	447.4	0.03678	1.738	45.35	1.907	1.421	3.306	7.290	1072	11.7
282,000	451.4	0.03409	1.611	41.42	1.742	1.297	3.331	8.042	1081	12.7
284,000	455.4	0.03160	1.493	37.81	1.590	1.184	3.355	8.873	1089	13.9
286,000	459.4	0.02933	1.386	34.60	1.455	1.083	3.379	9.766	1098	15.1
288,000	463.4	0.02726	1.288	31.67	1.332	0.9915	3.403	10.75	1107	16.3
290,000	467.4	0.02537	1.199	29.06	1.222	0.9095	3.427	11.79	1116	17.7
292,000	471.4	0.02362	1.116	26.66	1.121	0.8342	3.451	12.94	1124	19.2
294,000	475.4	0.02201	1.040	24.49	1.030	0.7663	3.475	14.19	1133	20.7
296,000	479.4	0.02055	0.9710	22.55	0.9484	0.7054	3.499	15.52	1142	22.4
298,000	483.4	0.01919	0.9069	20.77	0.8734	0.6495	3.522	16.96	1151	24.2
300,000	487.4	0.01794	0.8479	19.15	0.8053	0.5988	3.546	18.52	1160	26.1
302,000	491.4	0.01679	0.7933	17.67	0.7430	0.5524	3.569	20.20	1168	28.1
304,000	495.4	0.01573	0.7435	16.33	0.6869	0.5105	3.593	22.00	1177	30.2
306,000	499.4	0.01475	0.6970	15.10	0.6352	0.4720	3.616	23.95	1186	32.5
308,000	503.4	0.01383	0.6537	13.97	0.5877	0.4366	3.639	26.05	1195	34.9
310,000	507.4	0.01299	0.6140	12.95	0.5446	0.4046	3.662	28.28	1204	37.4
312,000	511.5	0.01221	0.5772	12.01	0.5051	0.3751	3.685	30.68	1213	40.1
314,000	515.5	0.01149	0.5431	11.15	0.4690	0.3482	3.708	33.26	1222	43.0
316,000	519.5	0.01082	0.5114	10.37	0.4359	0.3236	3.731	35.98	1231	46.0
318,000	523.5	0.01020	0.4819	9.640	0.4054	0.3009	3.754	38.94	1240	49.2
320,000	527.5	0.009620	0.4546	8.977	0.3775	0.2802	3.777	42.07	1248	52.5
322,000	531.5	0.009079	0.4290	8.361	0.3516	0.2609	3.799	45.44	1257	56.1
324,000	535.5	0.008579	0.4054	7.800	0.3280	0.2434	3.822	49.00	1266	59.8
326,000	539.5	0.008103	0.3829	7.274	0.3059	0.2269	3.844	52.85	1275	63.7
328,000	543.5	0.007663	0.3621	6.791	0.2856	0.2118	3.867	56.94	1284	67.9
328,083	543.6	0.007648	0.3614	6.775	0.2849	0.2113	3.867	57.08	1285	68.0
330,000	547.5	0.007248	0.3425	6.375	0.2681	0.1988	3.889	61.00	1289	72.3
332,000	551.5	0.006867	0.3245	5.997	0.2522	0.1871	3.911	65.22	1294	76.8
334,000	555.5	0.006505	0.3074	5.640	0.2372	0.1758	3.933	69.73	1298	81.7
336,000	559.5	0.006167	0.2914	5.307	0.2232	0.1654	3.955	74.52	1303	86.8
338,000	563.5	0.005843	0.2761	4.994	0.2100	0.1556	3.977	79.64	1308	92.2
340,000	567.5	0.005540	0.2618	4.701	0.1977	0.1464	3.999	85.07	1312	97.9
342,000	571.5	0.005257	0.2484	4.430	0.1863	0.1379	4.021	90.77	1317	104
344,000	575.5	0.004992	0.2359	4.178	0.1757	0.1301	4.043	96.77	1322	110
346,000	579.5	0.004736	0.2238	3.935	0.1655	0.1226	4.065	103.3	1326	117
348,000	583.5	0.004499	0.2126	3.714	0.1562	0.1156	4.086	110.0	1331	124
350,000	587.5	0.004275	0.2020	3.505	0.1474	0.1091	4.108	117.2	1335	131
352,000	591.5	0.004061	0.1919	3.305	0.1390	0.1029	4.129	124.9	1340	139
354,000	595.5	0.003860	0.1824	3.122	0.1313	0.09716	4.151	133.0	1344	147
356,000	599.5	0.003672	0.1735	2.949	0.1240	0.09173	4.172	141.5	1349	156
358,000	603.5	0.003494	0.1651	2.787	0.1172	0.08668	4.193	150.4	1353	165
360,000	607.5	0.003329	0.1573	2.637	0.1110	0.08205	4.214	159.8	1358	174
362,000	611.5	0.003168	0.1497	2.494	0.1049	0.07758	4.236	169.8	1362	184
364,000	615.5	0.003016	0.1425	2.359	0.09922	0.07333	4.257	180.4	1367	195
366,000	619.6	0.002874	0.1358	2.234	0.09395	0.06942	4.278	191.5	1371	206
368,000	623.6	0.002738	0.1294	2.115	0.08894	0.06571	4.299	203.3	1376	217
370,000	627.6	0.002611	0.1234	2.004	0.08428	0.06225	4.319	215.6	1380	229
372,000	631.6	0.002489	0.1176	1.898	0.07981	0.05894	4.340	228.7	1384	242
374,000	635.6	0.002374	0.1122	1.799	0.07566	0.05586	4.361	242.4	1389	255
376,000	639.6	0.002266	0.1071	1.707	0.07177	0.05298	4.382	256.7	1393	269
378,000	643.6	0.002163	0.1022	1.618	0.06806	0.05023	4.402	272.1	1398	283
380,000	647.6	0.002064	0.09754	1.535	0.06456	0.04764	4.423	288.1	1402	299
382,000	651.6	0.001971	0.09316	1.457	0.06128	0.04522	4.443	304.9	1406	315
384,000	655.6	0.001884	0.08901	1.384	0.05819	0.04293	4.464	322.5	1411	331
386,000	659.6	0.001800	0.08505	1.314	0.05527	0.04076	4.484	341.2	1415	349
388,000	663.6	0.001721	0.08131	1.249	0.05252	0.03873	4.504	360.6	1419	367
390,000	667.6	0.001646	0.07776	1.187	0.04992	0.03681	4.525	381.2	1423	386
392,000	671.6	0.001573	0.07434	1.128	0.04744	0.03497	4.545	402.9	1428	406
393,700	675.0	0.001515	0.07160	1.081	0.04546	0.03350	4.562	422.0	1431	424

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[1] The values for viscosity listed in these columns are not applicable at the higher altitudes where the mean free paths of the molecules are comparable to or longer than the dimensions of the body being considered. Furthermore, the values listed are based on the conventional Sutherland formula for normal air and, consequently, no allowance has been made for the effect of dissociated oxygen in the atmosphere at the higher levels.

TABLE V.– PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE— BRITISH ENGINEERING SYSTEM — Concluded

Altitude, h (ft)	Absolute temperature, T (°F abs.)	Pressure, p (lb/ft^2)	Pressure ratio, p/p_0	Density, ρ (slugs/ft^3)	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific weight, $w = g\rho$ (lb/ft^3)	Coefficient of viscosity μ (lb-sec/ft^2) (1)	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (ft^2/sec) (1)	Speed of sound, a (ft/sec)	Mean free path of molecules, λ (ft)
(c) For night only										
262,467	432.0	0.07527	3.557×10^{-5}	101.5×10^{-9}	4.268×10^{-5}	3.185×10^{-6}	3.212×10^{-7}	3.165	1019	5.53×10^{-3}
264,000	432.0	0.07051	3.332	95.07	3.998	2.983	3.212	3.379	1019	5.90
266,000	432.0	0.06480	3.062	87.36	3.674	2.741	3.212	3.677	1019	6.42
268,000	432.0	0.05955	2.814	80.30	3.377	2.519	3.212	4.000	1019	6.98
270,000	432.0	0.05473	2.586	73.79	3.103	2.314	3.212	4.353	1019	7.60
272,000	432.0	0.05032	2.378	67.87	2.854	2.128	3.212	4.732	1019	8.26
272,309	432.0	0.04965	2.346	66.94	2.815	2.099	3.212	4.798	1019	8.37
274,000	435.4	0.04622	2.184	61.83	2.600	1.938	3.232	5.227	1023	9.06
276,000	439.4	0.04252	2.009	56.36	2.370	1.766	3.257	5.779	1028	9.94
278,000	443.4	0.03913	1.849	51.41	2.162	1.611	3.282	6.384	1032	10.9
280,000	447.4	0.03604	1.703	46.92	1.973	1.470	3.306	7.046	1037	11.9
282,000	451.4	0.03320	1.569	42.85	1.802	1.342	3.331	7.774	1042	13.1
284,000	455.4	0.03066	1.449	39.21	1.649	1.228	3.355	8.551	1046	14.3
286,000	459.4	0.02832	1.338	35.91	1.510	1.124	3.379	9.401	1051	15.6
288,000	463.4	0.02618	1.237	32.91	1.384	1.030	3.403	10.34	1055	17.0
290,000	467.4	0.02423	1.145	30.20	1.270	0.9452	3.427	11.35	1060	18.5
292,000	471.4	0.02239	1.058	27.65	1.163	0.8654	3.451	12.48	1064	20.2
294,000	475.4	0.02072	0.9793	25.40	1.068	0.7949	3.475	13.68	1069	22.0
296,000	479.4	0.01919	0.9069	23.32	0.9806	0.7294	3.499	15.00	1073	24.0
298,000	483.4	0.01780	0.8409	21.44	0.9017	0.6706	3.523	16.43	1078	26.1
300,000	487.4	0.01653	0.7810	19.75	0.8306	0.6176	3.546	17.95	1082	28.3
302,000	491.4	0.01534	0.7247	18.18	0.7645	0.5683	3.569	19.63	1087	30.8
304,000	495.4	0.01424	0.6729	16.74	0.7041	0.5233	3.593	21.46	1091	33.4
306,000	499.4	0.01324	0.6255	15.44	0.6492	0.4824	3.616	23.42	1096	36.2
308,000	503.4	0.01231	0.5818	14.25	0.5991	0.4451	3.639	25.54	1100	39.2
310,000	507.4	0.01146	0.5414	13.15	0.5531	0.4109	3.662	27.84	1104	42.4
312,000	511.5	0.01067	0.5042	12.15	0.5110	0.3795	3.685	30.33	1109	46.0
314,000	515.5	0.009940	0.4697	11.23	0.4724	0.3508	3.708	33.02	1113	49.7
316,000	519.5	0.009265	0.4378	10.39	0.4369	0.3244	3.731	35.91	1117	53.7
318,000	523.5	0.008643	0.4084	9.616	0.4044	0.3002	3.754	39.04	1122	58.0
320,000	527.5	0.008061	0.3809	8.903	0.3744	0.2779	3.777	42.42	1126	62.7
322,000	531.5	0.007527	0.3557	8.251	0.3470	0.2575	3.799	46.04	1130	67.6
324,000	535.5	0.007028	0.3321	7.645	0.3215	0.2385	3.822	49.99	1134	73.0
326,000	539.5	0.006571	0.3105	7.096	0.2984	0.2213	3.844	54.17	1139	78.6
328,000	543.5	0.006146	0.2904	6.587	0.2770	0.2054	3.867	58.71	1143	84.6
330,000	547.5	0.005750	0.2717	6.118	0.2573	0.1908	3.889	63.57	1147	91.1
332,000	551.5	0.005379	0.2542	5.681	0.2389	0.1771	3.911	68.84	1151	98.1
334,000	555.5	0.005039	0.2381	5.284	0.2222	0.1647	3.933	74.43	1155	105
336,000	559.5	0.004721	0.2231	4.915	0.2067	0.1532	3.955	80.47	1160	113
338,000	563.5	0.004427	0.2092	4.577	0.1925	0.1426	3.977	86.91	1164	122
340,000	567.5	0.004152	0.1962	4.261	0.1792	0.1327	3.999	93.85	1168	131
342,000	571.5	0.003892	0.1839	3.966	0.1668	0.1235	4.021	101.4	1172	140
344,000	575.5	0.003655	0.1727	3.700	0.1556	0.1152	4.043	109.3	1176	150
344,487	576.5	0.003602	0.1702	3.638	0.1530	0.1134	4.048	111.2	1177	153
346,000	579.5	0.003433	0.1623	3.429	0.1442	0.1068	4.065	118.5	1185	161
348,000	583.5	0.003231	0.1527	3.179	0.1337	0.09896	4.086	128.5	1195	172
350,000	587.5	0.003041	0.1437	2.946	0.1239	0.09169	4.108	139.5	1205	184
352,000	591.5	0.002863	0.1353	2.732	0.1149	0.08502	4.129	151.1	1215	197
354,000	595.5	0.002700	0.1276	2.537	0.1067	0.07893	4.151	163.6	1226	211
356,000	599.5	0.002546	0.1203	2.358	0.09916	0.07334	4.172	176.9	1236	225
358,000	603.5	0.002404	0.1136	2.194	0.09227	0.06823	4.193	191.1	1246	240
360,000	607.5	0.002273	0.1074	2.044	0.08597	0.06356	4.214	206.2	1256	255
362,000	611.5	0.002150	0.1016	1.906	0.08015	0.05925	4.236	222.2	1266	271
364,000	615.5	0.002035	0.09614	1.778	0.07476	0.05525	4.257	239.4	1277	288
366,000	619.6	0.001928	0.09111	1.661	0.06984	0.05161	4.278	257.6	1287	306
368,000	623.6	0.001828	0.08639	1.553	0.06529	0.04824	4.299	276.8	1397	325
370,000	627.6	0.001736	0.08201	1.453	0.06111	0.04514	4.319	297.2	1308	345
372,000	631.6	0.001649	0.07790	1.361	0.05724	0.04227	4.340	318.9	1318	365
374,000	635.6	0.001567	0.07405	1.276	0.05366	0.03962	4.361	341.8	1328	386
376,000	639.6	0.001489	0.07038	1.197	0.05033	0.03716	4.382	366.1	1339	409
378,000	643.6	0.001417	0.06698	1.123	0.04722	0.03485	4.402	392.0	1349	433
380,000	647.6	0.001350	0.06379	1.055	0.04436	0.03274	4.423	419.2	1360	457
382,000	651.6	0.001286	0.06079	0.9916	0.04170	0.03077	4.443	448.0	1370	482
384,000	655.6	0.001227	0.05797	0.9331	0.03924	0.02895	4.464	478.4	1381	509
386,000	659.6	0.001170	0.05531	0.8784	0.03694	0.02725	4.484	510.5	1391	536
388,000	663.6	0.001118	0.05282	0.8277	0.03481	0.02567	4.504	544.2	1401	565
390,000	667.6	0.001068	0.05045	0.7804	0.03282	0.02420	4.525	579.8	1412	595
392,000	671.6	0.001020	0.04823	0.7364	0.03097	0.02282	4.545	617.2	1422	626
393,700	675.0	0.0009830	0.04645	0.7015	0.02950	0.02173	4.562	650.4	1431	653

[1] The values for viscosity listed in these columns are not applicable at the higher altitudes where the mean free paths of the molecules are comparable to or longer than the dimensions of the body being considered. Furthermore, the values listed are based on the conventional Sutherland formula for normal air and, consequently, no allowance has been made for the effect of dissociated oxygen in the atmosphere at the higher levels.

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TABLE VI.– LATITUDE CORRECTION FACTORS FOR VALUES OF PRESSURE IN TABLES IV AND V

Altitude, h (km)	Altitude, h (ft)	Latitude, deg 0	10	20	30	40	50	60	70	80	90
(a) For both day and night											
20	65,617	1.0078	1.0073	1.0060	1.0039	1.0014	0.9988	0.9963	0.9943	0.9929	0.9925
30	98,425	1.0120	1.0112	1.0092	1.0060	1.0022	.9981	.9943	.9912	.9892	.9885
40	131,233	1.0158	1.0148	1.0121	1.0080	1.0029	.9975	.9925	.9884	.9858	.9848
50	164,042	1.0187	1.0176	1.0144	1.0094	1.0034	.9971	.9911	.9863	.9832	.9821
60	196,850	1.0213	1.0200	1.0164	1.0108	1.0039	.9967	.9899	.9844	.9808	.9796
70	229,658	1.0242	1.0227	1.0186	1.0122	1.0044	.9962	.9886	.9824	.9783	.9769
80	262,467	1.0278	1.0260	1.0212	1.0140	1.0051	.9957	.9869	.9798	.9752	.9736
(b) For day only											
80	262,467	1.0278	1.0260	1.0212	1.0140	1.0051	0.9957	0.9869	0.9798	0.9752	0.9736
90	295,275	1.0312	1.0293	1.0239	1.0157	1.0057	.9952	.9853	.9774	.9722	.9704
100	328,083	1.0340	1.0319	1.0261	1.0171	1.0062	.9947	.9840	.9754	.9698	.9679
110	360,892	1.0364	1.0342	1.0279	1.0183	1.0066	.9944	.9830	.9738	.9678	.9657
120	393,700	1.0385	1.0361	1.0295	1.0193	1.0070	.9940	.9820	.9723	.9660	.9638
(c) For night only											
80	262,467	1.0278	1.0260	1.0212	1.0140	1.0051	0.9957	0.9869	0.9798	0.9752	0.9736
90	295,275	1.0314	1.0295	1.0241	1.0158	1.0057	.9951	.9852	.9772	.9721	.9703
100	328,083	1.0346	1.0325	1.0265	1.0174	1.0063	.9946	.9838	.9750	.9693	.9673
110	360,892	1.0374	1.0352	1.0287	1.0188	1.0068	.9942	.9825	.9730	.9669	.9647
120	393,700	1.0397	1.0373	1.0304	1.0199	1.0072	.9938	.9815	.9714	.9649	.9627

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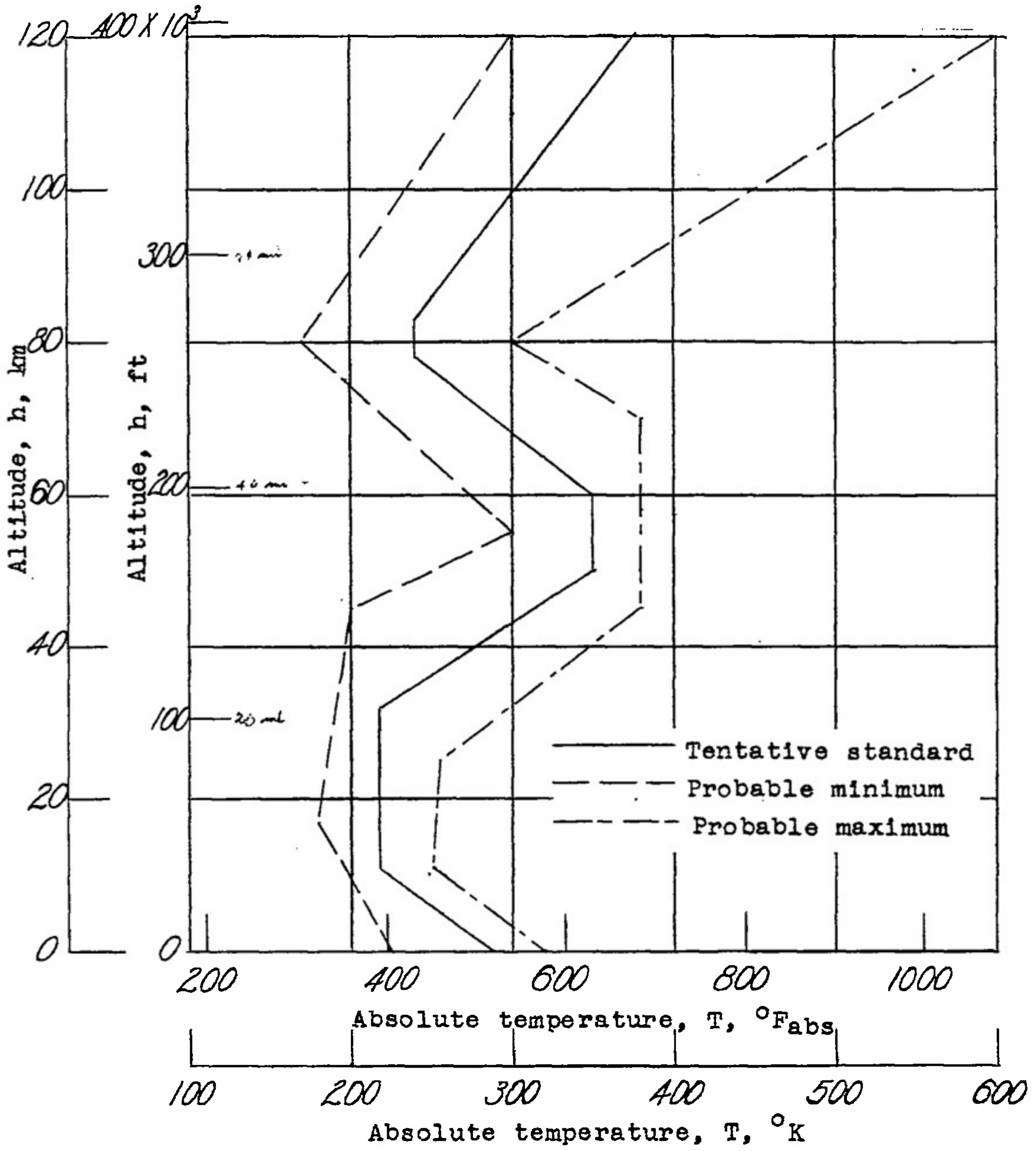

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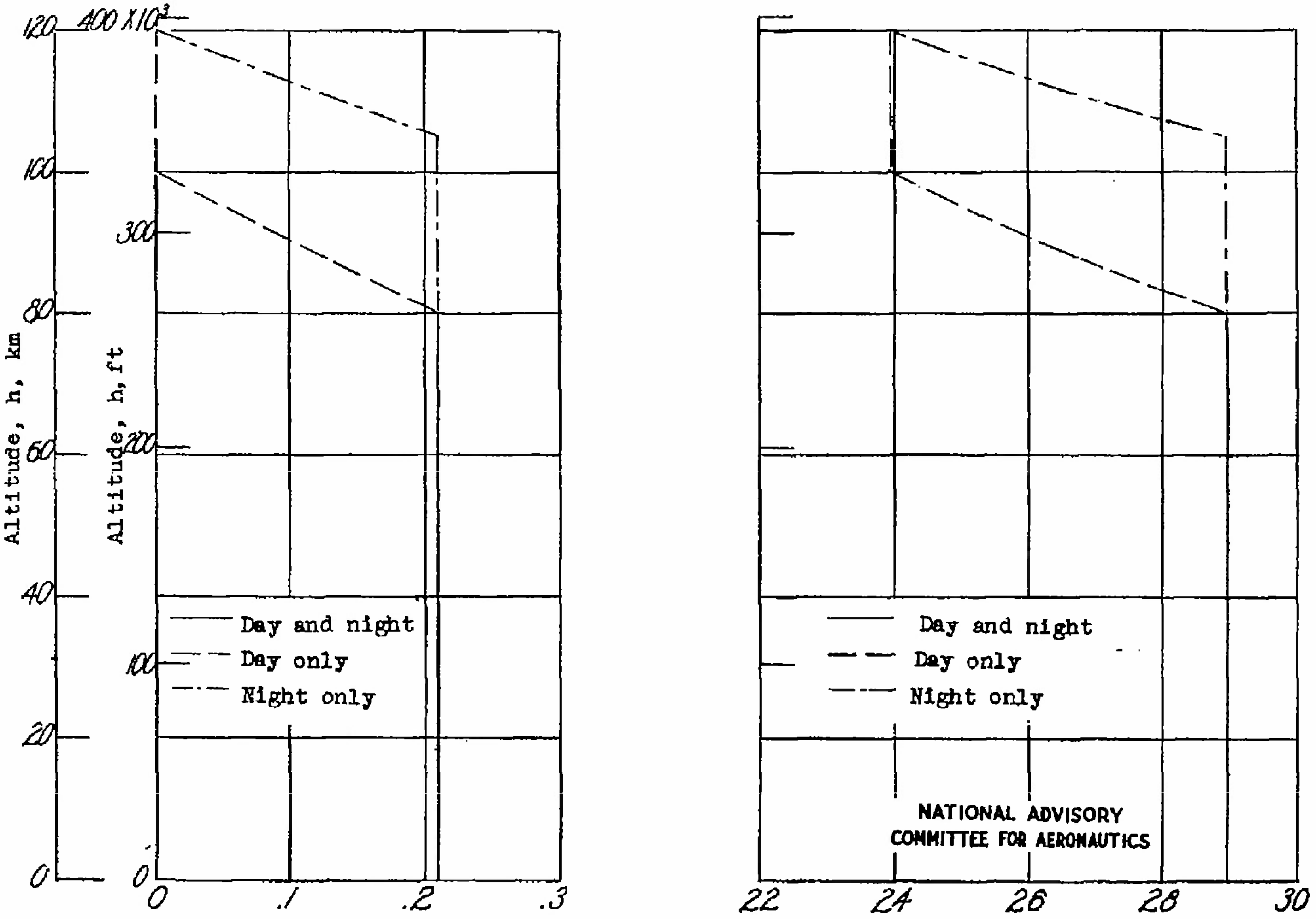
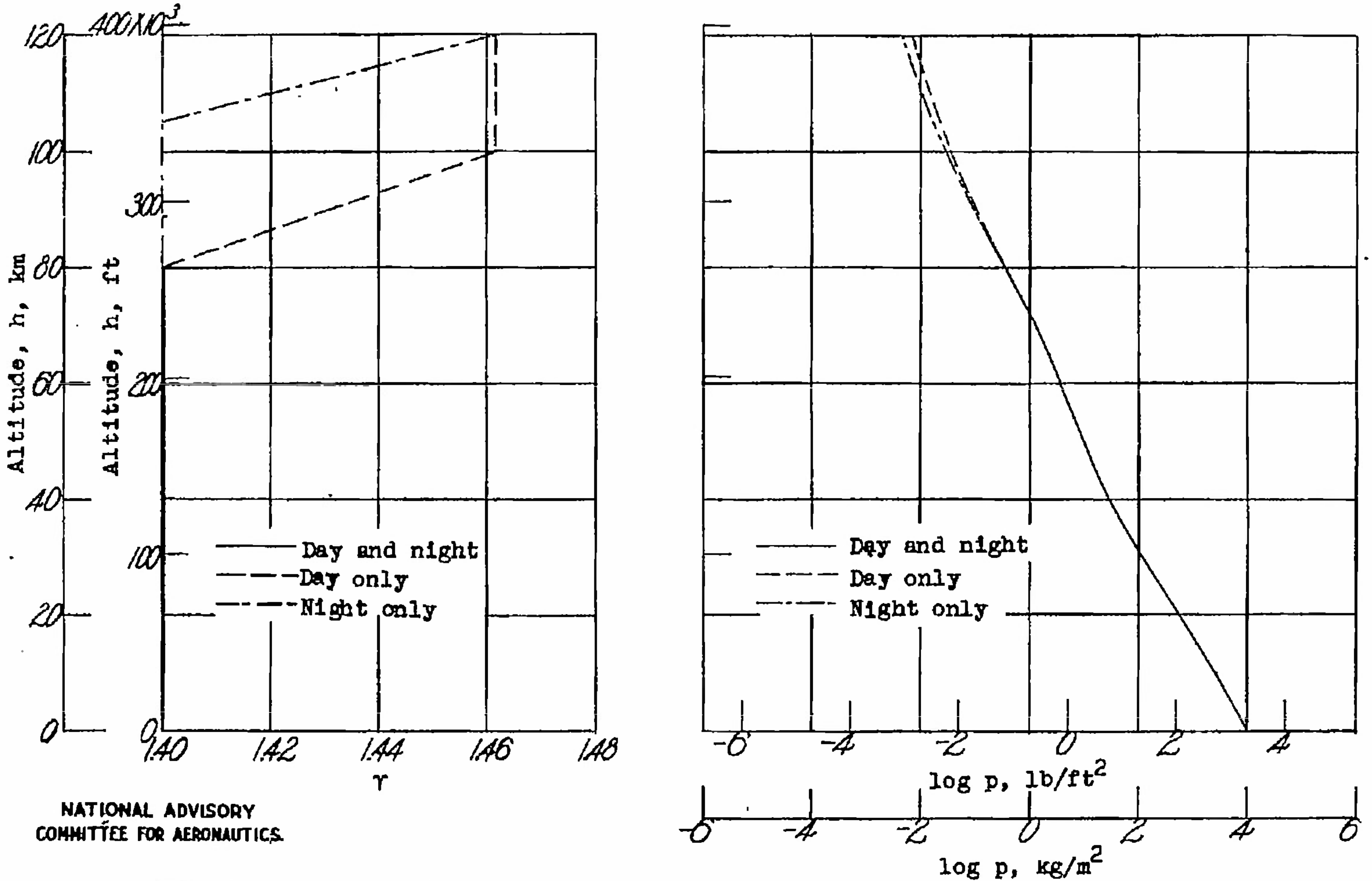
Figure 1.- Variation of ambient temperature with altitude.



(a) Relative volume of molecular oxygen, v_m.

(b) Average molecular weight, M.

Figure 2.- Variation of composition of the tentative standard atmosphere with altitude. (The dissociation of oxygen is the only change in composition occurring in the tentative standard atmosphere.)



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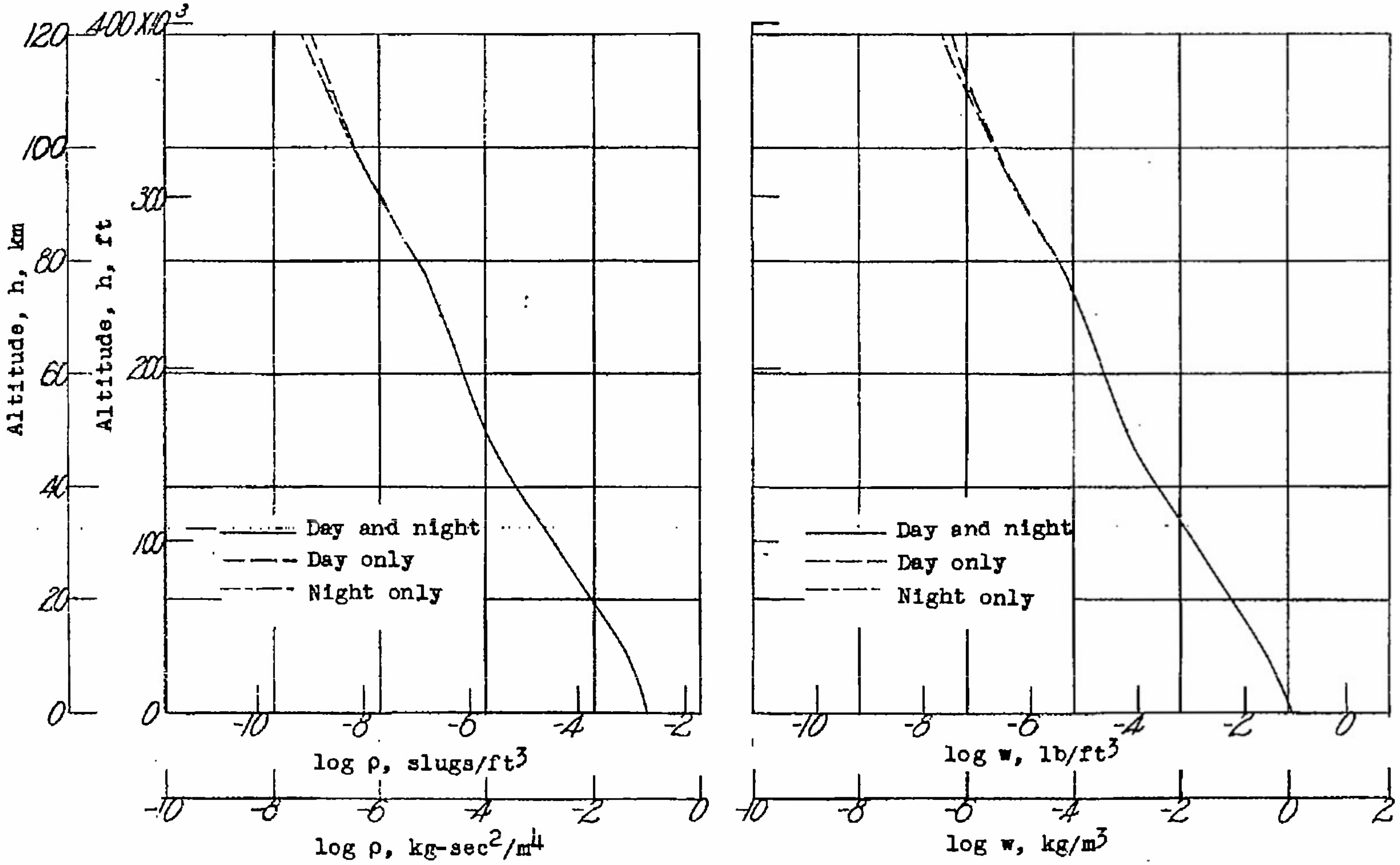
(a) Ratio of specific heats, γ.

(b) Pressure, p.

Figure 3. Variation with altitude of the physical properties of the tentative standard atmosphere.



(c) Density, ρ.

(d) Specific weight, w.

Figure 3.- Continued.

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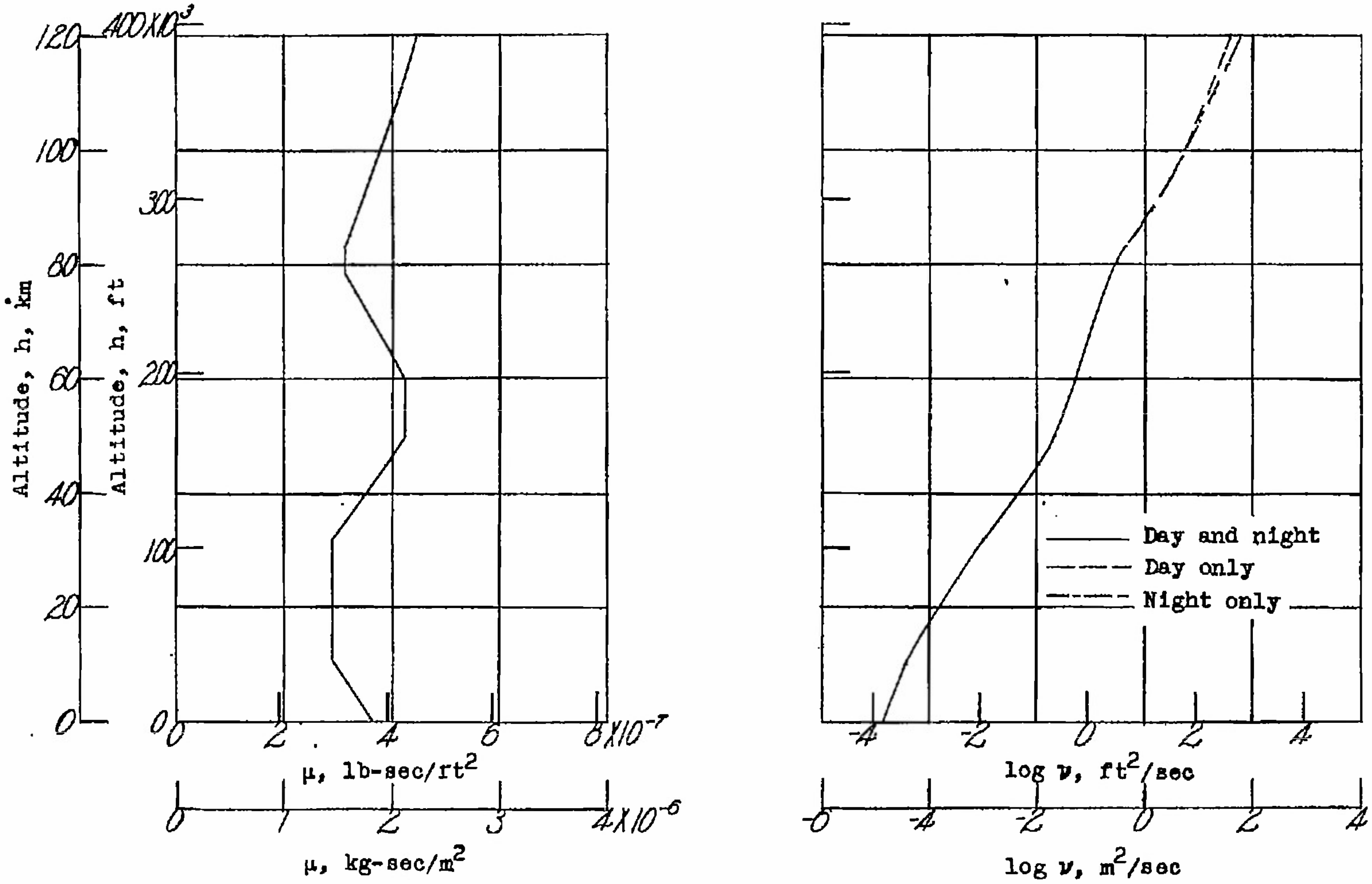

(e) Coefficient of viscosity, μ.

(f) Kinematic viscosity, ν.

Figure 3.- Continued.

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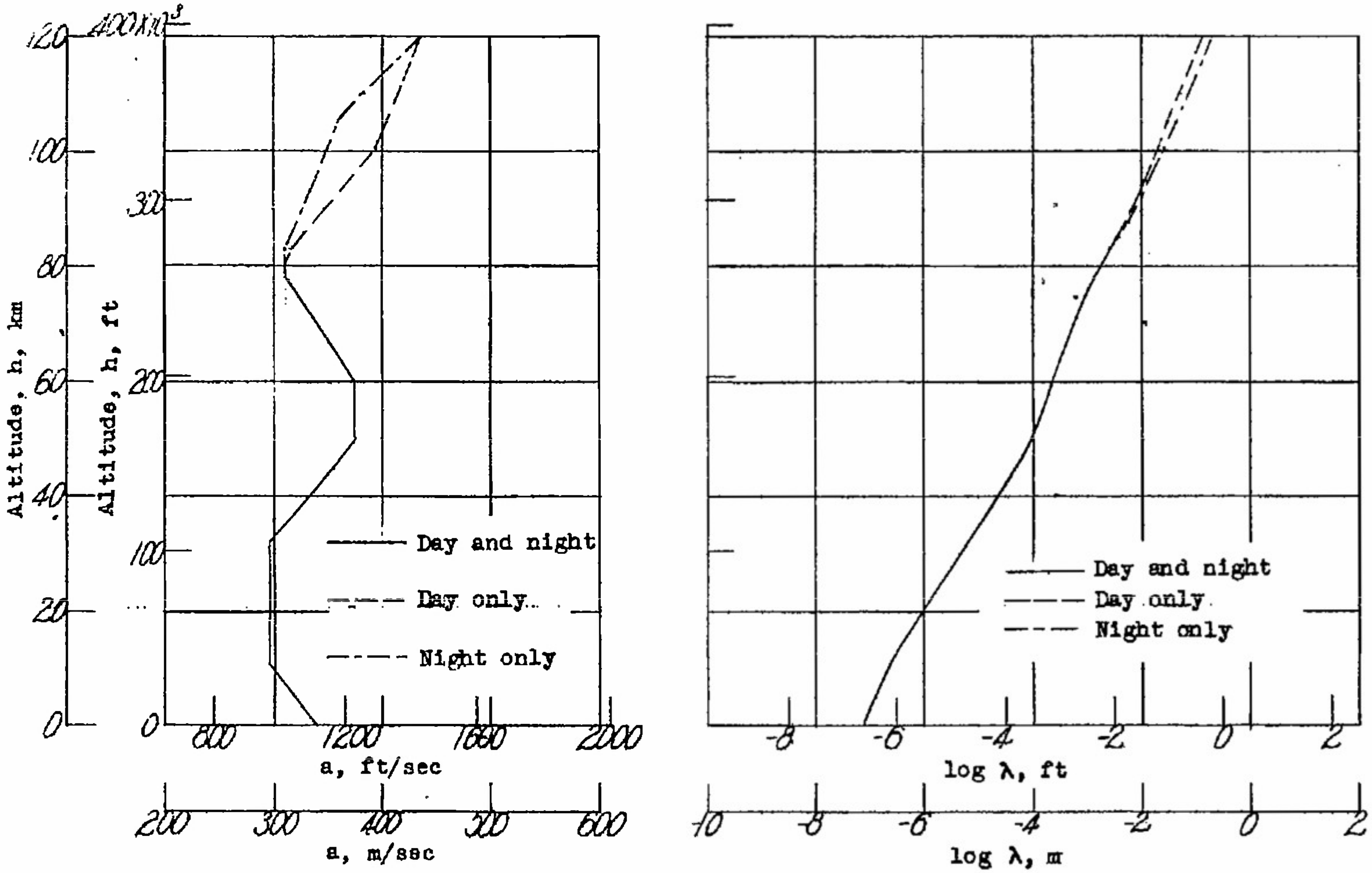

(g) Speed of sound, a.

(h) Mean free path of molecules, λ.

Figure 3.- Concluded.

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ABSTRACT:

Two sets of tables based upon tentative standard specifications for the upper atmosphere are presented. One set constitutes a consistent extension of the standard tables for the lower atmosphere. The other set takes into consideration the decrease in the acceleration of gravity with increasing altitude and, therefore, is more precise than the first set. All quantities listed in the tables against altitude are computed from adopted temperature-height and composition-height relationships.

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