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AERODYNAMICS, SUPERSONIC
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NAVORD REPORT 1488 (Vol. 1)

HANDBOOK OF SUPERSONIC AERODYNAMICS



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HANDBOOK OF SUPERSONIC AERODYNAMICS

Preface

Soon after the Applied Physics Laboratory+ of The Johns Hopkins University began its work on the BUMBLEBEE project, it became apparent that a great deal of basic information in the field of supersonic aerodynamics would be needed and that existing data and theories should be brought together in a form suitable for design use. Consequently, the Aerodynamics Group at the Applied Physics Laboratory undertook to compile, both through its own efforts and through those of interested associate contractors, material appropriate to a handbook of supersonic aerodynamics. It seemed likely that the project would be of interest also to numerous other organizations working in the same and allied fields. The project was discussed at some length with other interested agencies during the Symposium on Aerodynamics held at the Laboratory during December, 1945++. Many helpful suggestions resulted from this symposium discussion and the preparation and issuance of the Aerodynamics Handbook was undertaken. Initial sections of the Aerodynamics Handbook were distributed early in 1946 with subsequent parts being issued as monthly supplements. By September, 1946, the work had increased until it was no longer practical to continue it within the Aerodynamics Group, and consequently a separate Handbook staff was set up.

By the middle of 1947, the Handbook project seemed firmly enough established and the general interest sufficiently great to warrant preparation of a revised edition which would contain contributions from a larger number of agencies and would be of more professional format. Therefore, issuance of monthly supplements was terminated and work was begun on the second edition, called the Handbook of Supersonic Aerodynamics, and this edition was published January 1, 1949.

In February, 1950, full responsibility for the printing and distributing of the Handbook of Supersonic Aerodynamics was assumed by the Publications Branch, Bureau of Ordnance, Department of the Navy. However, the Applied Physics Laboratory continues to have editorial responsibility for the Handbook and for this reason it continues to maintain an editorial staff and a Reviewing Committee at the Laboratory as heretofore.

The Applied Physics Laboratory has been greatly assisted by other agencies working in supersonic aerodynamics, both in suggest-

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+ Operating under Contract NOrd 7386 with the Bureau of Ordnance, Department of the Navy, Washington 25, D. C.

++ Reported in BUMBLEBEE Report No. 29, page 75.

ing what kinds of material should be included in the Handbook and in preparing specific sections. The response of all agencies approached was gratifying and whatever value the Handbook may prove to have will be due in no small part to the excellent cooperation received both within and without the BUMBLEBEE group of Navy contractors. The Applied Physics Laboratory hereby gratefully acknowledges with sincere thanks the contributions made by all agencies and individuals. Specific acknowledgment is made in the respective sections for each contribution.

The primary criterion used in selecting material for the Handbook is its expected usefulness to designers of supersonic vehicles. Thus a collection of data directly useful in the design of supersonic vehicles, results of the more significant experiments, and outlines of basic theory are included at the risk of producing a Handbook that may be considered somewhat unconventional and heterogeneous in content.

Since the field of supersonic aerodynamics is still relatively new and since much of the work is of a pioneering nature, it is expected that the organization of the Handbook with respect to specific sections will require revision from time to time.

A decimal system was used in numbering sections and pages of the 1949 edition of the Handbook; for example, 3.11 referred to the eleventh page of Section 3. This same system of page numbering is used in Sections 1, 2, 3 and 4 of Volume One of the 1950 edition, with the exception that the decimal (.) is replaced by a dash (-); for example, 1.3 has been changed to 1-3. Future volumes of the Handbook will have a different page numbering system, to be explained when Volume Two is released.

The present edition of the Handbook, printed and distributed by the Bureau of Ordnance, is being published in separate volumes as material becomes available. The first volume contains the first four sections as given in the tentative outline of section titles shown on page iv, immediately following this preface. This outline represents the material that should be included in such a Handbook as this, according to answers to inquiries made of users of the first edition. Sections 1 and 3 of the 1950 edition represent revisions of the corresponding sections of the 1949 edition, while Sections 2 and 4 remain unchanged. It is planned to have Volume Two contain Sections 5, 14 and 15, as given in the tentative outline. Section 5 will represent a revision of the same section of the 1949 edition, and will also contain data on oblique shock flow. Classified material will be published in a separate classified volume as heretofore. All volumes of the Handbook are issued in loose-leaf form to permit the addition of supplementary material.

Section 1 of Volume One contains the American Standard Letter Symbols for Aeronautical Sciences approved by the American Standards

Association on January 24, 1950. The symbols used in Sections 2, 3 and 4 of Volume One do not conform, in every instance, to this Standard. The lack of conformity is a consequence of the early date of the first publication of these sections (January 1, 1949) and the economy resulting from using the original plates for the 1950 edition. Beginning with Section 5, in Volume Two, all symbols will be brought into conformity with the American Standard.

For technical editing of the Handbook, a Reviewing Committee was appointed by the Director of the Applied Physics Laboratory. The following have served as members of the committee: C. N. Warfield (Chairman), L. L. Cronvich, A. R. Eaton, G. M. Edelman, N. Edmonson+ and F. K. Hill.

All agencies and individuals interested in aerodynamics should feel free to submit and recommend material for inclusion in the Handbook; full credit will be given for all such material used. In the selection of material and the preparation of these volumes, the Applied Physics Laboratory lays claim neither to omniscience nor to infallibility; it earnestly solicits, therefore, constructive criticisms and suggestions. Correspondence relating to the editing of the Handbook should be sent to:

Thomas F. Ball, Supervisor
Aerodynamics Handbook Project
Applied Physics Laboratory
The Johns Hopkins University
8621 Georgia Avenue
Silver Spring, Maryland

The first 2000 copies of Volume One (unclassified 1950 edition) will be distributed by the Bureau of Ordnance, Department of the Navy free-of-charge to research organizations, industrial concerns, universities and individual investigators who are engaged in aerodynamic research pertaining to national defense, provided formal requests are submitted to, and approved by, the Bureau of Ordnance. All applications and communications concerning the future distribution of both the Classified and Unclassified Volumes of the Handbook should be sent to:

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+ Active until July, 1949.

TENTATIVE LIST OF MAJOR SECTIONS OF THE HANDBOOK OF SUPERSONIC AERODYNAMICS

Section No.	Title
1+	Symbols and Nomenclature
2+	Fundamental Equations and Formulae
3+	General Atmospheric Data
4+	The Mechanics and Thermodynamics of Steady One-Dimensional Gas Flow
5++	Collected Tables (Mach Tables, Adiabatic Tables, Miscellaneous Functions of γ)
6+++	Viscosity Effects
7	Compressible Flow and Shock Patterns
8	Two-Dimensional Airfoils
9	Three-Dimensional Wings
10	Three-Dimensional Bodies
11	Mutual Interference Phenomena
12	Static Stability
13	Dynamic Stability
14++	Aero-Elastic Phenomena (Flutter)
15++	Tables of Thermal Properties of Gases
16	Ducts, Nozzles and Diffusers
17	Heat Transfer
18	Free Jets
19	Wind Tunnel Design and Instrumentation
20	Measurement Techniques
21	Miscellaneous Problems
	References
	Alphabetical Index

+ These sections with applicable references and indices are published herein.

++ These sections will be published in the near future.

+++ Material in this section thus far is classified and has been published in the Classified Volume of the 1949 Edition of the Handbook.

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American Society of Mechanical Engineers
American Association for the Advancement of Science

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SECTION 1 - SYMBOLS AND NOMENCLATURE

The material appearing on pages 1-2 through 1-21, inclusive, represents a verbatim reproduction of the recently published American Standard Letter Symbols for Aeronautical Sciences, which was officially released by the American Standards Association on January 24, 1950. The approved American Standard is being reproduced in the Handbook with the full permission of the American Standards Association.

Introduction

Since July 1, 1947, the Handbook Project at the Applied Physics Laboratory of The Johns Hopkins University has been closely associated with the work of Subcommittee No. 7 (Letter Symbols for Aeronautical Sciences) of the American Standards Sectional Committee Z10 (Letter Symbols and Abbreviations for Science and Engineering). The purpose of this endeavor has been to effect standardization of letter symbols for the aeronautical sciences on a national basis. It is believed that such standardization will result in the promotion of uniformity in the preparation and presentation of technical papers and texts in the fields of aeronautical sciences. Moreover, its widespread use will lead to immeasurable savings in man-hours both in the preparation and understanding of such technical material and thus provide an added measure of security for the country as a whole at a time when our needs may necessitate rapid mobilization of our industrial facilities.

The use of these standard letter symbols throughout all technical levels of the aeronautical and allied industries is essential to the attainment of the foregoing objectives.

The National Advisory Committee for Aeronautics and the Institute of Aeronautical Sciences collaborated in sponsoring this phase of a general program of standardization for letter symbols with the following engineering and scientific societies: American Society of Civil Engineers, American Institute of Electrical Engineers, American Society for Engineering Education, American Society of Mechanical Engineers, and the American Association for the Advancement of Science.

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American Standard

Letter Symbols For Aeronautical Sciences

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Approved January 24, 1950
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American Standard

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Foreword

(This Foreword is not a part of the American Standard Letter Symbols for Aeronautical Sciences, Z10.7-1950.)

This standard was prepared by Subcommittee No. 7 on Aeronautical Sciences, one of twelve subcommittees appointed by Sectional Committee Z10 on Letter Symbols and Abbreviations for Use in Science and Engineering, for the purpose of preparing American Standard letter symbols and abbreviations. The other subcommittees cover mathematics, hydraulics, mechanics of solid bodies, structural analysis, heat and thermodynamics, photometry, electrical and magnetic quantities, radio, physics, chemical engineering, and abbreviations.

Sectional Committee Z10 was organized under the procedure of the American Standards Association in January, 1926, with the American Society of Civil Engineers, American Institute of Electrical Engineers, American Society for Engincering Education, American Society of Mechanical Engineers, and the American Association for the Advancement of Science as joint sponsors. The committee was reorganized in October, 1935. It now consists of representatives of thirty-five national societies, and associations.

Subcommittee No. 7 was originally constituted in April, 1926, and submitted a proposal which was issued as a standard in 1930. Rapid developments in concepts relating to the aeronautical sciences rendered the 1930 standard obsolete, and the subcommittee was reconstituted in June, 1947, with substantially its present membership, for the purpose of developing a new standard. A proposed standard was published in January, 1949, for trial and criticism.

During the course of its work the subcommittee has considered a number of special letter symbols relating particularly to meteorology and to servomechanisms. It has been the consensus that letter symbols and concepts in these fields are so specialized as not properly to fall within the scope of Subcommittee No. 7. For this reason no attempt has been made to include (in the present standard) letter symbols for special concepts in meteorology and in servomechanisms.

Recognizing the practical fact that most published and duplicated papers and other works in the fields of aeronautics and aerodynamics are duplicated by some process relying upon the use of a typewriter, the subcommittee has made no use of type-face variations in order to distinguish letter symbols. It is believed that this feature will simplify the preparation of typewritten duplications, but, of course, General Principle 8 (see page 1-7) will still be applicable to printed publications.

In the present standard there are two listings of the same symbols and quantities (in the case of letter symbols for primary concepts and for secondary concepts) in order to facilitate use of the standard. The first listing is alphabetical by symbol, and the second is alphabetical by concept (see Appendix, page 1-16). The first two columns (namely, the Symbol column and the Concept column) of the first listing constitute the American Standard, and all other columns and listings are merely to facilitate use of the standard. In the third column of the first listing of letter symbols for primary concepts, illustrative dimensions are given, but these dimensions are not a part of the standard; in the fourth column of the first listing the extent of agreement with current American Standards is indicated and it will be noted that this agreement is substantial; in the fifth column of the first listing are certain remarks including definitions, but these form no part of the standard.

In general, any of the recommended letter symbols for primary concepts may be employed as subscripts in application to another symbol for a primary concept. This recognizes the fact that a given primary concept may in certain circumstances be employed as a modifying or secondary concept. For this reason, there has been no deliberate attempt made to include in the subscript list all the symbols which may be employed as subscripts, particularly where such symbols may be found in the published listing of principal letter symbols.

In designating aircraft components, it is recommended that lower-case letters be generally used whenever the terms occur in mathematical expressions; *e.g.*, b_e—*elevator span;* S_w—*wing area.* Capital letters should be used to designate component parts of a configuration, as used in models for wind-tunnel testing, and various components of the model under test should be distinguished by means of numerical subscripts; thus, $F_1W_3N_2$ would represent a model including the No. 1 fuselage, the No. 3 wing, and the No. 2 nacelle. Since the configuration symbols are not usually employed as subscripts, they are not included in the present list of subscripts; thus, in the present list of subscripts, symbols for aircraft components appear as lower-case letters.

In the field of turbulent-flow analysis, practice is not well enough established to permit the recommendation of symbols pertaining to turbulence intensity, to turbulence energy distribution (*i.e.*, the so-called spectrum of turbulence), and to turbulent-fluctuation fre-

quency. Meanwhile, the limited needs for such symbols should be met by use of symbols for analogous concepts in other fields. It will be noted, however, that recommendations are made herein for symbols to express mean-velocity component ($\bar{u}$) and turbulent-velocity component (u'), the recommended symbols being the bar and the prime, respectively, to be applied to a suitable velocity symbol.

The subject of moment designations, moment-coefficient designations, etc, is definitely controversial, but the subcommittee has agreed to recommend a system (see page 1-20).

Officers of Sectional Committee on Letter Symbols and Abbreviations for Science and Engineering

H. M. Turner, Associate Professor, Electrical Engineering, Yale University, New Haven, Conn., *Chairman*
C. E. Hilton, American Standards Association, Incorporated, New York, N. Y., *Secretary*

Personnel of Subcommittee No. 7 on Letter Symbols for Aeronautical Sciences

Prof Thomas F. Ball, Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Md., *Chairman*
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General Principles of

Letter Symbol Standardization

1 Manuscript. In preparing manuscripts, it is suggested that authors give careful attention to the use of symbols from this and other standard lists and to the principles here given. Symbols used should be defined clearly. When a table of symbols is not given, it is desirable to make reference to the standard lists from which the symbols are taken. The many numbers, letters, and signs which are similar in appearance should be distinguished carefully.

2 Letter Symbol. A letter symbol is a single character, with subscript or superscript if required, used to designate a physical magnitude in mathematical equations and expressions. Two or more symbols together always represent a product.

Letter symbols are to be distinguished from abbreviations, mathematical signs and operators, graphical symbols, and chemical symbols:

(*a*) *Abbreviations* are shortened forms of names and expressions employed in texts and tabulations and should not be used as symbols in equations.

(*b*) *Mathematical Signs and Operators* are characters used with letter symbols to denote mathematical operations and relations.

(c) *Graphical Symbols* are conventionalized diagrams and letters used on plans and drawings.

(*d*) *Chemical Symbols* are letters and other characters designating chemical elements and groups.

3 The same symbol should be used for the same physical magnitude regardless of the units employed and regardless of special values occurring for different states, points, parts, times, etc. Units or special values may be distinguished when necessary by subscripts, superscripts, or by upper- and lower-case letters when both are specifically included as symbols in a standard list. The units used should be indicated when necessary. Sometimes different symbols are used for the components of a vector.

4 Subscript. A subscript preferably should be a simple character. It is commonly employed to indicate constancy of a particular physical magnitude, such as pressure or temperature, when there are other variables. A multiple subscript, sometimes divided by a comma, refers to more than one state, point, part, time, etc. A subscript should not be attached to a subscript. Further uses of subscripts are listed in Principles 3 and 6.

5 Superscript. A symbol with a superscript, such as a prime (′) or a second (″), should be enclosed in parentheses, braces, or brackets before affixing an exponent. A complicated exponent (or any other expression frequently repeated) may be replaced by a single symbol selected to represent it. Reference marks should not be attached to symbols. Further uses of superscripts are listed in Principles 3 and 6.

6 Conflicts. Conflicts which would occur when different physical magnitudes are assigned the identical symbol in the same or different standard symbol lists may be resolved in one of the following ways:

(*a*) For one or more of the conflicting uses, the given symbol may be employed with subscript or superscript selected by the author.

(*b*) If one of the magnitudes has an alternate symbol in a standard list, it may be used.

(*c*) A slight change in the name of the magnitude may remove the conflict. For instance, one may use L for "length of radius" when r for "radius" conflicts with r used for another magnitude.

7 Unlisted Magnitudes. To symbolize a special value of a listed magnitude, see Principle 3. The symbol chosen by an author for a physical magnitude not appearing in any standard list should be one that does not have already a different meaning in the field of the text.

8 Typography. Letter symbols, letter subscripts, and letter superscripts, whether upper- or lower-case, should be printed with italic type unless definitely specified otherwise. On manuscript this is indicated by underlining each symbol which is to be italicized. Special types, such as Old English and type that is currently used for vector magnitudes, should be avoided for scalar magnitudes. When special type is used for vector magnitudes, the same italic letter should be used for the corresponding scalar magnitude. Vertical Arabic numerals should be used as coefficients in equations and in subscripts and exponents. Bars, dots, and other modifying signs and operators should be used in the manner currently recognized by mathematicians.

American Standard

Letter Symbols for Aeronautical Sciences

A symbol indicated as an alternate is not preferred. Symbols having equal rank are not qualified as alternates.

The dimensions given in the third column and the definitions given in the fifth column are merely illustrative and form no part of the present standard. With regard to the indicated dimensions, and in a particular system of units, M represents Mass, L represents Length, T represents Time, and θ represents Temperature.

Letter Symbols for Primary Concepts

Symbol	Concept	Dimensions	Also Appears in Z10 Publication	Remarks
a (lc)	Slope of lift curve	Dimensionless	———	$a = \frac{dC_L}{d\alpha}$
a (lc)	Velocity of sound	LT^{-1}	———	Use c (lc) for alternate
A (cap)	Area, cross-sectional	L^2	Z10.2, Z10.4, Z10.6, Z10.8, Z10.12	Use S (cap) for surface or projected area
A (cap)	Aspect ratio	Dimensionless	———	See $\mathcal{A}$ (cap, written together) for alternate
$\mathcal{A}$ (cap, written together)	Aspect ratio, alternate for	Dimensionless	———	———
b (lc)	Span	L	———	Used in Z10.3, Z10.6, Z10.8 for breadth
b (lc)	Blade width (propellers)	L	———	———
c (lc)	Chord, of an airfoil	L	———	———
c (lc)	Velocity of sound, alternate for	LT^{-1}	Z10.6, Z10.12	———
c (lc)	Coefficient, alternate for; section coefficient	Dimensionless	———	———
c_p (lc)	Specific heat, at constant pressure	$L^2T^{-2}\theta^{-1}$	Z10.4, Z10.6, Z10.12	———
c_v (lc)	Specific heat, at constant volume	$L^2T^{-2}\theta^{-1}$	Z10.4. Z10.6, Z10.12	———
C (cap)	Coefficient	Dimensionless	Z10.2	See K (cap) for factor which may have dimensions; see page 19 for usages
C (cap)	Concentration	Dimensionless	Z10.4	———
d (lc)	Diameter	L	Z10.3, Z10.4	Interchangeable, but conflicts with differential operators shall be avoided
D (cap)	Diameter	L	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	Interchangeable, but conflicts with differential operators shall be avoided
D (cap)	Drag	MLT^{-2}	———	———
e (lc)	Span effectiveness	Dimensionless	———	———
E (cap)	Energy	ML^2T^{-2}	Z10.2, Z10.3, Z10.6, Z10.8, Z10.12	———
E (cap)	Modulus of elasticity; Young's modulus	$ML^{-1}T^{-2}$	Z10.3, Z10.6, Z10.8	———
f (lc)	Frequency	T^{-1}	Z10.3, Z10.6, Z10.8	———
F (cap)	Force	MLT^{-2}	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	See page 19 for usages
F (cap)	Thrust; stream thrust (combustion)	MLT^{-2}	———	Use T (cap) for propeller thrust
g (lc)	Accleration due to gravity	LT^{-2}	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	———
G (cap)	Mass velocity; mass-flow, per unit cross-sectional area, per unit time	$ML^{-2}T^{-1}$	Z10.4, Z10.12	———
G (cap)	Shear modulus	$ML^{-1}T^{-2}$	Z10.8	———

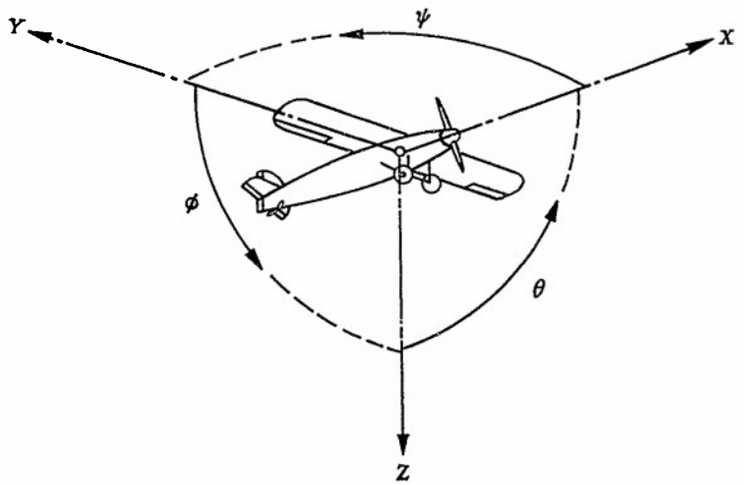
Symbol	Concept	Dimensions	Also Appears in Z10 Publication	Remarks
h (lc)	Enthalpy, per unit mass or per unit weight: specific enthalpy	L^2T^{-2} (per unit mass) L (per unit weight)	Z10.4, Z10.6, Z10.12	
h (lc)	Altitude	L	Z10.6, Z10.8	Use z (lc) for alternate
h (lc)	Heat-flow rate, per unit of area, per degree, across a boundary surface	$MT^{-3\theta^{-1}}$	Z10.4	Discourage use of the term film coefficient
H (cap)	Enthalpy; total heat content	ML^2T^{-2}	Z10.4, Z10.6, Z10.12	
H (cap)	Angular momentum	ML^2T^{-1}		
I (cap)	Impulse	MLT^{-1}		Subscripts must always be used to connote type of impulse
I (cap)	Moment of inertia	ML^2	Z10.3, Z10.6, Z10.8, Z10.12	
J (cap)	Advance ratio of propeller	Dimensionless		
J (cap)	Mechanical equivalent of heat; Joule s constant	Dimensionless	Z10.4, Z10.6, Z10.12	Numerical value is a function of mechanical and thermal units used
J (cap)	Polar moment of inertia	ML^2	Z10.6	
k (lc)	Radius of gyration	L	Z10.6, Z10.8	
k (lc)	Reduced frequency (flutter)	Dimensionless		$k=\frac{\omega c}{2V}$
k (lc)	Thermal conductivity	$MLT^{-3\theta^{-1}}$	Z10.4, Z10.6, Z10.12	
K (cap)	Factor, for comparison purposes	May have dimensions		
l (lc)	Length; distance	L	Z10.3, Z10.4, Z10.6	
L (cap)	Lift	MLT^{-2}		
L (cap)	Turbulence scale; correlation length (turbulence)	L		
m (lc)	Mass	M	Z10.2, Z10.3, Z10.4, Z10.6, Z10.12	
M (cap)	Mach number	Dimensionless		
M (cap)	Moment	ML^2T^{-2}	Z10.3, Z10.8	See page 19 for usages
n (lc)	Exponent of polytropic expansion	Dimensionless	Z10.4	
n (lc)	Load factor	Dimensionless		
n (lc)	Revolutions per unit time	T^{-1}	Z10.2, Z10.6, Z10.12	
N (cap)	Normal force	MLT^{-2}		
N (cap)	Number, in general	Dimensionless	Z10.2, Z10.3, Z10.4, Z10.12	
p (lc)	Pressure; static pressure	$ML^{-1}T^{-2}$	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	
p (lc)	Geometric pitch (propellers)	Dimensionless		
P (cap)	Power	ML^2T^{-3}	Z10.2, Z10.3, Z10.6, Z10.12	
q (lc)	Dynamic pressure; impact pressure	$ML^{-1}T^{-2}$		
q (lc)	Quantity of heat per unit time	ML^2T^{-3}	Z10.4	
q (lc)	Quantity of heat per unit mass or per unit weight; specific quantity of heat	L^2T^{-2} (per unit mass) L (per unit weight)	Z10.4, Z10.12	
Q (cap)	Quantity of heat	ML^2T^{-2}	Z10.4, Z10.6, Z10.12	
Q (cap)	Torque (propellers and rotary-wing aircraft)	ML^2T^{-2}		
r (lc)	Radius	L	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	
R (cap)	Correlation coefficient (turbulence)	Dimensionless		Identification is to be made by suitable subscripts, superscripts, or indication of functional dependence
R (cap)	Gas constant	$ML^2T^{-2\theta^{-1}}$	Z10.4, Z10.6, Z10.12	
R (cap)	Range	L		
R (cap)	Reynolds number	Dimensionless	Z10.2, Z10.4	
R (cap)	Richness; equivalence ratio (combustion)	Dimensionless		Richness is >1 on the rich side of the stoichiometric mixture, and <1 on the lean side; use R_f, meaning richness of the fuel, when necessary to distinguish from other concepts connoted by R

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Symbol	Concept	Dimensions	Also Appears in Z10 Publication	Remarks
s (lc)	Entropy, per unit mass or per unit weight; specific entropy	$L^2T^{-2}\theta^{-1}$ (per unit mass) $L\theta^{-1}$ (per unit weight)	Z10.4, Z10.6, Z10.12	———
S (cap)	Entropy	$ML^2T^{-2}\theta^{-1}$	Z10.4, Z10.6, Z10.12	———
S (cap)	Area, surface or projected	L^2	Z10.6, Z10.12	Use A (cap) for cross-sectional area
t (lc)	Temperature, general	θ	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	Use θ (lc) for alternate
t (lc)	Thickness	L	Z10.2, Z10.4, Z10.8	———
t (lc)	Time	T	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	———
T (cap)	Temperature, absolute	θ	Z10.2, Z10.3, Z10.4, Z10.6, Z10.12	———
T (cap)	Thrust (propellers and rotary-wing aircraft)	MLT^{-2}	———	Use F (cap) for other types of thrust
u (lc)	Internal energy, per unit mass or per unit weight; specific internal energy	L^2T^{-2} (per unit mass) L (per unit weight)	Z10.4, Z10.6, Z10.12	———
u (lc)	Velocity, longitudinal component of	LT^{-1}	Z10.2, Z10.6	For consistency, designate other components by v, w; see V for velocity
U (cap)	Internal energy	ML^2T^{-2}	Z10.4, Z10.6, Z10.12	———
U (cap)	Heat transfer coefficient, over-all	$MT^{-3}\theta^{-1}$	Z10.4, Z10.12	———
U (cap)	Velocity, alternate for	LT^{-1}	———	———
v (lc)	Velocity, lateral component of	LT^{-1}	Z10.2, Z10.6	See remarks for u
v (lc)	Volume, per unit mass or per unit weight; specific volume	$M^{-1}L^3$ (per unit mass) $M^{-1}L^2T^2$ (per unit weight)	Z10.4, Z10.6, Z10.12	———
V (cap)	Velocity	LT^{-1}	Z10.2, Z10.4, Z10.12	Use U (cap) for alternate; use subscripts for components (e.g., V_x, V_y, V_z); see also u, v, w for velocity components
V (cap)	Volume	L^3	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	———
w (lc)	Velocity, normal component of; magnitude of velocity vector	LT^{-1}	Z10.2, Z10.6	———
w (lc)	Weight flow, per unit time; mass-flow rate	MLT^{-3}	Z10.4, Z10.12	———
W (cap)	Weight	MLT^{-2}	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8	———
x, y, z (lc)	Coordinate system; earth-bound axes	———	———	Use plain, prime, and double prime to provide further coordinate systems; see also ξ, η, ζ and X, Y, Z
X (cap)	Isentropic factor	Dimensionless	Z10.4	———
X, Y, Z (cap)	Coordinate system; aircraft axes	———	———	Use plain (aircraft body axes), prime (trajectory axes, X' being along trajectory, and Y' being transverse horizontal), and double prime to provide further coordinate systems; see also ξ, η, ζ and x, y, z
z (lc)	Altitude, alternate for	L	———	———
α (lc)	Angle of attack	Dimensionless	———	———
α (lc)	Angular acceleration	T^{-2}	Z10.2, Z10.3, Z10.6, Z10.8	———
α (lc)	Diffusivity, thermal	L^2T^{-1}	———	———
β (lc)	Angle	Dimensionless	Z10.6, Z10.12	———
β (lc)	Angle of sideslip	Dimensionless	———	———
β (lc)	Blade angle (propellers)	Dimensionless	———	———
γ (lc)	Ratio of specific heats	Dimensionless	Z10.4, Z10.6, Z10.12	———
γ (lc)	Strain, shear	Dimensionless	Z10.3, Z10.8	———

Symbol	Concept	Dimensions	Also Appears in Z10 Publication	Remarks
Γ (cap)	Circulation; strength of a single vortex	L^2T^{-1}	———	———
Γ (cap)	Dihedral angle	Dimensionless	———	———
δ (lc)	Boundary layer thickness	L	———	See θ (lc) for momentum thickness of boundary layer
δ (lc)	Displacement, angular, of control surface	Dimensionless	———	———
δ (lc)	Relative pressure	Dimensionless	———	Ratio of a pressure to the standard pressure of atmospheric air at sea level
ϵ (lc)	Angle of downwash	Dimensionless	———	———
ϵ (lc)	Error signal	Dimensionless	———	———
ϵ (lc)	Strain, normal	Dimensionless	Z10.3, Z10.8	———
ϵ (lc)	Turbulence exchange coefficient	$ML^{-1}T^{-1}$	———	———
ϵ (lc)	Emissivity (for radiant heat)	Dimensionless	Z10.4, Z10.6, Z10.12	———
ξ, η, ζ (lc)	Coordinate system; inertial axes	———	———	Use plain, prime, and double prime to provide further coordinate systems; see also x, y, z and X, Y, Z
η (lc)	Efficiency	Dimensionless	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	———
η_r (lc)	Recovery factor	Dimensionless	———	———
θ (lc)	Angle	Dimensionless	Z10.6	See diagram, page 11
θ (lc)	Momentum thickness of boundary layer	L	———	———
θ (lc)	Temperature, alternate for	θ	Z10.4, Z10.6	Use t (lc) if possible
θ (lc)	Temperature ratio	Dimensionless	———	Ratio of an absolute temperature to the standard absolute temperature for atmospheric air at sea level
λ (lc)	Damping factor	T^{-1}	Z10.6	Used in $e^{-\lambda t}$
λ (lc)	Mean free path	L	———	———
λ (lc)	Microscale (turbulence)	L	———	Associated with turbulence decay
λ (lc)	Nozzle divergence factor	Dimensionless	Z10.6	The theoretical ratio of thrust of a diverging nozzle to the thrust without divergence of the flow
λ (lc)	Taper ratio	Dimensionless	———	In any given tapered wing element, the ratio of chord at the tip end to chord at the root end
λ (lc)	Wave length	L	Z10.3, Z10.4, Z10.6	———
Λ (cap)	Sweepback angle	Dimensionless	———	———
μ (lc)	Mach angle	Dimensionless	———	$\mu = \sin^{-1} \frac{1}{M}$
μ (lc)	Viscosity, absolute; viscosity, coefficient of	$ML^{-1}T^{-1}$	Z10.2, Z10.4, Z10.12	———
μ (lc)	Poisson's ratio	Dimensionless	Z10.3	———
ν (lc)	Kinematic viscosity	L^2T^{-1}	Z10.2, Z10.4, Z10.6, Z10.12	$\nu = \frac{\mu}{\rho}$
ρ (lc)	Density	ML^{-3}	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	Such that $\frac{1}{2}\rho V^2$ = pressure
σ (lc)	Angle of sidewash	Dimensionless	———	———
σ (lc)	Relative density	Dimensionless	———	Ratio of a density to the standard density of atmospheric air at sea level
σ (lc)	Solidity (propellers)	Dimensionless	———	———
σ (lc)	Stress, normal; stress (intensity)	$ML^{-1}T^{-2}$	Z10.2, Z10.3	———
τ (lc)	Stress, shearing	$ML^{-1}T^{-2}$	Z10.2, Z10.3	———
τ (lc)	Time, alternate for	T	Z10.4, Z10.6, Z10.12	Use t (lc) if possible

Symbol	Concept	Dimensions	Also Appears in Z10 Publication	Remarks
ϕ (lc)	Angle	Dimensionless	———	See diagram below
ϕ (lc)	Potential function	Dependent on definition	———	———
ϕ (lc)	Helical angle of advance (propellers)	Dimensionless	———	———
ψ (lc)	Angle; effective helix angle	Dimensionless	———	See diagram below
ψ (lc)	Stream function	Dependent on definition	———	———
ω (lc)	Angular velocity; circular frequency	T^{-1}	Z10.2, Z10.3, Z10.4, Z10.6, Z10.8, Z10.12	———
Ω (cap)	Angular velocity, alternate for; vorticity	T^{-1}	———	If possible, use ω (lc) for angular velocity



Positive directions of axes and angles (forces and moments) are shown by arrows.
Taken from Report No. 474, National Advisory Committee for Aeronautics.

Letter Symbols for Secondary Concepts

Symbols for Use as Subscripts

Subscript Symbols	Concept	Remarks
a (lc)	Absolute	
	Added; additional	
	Adiabatic	See also *ad* (lc) for alternate; use *aw* (lc) for adiabatic wall
	Aileron	
	Air; relative to air	
	Allowable	
	Ambient	See *am* (lc) for alternate
	Available	
ad (lc)	Adiabatic, alternate for	
am (lc)	Ambient, alternate for	
av (lc)	Average	See also *m* (lc) for mean
b (lc)	Base	
	Basis	
	Bending	
	Blade	
	Burner; burnt	
bar (lc)	Barometric	
B (cap)	Body	See also *f* (lc) for fuselage
c (lc)	Calibrated	Use *cal* (lc) for alternate
	Chord	
	Combustion; combustion chamber	Use *b* (lc) for combustion chamber in gas-turbine power plants to distinguish from *c* (lc) for compressor
	Compressibility, compressible, compression, compressor	
	Coolant	
	Critical	Use *cr* (lc) for alternate
cal (lc)	Calibrated, alternate for	
calc (lc)	Calculated	
cg (lc)	Center of gravity	
corr (lc)	Corrected	
cp (lc)	Center of pressure	
cr (lc)	Critical, alternate for	
C (cap)	Cross-wind	Perpendicular to plane of lift and drag
Ca	Cauchy (number)	
d (lc)	Damping, general	Replace by symbol indicating axis or angular velocity, when possible
	Diffuser; duct	
	Discharge	Use only for the discharge coefficients of nozzles and orifices
	Dry	

Subscript Symbols	Concept	Remarks
D (cap)	Drag	
e (lc)	Effective	Use *eff* (lc) as alternate
	Elevator	
	Endurance	
	Engine	
	Equivalent	
	Exhaust; exhaust nozzle; exit	
eff (lc)	Effective, alternate for	
Eu	Euler (number)	
f (lc)	Fin	
	Flap; flipper	
	Fluid; liquid phase	See *l* (lc) for alternate
	Friction; friction factor	
	Fuel	
	Fuselage; body	See also *B* (cap) for body
F (cap)	Force; thrust	See also *T* (cap) for thrust
	Frontal	
Fr	Froude (number)	
g (lc)	Gage	
	Gas; combustion gases; exhaust gas	
	Gross	May require care in definition
Gr	Grashof (number)	
Gz	Graetz (number)	
h (lc)	Heat; heat exchanger	
	Hinge	
	Horizontal	
	Hub	See also *r* (lc) for root
H (cap)	Higher	Use primarily as applied to heat of combustion
i (lc)	Incidence (angle)	
	Ideal	
	Indicated; observed	
	Induced	
	Inlet; intake; input	
	Inner; internal	
	Interference	
j (lc)	Jet	May require care in definition
k (lc)	Kinetic	
l (lc)	Liquid phase, alternate for	If italicized symbol is not available, it is recommended that the script ell be used
	Local condition, just outside boundary layer	
	Lower (surface)	
lam (lc)	Laminar	

Subscript Symbols	Concept	Remarks
lat (lc)	Lateral	
L (cap)	Landing conditions	
	Level	
	Lift	
	Lower	Use primarily as applied to heat of combustion
m (lc)	Mean	See also *av* (lc) for average
max (lc)	Maximum	
min (lc)	Minimum	
M (cap)	Moment, in general	
Ma	Mach (number)	When used as a subscript this double-letter form is recommended for consistency with designations for other dimensionless numbers
n (lc)	Net	May require care in definition
	Nozzle	
N (cap)	Normal (perpendicular to longitudinal axis); normal (force)	
Nu	Nusselt (number)	
o (lc)	Initial	
	Outer	
	Oxidizer	See *ox* (lc) for alternate
	Profile (drag)	
	Standard or reference condition; standard sea-level conditions	See superscript asterisk (*) for characteristic or reference value; see *sl* (lc) for alternate for sea-level conditions
	Zero lift	
ox (lc)	Oxidizer, alternate for	
p (lc)	Parasite; parasitic	See *para* (lc) for alternate
	Potential	
	Pressure, based on	
	Profile	
	Propellant; propeller; propulsive; tailpipe	
para (lc)	Parasite, alternate for	
P (cap)	Power	
Pe	Peclet (number)	
Pr	Prandtl (number)	
Q (cap)	Torque (propellers and rotary-wing aircraft)	See also *M* (cap) for moment
r (lc)	Radial	
	Ram	May require care in definition
	Recovery	
	Relative	
	Root	
	Rotor; rotational	See *R* (cap) for alternate
	Rudder	
R (cap)	Resultant	
	Rotor, alternate for; rotational, alternate for	
Re	Reynolds (number)	
s (lc)	Shaft	
	Shear	
	Slipstream	
	Speed-power	
	Stabilizer	
	Surface, alternate for	
sl (lc)	Standard sea-level, alternate for	
sp (lc)	Specific	
std (lc)	Standard, alternate for	
S (cap)	Stall conditions	
St	Stanton (number)	
t (lc)	Tail	
	Tangential	
	Tensile	
	Throat	See *th* (lc) for alternate
	Tip	
	Total; isentropic stagnation conditions	See also superscript zero (0)
	Turbine	
th (lc)	Theoretical	
	Throat, alternate for	
turb (lc)	Turbulent	
T (cap)	Take-off and terminal velocity conditions	
	Thrust (for propellers and rotary-wing aircraft)	See also *F* (cap) for force; thrust
	Tunnel	
u (lc)	Ultimate	
	Upper (surface)	
v (lc)	Vertical	
	Vapor	
vol (lc)	Volumetric	
w (lc)	Wall; surface	See *s* (lc) for alternate
	Wing	
We	Weber (number)	
W (cap)	Wave	
xs (lc)	Excess	
y (lc)	Yield	
δ (lc)	Boundary-layer thickness, based on	
ρ (lc)	Density, based on	
σ (lc)	Condition which applies immediately after shock	
0,1,2,3,4....	Station subscripts	
∞	Undisturbed; free-stream	

Symbols for Use as Superscripts

Superscript Symbol	Concept	Remarks
˙(Dot)	First derivative, with respect to time	These symbols are written over, not after, the principal symbol to which they are applied
¨(Double dot)	Second derivative, with respect to time	
′(Prime)	First derivative, with respect to distance; effective or precise value	Used in turbulent-flow analysis to identify a turbulent-velocity component. *e.g.*, $u' = u - \bar{u}$; also used to designate the pressure measured by a total-head tube in a supersonic stream, *e.g.*, P_t'
″(Double prime)	Second derivative, with respect to distance	Commonly used for value per unit area
− (Bar)	Mean value	This symbol is written over, not after, the principal symbol to which it is applied
+(Plus)	A dimensionless measure of the quantity considered	Commonly used for boundary-layer flow and for flow in pipes
0(Zero)	Total; isentropic stagnation conditions	See also subscript *t* (lc)
*(Asterisk)	Characteristic or reference value; critical conditions at $M=1$	As applied to u (lc) — friction velocity (u^*); as applied to δ (lc) — displacement thickness of boundary layer (δ^*)

Appendix

This Appendix is not a part of the American Standard Letter Symbols for Aeronautical Sciences, Z10.7-1950, but is included to assist in the use of the standard.

Alphabetical Index by Concepts

Concept	Principal Symbols	Subscript Symbols	Superscript Symbols
Absolute	—	a	—
Acceleration, angular	α	—	—
Acceleration due to gravity	g	—	—
Added; additional	—	a	—
Adiabatic	—	a, ad	—
Adiabatic wall	—	aw	—
Advance, helical angle of (propellers)	ϕ	—	—
Advance ratio (propellers)	J	—	—
Aileron	—	a	—
Air; relative to air	—	a	—
Airplane	—	A	—
Allowable	—	a	—
Altitude	h, z	—	—
Ambient	—	a, am	—
Angle	α, β, θ, ϕ, ψ	—	—
Angle of attack	α	—	—
Angle of blade (propellers)	β	—	—
Angle, dihedral	Γ	—	—
Angle of downwash	ϵ	—	—
Angle, effective helix	ψ	—	—
Angle, helical, of advance (propellers)	ϕ	—	—
Angle, Mach	μ	—	—
Angle of sideslip	β	—	—
Angle of sidewash	σ	—	—
Angle of sweepback	Λ	—	—
Angular acceleration	α	—	—
Angular momentum	H	—	—
Angular velocity; circular frequency	ω, Ω	—	—
Area, cross-sectional	A	—	—
Area, surface or projected	S	—	—
Aspect ratio	A, AR	—	—
Available	—	a	—
Average	—	av	—
Barometric	—	bar	—
Base	—	b	—
Basic	—	b	—
Bending	—	b	—
Blade	—	b	—
Blade angle (propellers)	β	—	—
Blade width (propellers)	b	—	—
Body	—	B, f	—
Boundary layer, displacement thickness of	δ^*	—	—
Boundary layer, momentum thickness of	θ	—	—
Boundary-layer thickness	δ	δ	—
Burner, burnt	—	b	—
Calculated	—	$calc$	—
Calibrated	—	c, cal	—
Cauchy (number)	—	Ca	—
Center of gravity	—	cg	—

Concept	Principal Symbols	Subscript Symbols	Superscript Symbols
Center of pressure	—	cp	—
Chamber, combustion	—	c	—
Characteristic or reference value	—	—	* (asterisk)
Chord, of an airfoil	c	c	—
Circular frequency	ω	—	—
Circulation; strength of a single vortex	Γ	—	—
Coefficient	C, c	—	—
Coefficient, section	c	—	—
Coefficient, turbulence correlation	R	—	—
Combustion; combustion chamber	—	c	—
Combustion gases	—	g	—
Compressible; compressibility; compressor; compression	—	c	—
Components, force	—	See footnote	—
Components, velocity	u, v, w	See footnote	—
Concentration	C	—	—
Conductivity, thermal	k	—	—
Coolant	—	c	—
Coordinate system; aircraft axes	X, Y, Z	—	—
Coordinate system; earth-bound axes	x, y, z	—	—
Coordinate system; inertial axes	ξ, η, ζ	—	—
Correlation coefficient (turbulence)	R	—	—
Correlation length (turbulence)	L	—	—
Corrected	—	cor	—
Critical	—	c, cr	—
Cross-sectional area	A	—	—
Cross-wind	—	C	—
Damping (general)	—	d	—
Damping factor	λ	—	—
Density	ρ	ρ	—
Density, relative	σ	—	—
Derivative, first, with respect to distance	—	—	′ (prime)
Derivative, first, with respect to time	—	—	· (dot)
Derivative, second, with respect to distance	—	—	″ (double prime)
Derivative, second, with respect to time	—	—	¨ (double dot)
Diameter	d, D	—	—
Diffuser	—	d	—
Diffusivity, thermal	α	—	—
Dihedral angle	Γ	—	—
Dimensionless measure of the quantity considered (boundary-layer flow; flow in pipes)	—	—	+ (plus)

NOTE: Axis designations for particular coordinate systems may be used to connote direction (e.g., F_X, F_Y, F_Z; V_x, V_y, V_z).

Concept	Principal Symbols	Subscript Symbols	Superscript Symbols
Discharge	—	d	—
Displacement, angular, of control surface	δ	—	—
Displacement thickness of boundary layer	δ^*	—	—
Distance; length	l	—	—
Divergence factor of a nozzle	λ	—	—
Downwash, angle of	ϵ	—	—
Drag	D	D	—
Dry	—	d	—
Duct	—	d	—
Dynamic pressure; impact pressure	q	—	—
Effective	—	e or eff	—
Effective or precise value	—	—	′(prime)
Effectiveness, span	e	—	—
Efficiency	η	—	—
Elasticity, modulus of; Young's modulus	E	—	—
Elevator	—	e	—
Emissivity (for radiant heat)	ϵ	—	—
Endurance	—	e	—
Energy	E	—	—
Engine	—	e	—
Enthalpy, per unit mass or per unit weight; specific enthalpy	h	—	—
Enthalpy; total heat content	H	—	—
Entropy	S	—	—
Entropy, per unit weight; specific entropy	s	—	—
Equivalence ratio; richness (combustion)	R or R_f	—	—
Equivalent	—	e	—
Error signal	ϵ	—	—
Euler (number)	—	Eu	—
Excess	—	xs	—
Exchanger, heat	—	h	—
Exhaust; exhaust nozzle	—	e	—
Exhaust gas	—	g	—
Exit	—	e	—
Exponent of polytropic expansion	n	—	—
Factor, for comparison purposes	K	—	—
Factor, friction	—	f	—
Fin	—	f	—
Flap	—	f	—
Flipper	—	f	—
Fluid	—	f	—
Force	F	F	—
Force components	—	See footnote	—
Force, normal	N	—	—
Free-stream; undisturbed	—	∞	—
Frequency	f	—	—
Frequency, circular; angular velocity	ω or Ω	—	—
Frequency, reduced	k	—	—
Friction; friction factor	—	f	—
Friction velocity	u^*	—	—
Frontal	—	F	—
Froude (number)	N_{Fr}	Fr	—
Fuel	—	f	—
Fuselage	—	f	—
Gage	—	g	—
Gas; combustion gases; exhaust gas	—	g	—
Gas constant	R	—	—
Geometric pitch (propellers)	p	—	—
Graetz (number)	N_{Gz}	Gz	—
Grashof (number)	N_{Gr}	Gr	—
Gravity, acceleration due to	g	—	—
Gravity, center of	—	cg	—
Gross	—	g	—
Gyration, radius of	k	—	—
Heat; heat exchanger	—	h	—
Heat-flow rate, per unit area, per degree, across a boundary surface	h	—	—
Heat-flow rate, per unit time	q	—	—
Heat transfer coefficient, over-all	U	—	—
Helical angle of advance (propellers)	ϕ	—	—
Higher	—	H	—
Hinge	—	h	—
Horizontal	—	h	—
Hub	—	h	—
Ideal	—	i	—
Impact pressure; dynamic pressure	q	—	—
Impulse	I	—	—
Incidence (angle)	—	i	—
Indicated; observed	—	i	—
Induced	—	i	—
Inertia, moment of	I	—	—
Inertia, polar moment of	J	—	—
Initial	—	0	—
Inlet	—	i	—
Inner	—	i	—
Input	—	i	—
Intake	—	i	—
Interference	—	i	—
Internal	—	i	—
Internal energy	U	—	—
Internal energy, per unit mass or per unit weight; specific internal energy	u	—	—
Isentropic factor	X	—	—
Isentropic stagnation conditions; total	—	t	0 (zero)
Jet	—	j	—
Joule's constant; mechanical equivalent of heat	J	—	—
Kinematic viscosity	ν	—	—
Kinetic	—	k	—
Laminar	—	lam	—
Landing (conditions)	—	L	—
Lateral	—	lat	—
Length; distance	l	—	—
Length correction (turbulence)	L	—	—
Level	—	L	—
Lift	L	L	—
Lift curve, slope of	a	—	—
Lift, zero	—	0	—
Liquid phase	—	l	—
Load factor	n	—	—
Local conditions, just outside boundary layer	—	l	—
Lower	—	L	—
Lower (surface)	—	l	—
Mach angle	μ	—	—
Mach number	M or N_{Ma}	Ma	—
Mass	m	—	—
Mass-flow, per unit cross-sectional area, per unit time; mass velocity	G	—	—
Mass-flow rate; weight flow, per unit time	w	—	—
Mass velocity; mass-flow, per unit cross-sectional area, per unit time	G	—	—

NOTE: Axis designations for particular coordinate systems may be used to connote direction (e.g., F_X, F_Y, F_Z).

Concept	Principal Symbols	Subscript Symbols	Superscript Symbols
Maximum		*max*	
Mean		*m*	— (bar)
Mean free path	λ		
Mean velocity component (turbulent flow)			— (bar)
Measure (dimensionless) of the quantity considered (boundary-layer flow; flow in pipes)			+ (plus)
Mechanical equivalent of heat; Joule's constant	J		
Microscale, turbulence	λ		
Minimum		*min*	
Modulus of elasticity; Young's modulus	E		
Modulus, shear	G		
Moment	M	M	
Moment of inertia	I		
Moment of inertia, polar	J		
Momentum, angular	H		
Momentum thickness of boundary layer	θ		
Net		*n*	
Normal (perpendicular to longitudinal axis)		N	
Normal force	N	N	
Normal strain	ϵ		
Normal stress; stress (intensity)	σ		
Nozzle		*n*	
Nozzle, exhaust		e	
Nozzle divergence factor	λ		
Number; in general	N		
Numbers:			
Cauchy	N_{Ca}	*Ca*	
Euler	N_{Eu}	*Eu*	
Froude	N_{Fr}	*Fr*	
Graetz	N_{Gz}	*Gz*	
Grashof	N_{Gr}	*Gr*	
Mach	M or N_{Ma}	*Ma*	
Nusselt	N_{Nu}	*Nu*	
Peclet	N_{Pe}	*Pe*	
Prandtl	N_{Pr}	*Pr*	
Reynolds	R or N_{Re}	*Re*	
Stanton	N_{St}	*St*	
Weber	N_{We}	*We*	
Nusselt (number)	N_{Nu}	*Nu*	
Observed; indicated		*i*	
Outer		o	
Oxidizer		*o* or *ox*	
Parasite; parasitic		*p* or *para*	
Peclet (number)	N_{Pe}	*Pe*	
Phase, liquid		*l* or *f*	
Pitch, geometric (propellers)	p		
Poisson's ratio	μ		
Polar moment of inertia	J		
Polytropic expansion, exponent of	n		
Potential		p	
Potential function	ϕ		
Power	P	P	
Prandtl number	N_{Pr}	*Pr*	
Precise or effective value			′ (prime)
Pressure	p	p	
Pressure, center of		cp	
Pressure, dynamic; impact pressure	q		
Pressure, relative	δ		
Pressure, static	p		

Concept	Principal Symbols	Subscript Symbols	Superscript Symbols
Pressure, total-head (measured by total-head tube)			′ (prime)
Profile		o	
Projected area; surface area	S		
Propellant		*p*	
Propeller		*p*	
Propulsive		*p*	
Quantity of heat	Q		
Quantity of heat per unit time	q		
Quantity of heat per unit mass or per unit weight; specific quantity of heat	q		
Radial		*r*	
Radius	r		
Radius of gyration	k		
Ram		*r*	
Range	R		
Ratio of specific heats	γ		
Recovery		*r*	
Recovery factor	η_r		
Reduced frequency	k		
Reference (or standard) conditions		o	
Reference (or characteristic) value			* (asterisk)
Relative		*r*	
Relative to air		*a*	
Relative density	σ		
Relative pressure	δ		
Resultant		*R*	
Revolutions, per unit time	n		
Reynolds number	R or N_{Re}	Re	
Richness; equivalence ratio (combustion)	R or R_f		
Root		*r*	
Rotor; rotational		*r* or *R*	
Rudder		*r*	
Scale, turbulence	L		
Section coefficient	c		
Shaft		*s*	
Shear		*s*	
Shear modulus	G		
Shear strain	γ		
Shearing stress	τ		
Shock, condition which applies immediately after		σ	
Sideslip, angle of	β		
Sidewash, angle of	σ		
Slipstream		*s*	
Slope of lift curve	a		
Solidity (propellers)	σ		
Sound, velocity of	a or c		
Span	b		
Span effectiveness	e		
Specific		*sp*	
Specific enthalpy; enthalpy per unit weight	h		
Specific entropy; entropy per unit weight	s		
Specific heat, at constant pressure	c_p		
Specific heat, at constant volume	c_v		
Specific heats, ratio of	γ		
Specific internal energy; internal energy, per unit weight	u		
Specific quantity of heat; quantity of heat per unit weight	q		

Concept	Principal Symbols	Subscript Symbols	Superscript Symbols
Specific volume; volume per unit weight	v	—	—
Speed-power	—	s	—
Stabilizer	—	s	—
Stagnation conditions, isentropic	—	t	^{0} (zero)
Stall conditions	—	S	—
Standard (or reference) conditions	—	o, std	—
Standard sea-level conditions	—	o, sl	—
Static pressure	p	—	—
Station subscripts	—	0,1,2,3,4,...	—
Stanton number	N_{St}	St	—
Strain, normal	ϵ	—	—
Strain, shear	γ	—	—
Stream function	ψ	—	—
Stream thrust; thrust (combustion)	F	—	—
Stress, normal; stress (intensity)	σ	—	—
Stress, shearing	τ	—	—
Surface	—	w, s	—
Surface area; projected area	S	—	—
Sweepback angle	Λ	—	—
Tail	—	t	—
Tailpipe	—	p	—
Take-off conditions	—	T	—
Tangential	—	t	—
Taper ratio	γ	—	—
Temperature, absolute	T	—	—
Temperature, general	t, θ	—	—
Temperature ratio	θ	—	—
Tensile	—	t	—
Terminal-velocity conditions	—	T	—
Theoretical	—	th	—
Thermal conductivity	k	—	—
Thermal diffusivity	α	—	—
Thickness	t	—	—
Thickness of boundary layer	δ	δ	—
Thickness (displacement) of boundary-layer	δ^*	—	—
Thickness (momentum) of boundary layer	θ	—	—
Throat	—	t, th	—
Thrust; steam thrust (combustion)	F	F	—
Thrust (propellers and rotary-wing aircraft)	T	T	—
Time	t, τ	—	—
Tip	—	t	—
Torque (propellers and rotary-wing aircraft)	—	Q	—
Total; isentropic stagnation conditions	—	t	^{0} (zero)
Total-head pressure (measured by total-head tube)	—	—	$'$ (prime)
Tunnel	—	T	—
Turbine	—	t	—
Turbulence correlation coefficient	R	—	—

Concept	Principal Symbols	Subscript Symbols	Superscript Symbols
Turbulence exchange coefficient	ϵ	—	—
Turbulence microscale	λ	—	—
Turbulence scale	L	—	—
Turbulent	—	$turb$	—
Turbulent-velocity component, particular	—	—	$'$ (prime)
Ultimate	—	u	—
Undisturbed; free-stream	∞	—	—
Upper (surface)	—	u	—
Vapor	—	v	—
Velocity	V, U	—	—
Velocity, angular; circular frequency	ω, Ω	—	—
Velocity components	u, v, w	See footnote	—
Velocity (mean) component (turbulent flow)	—	—	$-$ (bar)
Velocity (turbulent) component, particular	—	—	$'$ (prime)
Velocity, friction	u^*	—	—
Velocity, lateral component of	v	—	—
Velocity, longitudinal component of	u	—	—
Velocity, normal component of	w	—	—
Velocity, mass; mass-flow, per unit cross-sectional area, per unit time	G	—	—
Velocity of sound	a, c	—	—
Velocity (conditions), terminal	—	T	—
Velocity vector, magnitude of	w	—	—
Vertical	—	v	—
Viscosity, absolute; viscosity, coefficient of	μ	—	—
Viscosity, coefficient of; absolute viscosity	μ	—	—
Viscosity, kinematic	ν	—	—
Volume	V	—	—
Volume, per unit mass or per unit weight; specific volume	v	—	—
Volumetric	—	vol	—
Vortex, strength of a single; circulation	Γ	—	—
Vorticity	Ω	—	—
Wall; surface	—	w	—
Wave	—	W	—
Wavelength	λ	—	—
Weber (number)	N_{We}	We	—
Weight	W	—	—
Weight per unit time; mass-flow rate	w	—	—
Width, blade (propellers)	b	—	—
Wing	—	w	—
Yield	—	y	—
Young's modulus; modulus of elasticity	E	—	—
Zero lift	—	o	—

NOTE: Axis designations for particular coordinate systems may be used to connote direction (*e.g.*, V_x, V_y, V_z).

Recommended Designations for Forces, Moments, Coefficients, etc

Concept	Designation commonly used in the past	Recommended Designation
Force	F	F
Momcnt	M	M
Airplane axes	X, Y, Z	X, Y, Z
Angle of pitch	θ	θ
Angle of roll	ϕ	ϕ
Angle of yaw	ψ	ψ
Pitch velocity	q	$\dot{\theta}$
Roll velocity	p	$\dot{\phi}$
Yaw velocity	r	$\dot{\psi}$
Force components	$\begin{cases} F_X F_Y F_Z \\ L\ D\ N \end{cases}$	$\begin{cases} F_X F_Y F_Z \\ L\ D\ N \end{cases}$
Moment component (pitch, roll, yaw)	$M\ L\ N$	$M_\theta M_\phi M_\psi$
Force coefficients	$C_L\ C_D\ C_N$	$\begin{cases} C_X C_Y C_Z \\ C_L C_D C_N \end{cases}$
Moment coefficients	$C_m\ C_l\ C_n$	$C_\theta C_\phi C_\psi$
Contribution of a constant pitch angle	$C_{m\theta}$	$C_{\theta\theta}$
Contribution of a constant roll velocity	$C_{lp}\ C_{np}$	$C_{\phi\dot{\phi}}\quad C_{\psi\dot{\phi}}$
Contribution of a constant yaw velocity	$C_{lr}\ C_{nr}$	$C_{\phi\dot{\psi}}\quad C_{\psi\dot{\psi}}$
Helix angle in roll	$\frac{pb}{2v}$	$\frac{\dot{\phi}b}{2v}$

Addendum to Section 1 of Volume 1 of the Handbook of Supersonic Aerodynamics, NAVORD REPORT 1488

In Section 1, Symbols and Nomenclature, of Volume 1 there appears a verbatim reproduction of the American Standard Letter Symbols for Aeronautical Sciences. On the last page of this list of Letter Symbols (page 1-20 of the Handbook) there appears a list of "Recommended Designations for Forces, Moments, Coefficients, etc," about which the American Standards Association comments in its Foreword to the above mentioned Standard as follows:

> "The subject of moment designations, moment-coefficient designations, etc. is definitely controversial, but the subcommittee has agreed to recommend a system (see page 19)."

It appears that this list of Recommended Designations has been variously interpreted, and therefore the Handbook Reviewing Committee and Handbook Staff have prepared a table which they believe indicates the interpretation that was intended by the compilers of the original list. This interpretation is given on the reverse side of this sheet, and it is suggested that this sheet be inserted opposite page 1-20 of Volume 1.

OLD AND NEW DESIGNATIONS FOR FORCES, MOMENTS, COEFFICIENTS, ETC.

(An interpretation of the "Recommended Designations" appearing on page 1-20 of the Handbook of Supersonic Aerodynamics, NAVORD REPORT 1488, Vol. 1)

1. Using Airplane or Missile Axes (See page 1-12)

	Old			New		
Axes	X	Y	Z	X	Y	Z
Force components along axes	F_X or X	F_Y or Y	F_Z or Z	F_X	F_Y	F_Z
Force coefficients	C_X	C_Y or $-C_N$	C_Z or $-C_N$	C_X	C_Y	C_Z
Velocity components along axes	u	v	w	u	v	w
Rotation about axes (roll, pitch and yaw)	ϕ	θ	ψ	ϕ	θ	ψ
Rotational velocity about axes	p	q	r	$\dot{\phi}$	$\dot{\theta}$	$\dot{\psi}$
Moments about axes	L	M	N	M_ϕ	M_θ	M_ψ
Moment coefficients	C_l	C_m	C_n	C_ϕ	C_θ	C_ψ

2. Using Wind Axes

	Old			New		
Force components (drag, cross-wind force, lift)	D	C	L	D	C	L
Force coefficients	C_D	C_C	C_L	C_D	C_C	C_L

3. Other Usages for Primary Symbols

In accordance with the foregoing lists of new symbols it is recommended that the appropriate new symbol for the primary concept be used in the appropriate formula. For example, instead of using $\frac{pb}{2v}$ for the helix angle in roll, the recommended formula is $\frac{\dot{\phi}b}{2u}$.

4. Symbols for Subscripts

In accordance with the foregoing lists of new symbols involving subscripts, it is recommended that the appropriate new symbol for the primary concept be used as a subscript, or double subscript, instead of the old primary symbol. For example, instead of using C_{l_r} to indicate the contribution of yaw velocity to the rolling moment coefficient, the recommended symbol is $C_{\phi\dot{\psi}}$.

American Standards

The standard in this booklet is one of more than 1100 American Standards approved to date.

These standards represent in each case general agreement on the part of maker, seller, and user groups as to the best current industrial practice with regard to some specific problem. The completed standards cut across the whole fabric of production. Manufacturers, consumers, technical, and governmental agencies are represented on the committees which set up these standards. Many hundreds of groups throughout the country are taking part in the work and the completed standards are used widely by industry, municipal, state, and federal governments.

The American Standards Association, Incorporated, under whose auspices this work is being done, is a federation of 100 trade associations, technical societies, and consumer organizations maintained by industry as a clearinghouse for standards and to promote their development and use.

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SECTION 2 - FUNDAMENTAL EQUATIONS AND FORMULAE

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SECTION 2 - FUNDAMENTAL EQUATIONS AND FORMULAE

SYMBOLS

The following symbols are used in the material appearing on pages 2.1-2.35 of Section 2.

a = velocity of sound

A = area; also a factor of proportionality, as in $p = A\rho^{\gamma}$

A, B = successive states of a gas, as in $\int_A^B dQ/T$

$\vec{A}$ = a general vector function

c_p = specific heat at constant pressure

c_v = specific heat at constant volume

e = base of natural logarithms

E = internal energy

e_1, e_2, e_3 = quantities defined by the equation $ds^2 = e_1^2\, d\theta_1^2 + e_2^2\, d\theta_2^2 + e_3^2\, d\theta_3^2$ where ds is the differential element of length and $d\theta_1$, $d\theta_2$, $d\theta_3$ are differentials of the coordinates in a general orthogonal coordinate system.

g = acceleration due to gravity

h = enthalpy

K = a constant of integration

l = length

m = mass flow rate; also mass

$\overset{o}{m}$ = mass flow function

M = Mach number

M^* = q/a^*

N = molecular weight

p = pressure

q = magnitude of the velocity

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q = the velocity vector

$\hat{q}$ = ultimate or limiting speed

q_n = normal component of velocity

q_r = radial component of velocity

q_t = tangential component of velocity

Q = heat

r = radial coordinate of a point (see Fig. 2.10)

$\bar{r}$ = a particular value of r (see Fig. 2.10)

s = length along a curve

S = entropy

t = time

T = temperature

u, v, w = x-, y-, z-components, respectively, of velocity

v = y-component of velocity; also specific volume $1/\rho$

V = volume

W = work

x, y, z = the rectangular coordinates of a point

X, Y, Z = x-, y-, z-components, respectively, of the external force acting on a unit mass.

α = angular coordinate in cylindrical and spherical coordinates

β = angle between a shock front and the flow before the shock

γ = ratio of specific heats

Γ = circulation

$\delta = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = \text{div } \vec{q}$

Δ = increment, thus $\Delta p = p_2 - p_1$

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

θ = the angle between the direction of flow and a selected reference direction; also the co-altitude angle in spherical coordinates.

θ_1, θ_2, θ_3 = general orthogonal curvilinear coordinates

$\vec{\theta_1}$, $\vec{\theta_2}$, $\vec{\theta_3}$ = unit vectors in the direction of increase of θ_1, θ_2, and θ_3, respectively

Θ = flow density

μ = absolute coefficient of viscosity; also Mach angle.

ρ = density

σ = strength of a source distribution

Σ = a boundary surface

ϕ = the velocity potential; also the angle of expansion in the flow around a corner.

Φ = a general scalar function

ψ = the stream function

$\vec{\omega}$ = the vorticity vector (curl $\vec{q}$)

ω_x, ω_y, ω_z = the x-, y-, z-components, respectively, of the vorticity.

Subscripts:

In addition to the subscripts whose meanings are defined above, subscripts are used as follows:

Literal subscripts denote partial differentiation with respect to the indicated variable, thus $u_t = \partial u / \partial t$. Exceptions to this usage are found in the symbols list above.

Other subscripts denote the conditions indicated below:

- o stagnation state
- 1 value before a shock front
- 2 value after a shock front

The superscript * denotes critical value.

SECTION 2 - FUNDAMENTAL EQUATIONS AND FORMULAE

SUMMARY

Derivations and discussion of conditions under which the equations hold are to be found on pages 2.1-2.35.

Equations of Continuity for Source-Free Flow

$$\frac{1}{\rho}\frac{d\rho}{dt} + \operatorname{div}\vec{q} = 0 \qquad (2.1c)$$

For steady flow

$$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0 \qquad (2.1d)$$

The condition that a fluid be incompressible

$$\operatorname{div} q = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (2.1e)$$

One-dimensional case, compressible, steady flow.

$$\rho q A = \text{const.} \qquad (2.1f)$$

The Navier-Stokes Equations for a Viscous Fluid

$$\left.\begin{aligned} \frac{du}{dt} - X &= -\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{1}{3}\frac{\mu}{\rho}\frac{\partial \delta}{\partial x} + \frac{\mu}{\rho}\nabla^2 u \\ \frac{dv}{dt} - Y &= -\frac{1}{\rho}\frac{\partial p}{\partial y} + \frac{1}{3}\frac{\mu}{\rho}\frac{\partial \delta}{\partial y} + \frac{\mu}{\rho}\nabla^2 v \\ \frac{dw}{dt} - Z &= -\frac{1}{\rho}\frac{\partial p}{\partial z} + \frac{1}{3}\frac{\mu}{\rho}\frac{\partial \delta}{\partial z} + \frac{\mu}{\rho}\nabla^2 w \end{aligned}\right\} \qquad (2.2a)$$

To obtain the Euler equations for non-viscous flow, put $\mu = 0$ in Equations (2.2a).

Vector form of the Euler equations, unit mass force negligible

$$\vec{q}_t + \operatorname{grad}\frac{q^2}{2} - \vec{q} \times \operatorname{curl}\vec{q} = -\frac{1}{\rho}\operatorname{grad} p \qquad (2.2d)$$

The Vorticity ($\vec{\omega}$)

$\vec{\omega} = \text{curl } \vec{q}$. In rectangular coordinates,

$$\omega_x = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} \qquad \omega_y = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \qquad \omega_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \tag{2.3}$$

For the vorticity components in other coordinate systems, see Equation (2.29).

Thermodynamic Definitions and Relations

For a perfect gas

$$pV = \frac{m}{N} RT \tag{2.4a}$$

When the external pressure is equal to the fluid pressure

$$dQ = dE + pdV \tag{2.6a}$$

For a reversible transformation

$$TdS = dE + pdV \tag{2.6b}$$

For a perfect gas

$$dQ = c_V dT + pdV \tag{2.6c}$$

Adiabatic processes

$$p = A\rho^{\gamma} \tag{2.7c}$$

Definition of enthalpy, per unit mass

$$h = E + pv \tag{2.8a}$$

$$dh = dQ + vdp \tag{2.8b}$$

$$dh = TdS + vdp \tag{2.8c}$$

In adiabatic processes

$$dh = vdp = \frac{dp}{\rho} = \frac{p'(\rho)d\rho}{\rho} \tag{2.8d}$$

Bernoulli's Formulae

For steady, non-viscous, isentropic flow

$$\tfrac{1}{2}q^2 + h = \tfrac{1}{2}q_0^2 \tag{2.9b}$$

For isentropic, irrotational flow

$$\tfrac{1}{2}q^2 + \phi_t + h = \tfrac{1}{2}\hat{q}^2 \qquad (2.9c)$$

For an adiabatic process, perfect gas

$$\tfrac{1}{2}q^2 + \frac{\gamma}{\gamma - 1}\frac{p}{\rho} = \tfrac{1}{2}\hat{q}^2 = \frac{\gamma}{\gamma - 1}\frac{p_o}{\rho_o} \qquad (2.12a) \text{ and } (2.12b)$$

$$\hat{q} = \sqrt{\frac{2\gamma}{\gamma - 1}\frac{p_o}{\rho_o}} \qquad (2.13)$$

$$q^2 = \hat{q}^2\left[1 - \left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}}\right] \qquad (2.14)$$

$$a^* = \sqrt{\frac{\gamma - 1}{\gamma + 1}}\,\hat{q} = \sqrt{\frac{2\gamma}{\gamma + 1}}\left(\frac{p_o}{\rho_o}\right) = a_o\sqrt{\frac{2}{\gamma + 1}} \qquad (2.15)$$

$$a_o = \sqrt{\frac{\gamma - 1}{2}}\,\hat{q} = \sqrt{\gamma R T_o} \qquad (2.16)$$

$$\frac{p^*}{p_o} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma-1}} = 0.528 \qquad \text{for } \gamma = 1.400 \qquad (2.17)$$

$$\frac{\rho^*}{\rho_o} = \left(\frac{2}{\gamma + 1}\right)^{\frac{1}{\gamma-1}} = 0.634 \qquad \text{for } \gamma = 1.400 \qquad (2.18)$$

$$\frac{T^*}{T_o} = \left(\frac{2}{\gamma + 1}\right) = 0.833 \qquad \text{for } \gamma = 1.400 \qquad (2.19)$$

<u>The Mach Number and Mach Angle</u>

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

$$M^{*2} = \frac{(\gamma + 1)\,M^2}{(\gamma - 1)\,M^2 + 2} \qquad (2.20a)$$

$$M^2 = \frac{2M^{*2}}{(\gamma + 1) - (\gamma - 1) M^{*2}} = \frac{2q^2}{(\gamma + 1) a^{*2} - (\gamma - 1) q^2} \qquad (2.20b)$$

$$\frac{p_o}{p} = \left[\frac{\gamma - 1}{2} M^2 + 1\right]^{\frac{\gamma}{\gamma-1}} = \left[\frac{\gamma + 1}{(\gamma + 1) - (\gamma - 1) M^{*2}}\right]^{\frac{\gamma}{\gamma-1}} \qquad (2.21)$$

The Circulation of a Fluid. Irrotational Motion

$$\Gamma = \oint_C (u\,dx + v\,dy + w\,dz) \qquad (2.22a)$$

Stokes' theorem

$$\oint_C (u\,dx + v\,dy + w\,dz) = \iint_\Sigma (\omega_x \cos\alpha + \omega_y \cos\beta + \omega_z \cos\gamma)\, d\Sigma \qquad (2.22c)$$

Condition for irrotational flow

$$\omega_x = \omega_y = \omega_z = 0 \qquad (2.23)$$

General Vector Equations

$$\nabla\Phi = \vec{\theta}_1 \frac{1}{e_1} \frac{\partial\Phi}{\partial\theta_1} + \vec{\theta}_2 \frac{1}{e_2} \frac{\partial\Phi}{\partial\theta_2} + \vec{\theta}_3 \frac{1}{e_3} \frac{\partial\Phi}{\partial\theta_3} \qquad (2.27)$$

$$\operatorname{div} \vec{A} = \frac{1}{e_1 e_2 e_3} \left[\frac{\partial A_1 e_2 e_3}{\partial\theta_1} + \frac{\partial A_2 e_1 e_3}{\partial\theta_2} + \frac{\partial A_3 e_1 e_2}{\partial\theta_3}\right] \qquad (2.28)$$

$$\begin{aligned} \operatorname{curl} \vec{A} = {} & \vec{\theta}_1 \frac{1}{e_2 e_3} \left[\frac{\partial(e_3 A_3)}{\partial\theta_2} - \frac{\partial(e_2 A_2)}{\partial\theta_3}\right] \\ & + \vec{\theta}_2 \frac{1}{e_3 e_1} \left[\frac{\partial(e_1 A_1)}{\partial\theta_3} - \frac{\partial(e_3 A_3)}{\partial\theta_1}\right] \\ & + \vec{\theta}_3 \frac{1}{e_1 e_2} \left[\frac{\partial(e_2 A_2)}{\partial\theta_1} - \frac{\partial(e_1 A_1)}{\partial\theta_2}\right] \end{aligned} \qquad (2.29)$$

Basic Partial Differential Equations for Isentropic, Steady Flow

$$\left(1 - \frac{u^2}{a^2}\right)\frac{\partial u}{\partial x} + \left(1 - \frac{v^2}{a^2}\right)\frac{\partial v}{\partial y} + \left(1 - \frac{w^2}{a^2}\right)\frac{\partial w}{\partial z} + \frac{uv}{a^2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)$$

$$+ \frac{uw}{a^2}\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right) + \frac{vw}{a^2}\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right) = 0 \qquad (2.30)$$

For irrotational flow

$$\left(1 - \frac{\phi_x^2}{a^2}\right)\phi_{xx} + \left(1 - \frac{\phi_y^2}{a^2}\right)\phi_{yy} + \left(1 - \frac{\phi_z^2}{a^2}\right)\phi_{zz}$$

$$- 2\phi_{yz}\frac{\phi_y\phi_z}{a^2} - 2\phi_{zx}\frac{\phi_z\phi_x}{a^2} - 2\phi_{xy}\frac{\phi_x\phi_y}{a^2} = 0 \qquad (2.31)$$

In cylindrical coordinates

$$\phi_{xx}\left(1 - \frac{\phi_x^2}{a^2}\right) + \phi_{rr}\left(1 - \frac{\phi_r^2}{a^2}\right) + \frac{\phi_{aa}}{r^2}\left(1 - \frac{\phi_a^2}{r^2a^2}\right)$$

$$- 2\frac{\phi_x\phi_r}{a^2}\phi_{xr} - 2\frac{\phi_a\phi_r}{r^2a^2}\phi_{ar} - 2\frac{\phi_x\phi_a}{r^2a^2}\phi_{xa} + \frac{\phi_r}{r}\left(1 + \frac{\phi_a^2}{a^2r^2}\right) = 0 \qquad (2.32)$$

In spherical coordinates

$$\phi_{rr}\left(1 - \frac{\phi_r^2}{a^2}\right) + \frac{\phi_{\theta\theta}}{r^2}\left(1 - \frac{\phi_\theta^2}{r^2a^2}\right) + \frac{\phi_{aa}}{r^2\sin^2\theta}\left(1 - \frac{\phi_a^2}{r^2a^2\sin^2\theta}\right)$$

$$- 2\frac{\phi_r\phi_\theta}{r^2a^2}\phi_{\theta r} - 2\frac{\phi_r\phi_a}{r^2a^2\sin^2\theta}\phi_{ar}$$

$$- 2\frac{\phi_\theta\phi_a}{r^4a^2\sin^2\theta}\phi_{\theta a} + 2\frac{\phi_r}{r} + \frac{\phi_r}{r^3a^2}\phi_\theta^2$$

$$+ \frac{\phi_\theta\cos\theta}{r^2\sin\theta} + \frac{\phi_r}{r^3a^2\sin^2\theta}\phi_a^2 + \frac{\phi_\theta\cos\theta}{r^4a^2\sin^3\theta}\phi_a^2 = 0 \qquad (2.33)$$

Equations for the velocity potential(ϕ)and the stream function(ψ)

In axially symmetric flow

$$\phi_{xx}\left(1-\frac{\phi_x^2}{a^2}\right)+\phi_{rr}\left(1-\frac{\phi_r^2}{a^2}\right)-2\,\phi_{xr}\,\frac{\phi_x\phi_r}{a^2}+\frac{\phi_r}{r}=0 \qquad (2.34)$$

$$\psi_{xx}\left[1-\left(\frac{\rho_o}{r\rho a}\right)^2\psi_r^2\right]+\psi_{rr}\left[1-\left(\frac{\rho_o}{r\rho a}\right)^2\psi_x^2\right]$$

$$+2\left(\frac{\rho_o}{r\rho a}\right)^2\psi_{xr}\,\psi_x\,\psi_r-\frac{\psi_r}{r}=0 \qquad (2.35)$$

In plane flow

$$\phi_{xx}\left(1-\frac{\phi_x^2}{a^2}\right)+\phi_{yy}\left(1-\frac{\phi_y^2}{a^2}\right)-2\phi_{xy}\left(\frac{\phi_x\phi_y}{a^2}\right)=0 \qquad (2.36)$$

$$\psi_{xx}\left[1-\left(\frac{\rho_o}{\rho a}\right)^2\psi_y^2\right]+\psi_{yy}\left[1-\left(\frac{\rho_o}{\rho a}\right)^2\psi_x^2\right]$$

$$+2\left(\frac{\rho_o}{\rho a}\right)^2\psi_{xy}\,\psi_x\,\psi_y=0 \qquad (2.38)$$

The hodograph equations in two-dimensional flow

$$q^2\left(1-\frac{q^2}{a^2}\right)\phi_{qq}+q\left(1+\frac{\gamma q^4}{a^4}\right)\phi_q+\left(1-\frac{q^2}{a^2}\right)\phi_{\theta\theta}=0 \qquad (2.39)$$

$$q^2\,\psi_{qq}+q\left(1+\frac{q^2}{a^2}\right)\psi_q+\left(1-\frac{q^2}{a^2}\right)\psi_{\theta\theta}=0 \qquad (2.40)$$

Formulae for Isentropic Channel Flow

$$\frac{T_o}{T}=1+\frac{\gamma-1}{2}M^2 \qquad (2.41)$$

$$\frac{T}{T_o} = 1 - \frac{\gamma - 1}{2}\left(\frac{q}{a_o}\right)^2 \tag{2.42}$$

$$\frac{T}{T_o} = 1 - \frac{\gamma - 1}{\gamma + 1} M^{*2} \tag{2.43}$$

$$\frac{p_o}{p} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} \tag{2.44}$$

$$\frac{\rho_o}{\rho} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{1}{\gamma-1}} \tag{2.45}$$

$$\frac{p}{p_o} = \left[1 - \frac{\gamma - 1}{2}\left(\frac{q}{a_o}\right)^2\right]^{\frac{\gamma}{\gamma-1}} \tag{2.46}$$

$$\frac{\rho}{\rho_o} = \left[1 - \frac{\gamma - 1}{2}\left(\frac{q}{a_o}\right)^2\right]^{\frac{1}{\gamma-1}} \tag{2.47}$$

$$\frac{p}{p_o} = \left(1 - \frac{\gamma - 1}{\gamma + 1} M^{*2}\right)^{\frac{\gamma}{\gamma-1}} \tag{2.48}$$

$$\frac{\rho}{\rho_o} = \left(1 - \frac{\gamma - 1}{\gamma + 1} M^{*2}\right)^{\frac{1}{\gamma-1}} \tag{2.49}$$

Laval Nozzle Equations

$$m = A\sqrt{\frac{2\gamma}{\gamma - 1} p_o \rho_o \left(\frac{p}{p_o}\right)^{2/\gamma}\left[1 - \left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}}\right]} \tag{2.51}$$

m is maximum for $p/p_o = \left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1}$

$$A = \frac{m}{\sqrt{\frac{2\gamma}{\gamma - 1} p_o \rho_o \left(\frac{p}{p_o}\right)^{\frac{2}{\gamma}} \left[1 - \left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}}\right]}} \tag{2.52}$$

$$\left(\frac{A}{A^*}\right)^2 = \frac{\gamma - 1}{2} \frac{\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{\gamma-1}}}{\left(\frac{p}{p_o}\right)^{\frac{2}{\gamma}} \left[1 - \left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}}\right]} \tag{2.53}$$

$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2} \left[\frac{2}{\gamma + 1} \left(1 + \frac{\gamma - 1}{2} M^2\right)\right]^{\frac{\gamma+1}{\gamma-1}} \tag{2.54}$$

Prandtl-Meyer two-dimensional steady flow around a convex corner

$$q_r = \hat{q} \sin\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\, \phi\right) \tag{2.55}$$

$$q_n = a^* \cos\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\, \phi\right) \tag{2.56}$$

$$M^2 = \frac{(\gamma + 1) - 2 \cos^2\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\, \phi\right)}{(\gamma - 1) \cos^2\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\, \phi\right)} \tag{2.57}$$

$$M^{*2} = 1 + \frac{2}{\gamma - 1} \sin^2\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\, \phi\right) \tag{2.58}$$

$$\frac{p_o}{p} = \left[\frac{\gamma + 1}{2} \frac{1}{\cos^2\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\, \phi\right)}\right]^{\frac{\gamma}{\gamma-1}} \tag{2.59}$$

$$2\,\theta = \arccos\left[\gamma - (\gamma+1)\frac{1}{M^{*2}}\right] + \sqrt{\frac{\gamma+1}{\gamma-1}}\arccos\left[\gamma - (\gamma-1)M^{*2}\right] - \Pi \tag{2.60}$$

The equation of the streamlines

$$r = \bar{r}\left[\cos\left(\sqrt{\frac{\gamma-1}{\gamma+1}}\,\phi\right)\right]^{-\frac{\gamma+1}{\gamma-1}} \tag{2.61}$$

$$\phi_{max} = \frac{\Pi}{2}\sqrt{\frac{\gamma+1}{\gamma-1}}, \qquad \theta_{max} = \phi_{max} - \frac{\Pi}{2} \tag{2.62}$$

Flow over a two-dimensional curved surface

$$\theta_1 - \theta = f(\mu_1) - f(\mu) \tag{2.63}$$

$$f(\mu) = \sqrt{\frac{\gamma+1}{\gamma-1}}\tan^{-1}\left(\sqrt{\frac{\gamma+1}{\gamma-1}}\tan\mu\right) - \mu \tag{2.64}$$

$$\frac{p}{p_1} = \frac{g(\mu)}{g(\mu_1)} \tag{2.65}$$

$$g(\mu) = \left(\frac{\sin^2\mu}{\gamma - \cos^2\mu}\right)^{\frac{\gamma}{\gamma-1}} \tag{2.66}$$

Plane Shock Wave Relations for Two-Dimensional Steady Flow

$$q_{1n}^2 = \frac{\rho_2}{\rho_1}\left(\frac{p_2 - p_1}{\rho_2 - \rho_1}\right) = \frac{\rho_2}{\rho_1}\frac{\Delta p}{\Delta\rho}$$

$$q_{2n}^2 = \frac{\rho_1}{\rho_2}\frac{\Delta p}{\Delta\rho} \tag{2.72}$$

$$q_{1n}q_{2n} = \frac{\Delta p}{\Delta\rho}$$

$$\Delta p = -\rho_1 q_{1n}\,\Delta q_n$$

Rankine-Hugoniot relations

$$\frac{p_2}{p_1} = \frac{(\gamma + 1)\,\rho_2 - (\gamma - 1)\,\rho_1}{(\gamma + 1)\,\rho_1 - (\gamma - 1)\,\rho_2} \tag{2.73}$$

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma + 1)\,p_2 + (\gamma - 1)\,p_1}{(\gamma - 1)\,p_2 + (\gamma + 1)\,p_1} \tag{2.74}$$

The angle between the shock front and the direction of flow before the shock

$$\sin^2\beta = \frac{\left[(\gamma - 1) + (\gamma + 1)\frac{p_2}{p_1}\right](\gamma - 1)}{4\gamma\left[\left(\frac{p_{1o}}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \tag{2.75}$$

$$\tan\beta = \frac{(\gamma - 1)\,p_1 + (\gamma + 1)\,p_2}{(\gamma - 1)\,p_2 + (\gamma + 1)\,p_1}\tan(\beta - \theta) \tag{2.76}$$

Flow relations before and after the shock

$$q_{1n}q_{2n} = \frac{\Delta p}{\Delta\rho} = a^{*2} - \frac{\gamma - 1}{\gamma + 1}\,q_t^2 \tag{2.77}$$

$$\frac{p_2}{p_{1o}} = \frac{\gamma+1}{\gamma-1}\left(\frac{p_1}{p_{1o}}\right)^{\frac{1}{\gamma}}\left[\frac{4\,\gamma\sin^2\beta}{(\gamma+1)^2} - \left(\frac{\gamma-1}{\gamma+1}\right)^2\left(1 + \frac{4\,\gamma\sin^2\beta}{(\gamma-1)^2}\right)\left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right] \tag{2.78}$$

$$\frac{\rho_2}{\rho_{1o}} = \left(\frac{\gamma + 1}{\gamma - 1}\right)\frac{\rho_1}{\rho_{1o}}\,\frac{1 - \left(\frac{\rho_1}{\rho_{1o}}\right)^{\gamma-1}}{1 + \left(\frac{\rho_1}{\rho_{1o}}\right)^{\gamma-1}\left(\cot^2\beta\right)} \tag{2.79}$$

$$\frac{T_2}{T_{1o}} = \frac{1 + \frac{T_1}{T_{1o}} \cot^2\beta}{1 - \frac{T_1}{T_{1o}}} \left[\frac{4\gamma \sin^2\beta}{(\gamma+1)^2} - \left(\frac{\gamma-1}{\gamma+1}\right)^2 \left(1 + \frac{4\gamma \sin^2\beta}{(\gamma-1)^2}\right) \frac{T_1}{T_{1o}} \right] \tag{2.80}$$

The Prandtl relation

$$q_1 q_2 = a_*^2 \tag{2.81}$$

The entropy change

$$S_2 - S_1 = R \ell n \left(\frac{p_{1o}}{p_{2o}}\right) \tag{2.82}$$

The stagnation pressure ratio

$$\frac{p_{2o}}{p_{1o}} = \frac{\gamma+1}{\gamma-1} \frac{\left(\frac{p_1}{p_{1o}}\right)^{\frac{1}{\gamma}} \left[1 - \left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}}{\left[1 + \left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}} \left(\cot^2\beta\right)\right]^{\frac{\gamma}{\gamma-1}} \left[\frac{4\gamma\sin^2\beta}{(\gamma+1)^2} - \left(\frac{\gamma-1}{\gamma+1}\right)^2 \left(1 + \frac{4\gamma\sin^2\beta}{(\gamma-1)^2}\right) \left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{1}{\gamma-1}}} \tag{2.83}$$

For normal shock

$$\frac{p_{2o}}{p_{1o}} = \frac{\gamma+1}{\gamma-1} \left(\frac{p_1}{p_{1o}}\right)^{\frac{1}{\gamma}} \frac{\left[1 - \left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}}{\left[\frac{4\gamma}{(\gamma+1)^2} - \left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{1}{\gamma-1}}} \tag{2.84}$$

$$\frac{p_{2o}}{p_{1o}} = \left[\frac{\frac{\gamma+1}{2}M_1^2}{\frac{\gamma-1}{2}M_1^2+1}\right]^{\frac{\gamma}{\gamma-1}}\left[\frac{\frac{\gamma+1}{2}}{\gamma M_1^2-\frac{\gamma-1}{2}}\right]^{\frac{1}{\gamma-1}} = M_1^{*}\left[\frac{1-\frac{\gamma-1}{\gamma+1}M_1^{*2}}{M_1^{*2}-\frac{\gamma-1}{\gamma+1}}\right]^{\frac{1}{\gamma-1}} \qquad (2.85)$$

Rayleigh's Pitot tube formula

$$\frac{p_1}{p_{2o}} = \frac{\left(\frac{2\gamma}{\gamma+1}M_1^2-\frac{\gamma-1}{\gamma+1}\right)^{\frac{1}{\gamma-1}}}{\left(\frac{\gamma+1}{2}M_1^2\right)^{\frac{\gamma}{\gamma-1}}} \qquad (2.86)$$

Flow Density (Θ)

$$\Theta = \frac{\rho q}{\rho^* q^*} = \left[\frac{\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}}}{\frac{\gamma-1}{2}}\right]^{\frac{1}{2}}\left(\frac{p}{p_o}\right)^{\frac{1}{\gamma}}\left[1-\left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{1}{2}} = \left[\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}}\right]^{\frac{1}{2}}\frac{M}{\left(\frac{\gamma-1}{2}M^2+1\right)^{\frac{\gamma+1}{2(\gamma-1)}}} \qquad (2.87)$$

The Mass Flow Function ($\overset{o}{m}$)

$$\overset{o}{m} = g\sqrt{\gamma/R}\cdot M\left[1+\frac{\gamma-1}{2}M^2\right]^{\frac{1}{2}} \qquad (2.88)$$

SECTION 2 - FUNDAMENTAL EQUATIONS AND FORMULAE

The material appearing on pages 2.1-2.35 was prepared for the Handbook of Supersonic Aerodynamics by N. Edmonson, Jr. at the Applied Physics Laboratory of The Johns Hopkins University.

1. Equation of Continuity

The equation of continuity is the mathematical formulation of the principle of the conservation of mass.

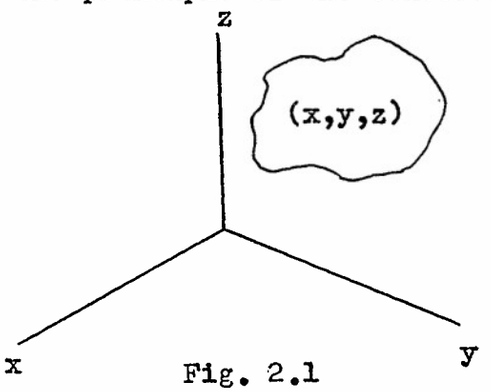


Fig. 2.1

Consider an element of volume ΔV containing the point (x,y,z), at the time t, bounded by a closed surface Σ.

Let $\sigma\,(x,y,z,t)$ be the strength or intensity of a source distribution in the fluid. This means that at (x,y,z) at time t, fluid is being added, positively or negatively, at the rate of σ units of volume per unit of time.

The mass of the fluid in the element of volume is

$$\iiint_{\Delta V} \rho dV$$

where the integration is extended over the volume.

The rate of change of this fluid mass is

$$\frac{\partial}{\partial t}\iiint_{\Delta V} \rho dV = \iiint_{\Delta V} \frac{\partial \rho}{\partial t}\, dV \ .$$

The fluid added to the element consists of two parts:

a. The flux through surface Σ is given by

$$-\iint_{\Sigma} \rho q_n d\,\Sigma \ ,$$

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where q_n is the component of the velocity $\vec{q}$ normal to the surface. The positive direction of the normal is outward.

From the divergence theorem

$$\iint_{\Sigma} \rho q_n d\Sigma = \iiint_{\Delta V} \left[\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) \right] dV .$$

b. The fluid added by the source distribution is given by

$$\iiint_{\Delta V} \rho \sigma \, dV .$$

Hence

$$\iiint_{\Delta V} \left[\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) - \rho\sigma \right] dV = 0 .$$

All quantities in the integrand are assumed continuous. Therefore as the element of volume ΔV is contracted down to the point (x,y,z)

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) - \rho\sigma = 0 , \qquad (2.1a)$$

or in terms of the divergence of $\vec{q}$

$$\frac{1}{\rho}\frac{d\rho}{dt} + \operatorname{div} \vec{q} - \sigma = 0 . \qquad (2.1b)$$

For a source-free fluid flow

$$\frac{1}{\rho}\frac{d\rho}{dt} + \operatorname{div} \vec{q} = 0 . \qquad (2.1c)$$

For a steady source-free flow, $\frac{\partial \rho}{\partial t} = 0$, and $\sigma = 0$,

$$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0 . \qquad (2.1d)$$

It follows from Equation (2.1c) that the necessary and sufficient condition that a fluid be incompressible is

$$\text{div}\,\vec{q} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \ . \qquad (2.1e)$$

For a one-dimensional, steady, source-free flow on integrating the flow across two sections Σ_1 and Σ_2 perpendicular to the flow, we have

$$\int_{\Sigma_1} \rho_1 u_1 dA_1 - \int_{\Sigma_2} \rho_2 u_2 dA_2 = 0 \ .$$

The integration is done over the sections Σ_1 and Σ_2 throughout which ρ_1, u_1, ρ_2 and u_2 are constant, hence we have

$$\rho_1 u_1 A_1 = \rho_2 u_2 A_2 \ ,$$

or, for flow of this type,

$$\rho q A = \text{const.} \qquad (2.1f)$$

which may be written in differential form as

$$\frac{d\rho}{\rho} + \frac{dq}{q} + \frac{dA}{A} = 0 \ . \qquad (2.1g)$$

See references: 2.1, page 45; 2.2, page 142; and 2.3, page 2.

2. The Navier-Stokes Equations for a Viscous Fluid

Consider an element dV of the fluid at (x,y,z) at the time t. The mass of this element is ρdV. The unit mass force (X,Y,Z) acts on this mass to produce a force having the components

$$\rho X dV \ , \quad \rho Y dV \ , \quad \rho Z dV \ .$$

This force must be carefully distinguished from the inertial force

$$\rho \frac{d^2x}{dt^2} dV \ , \ \rho \frac{d^2y}{dt^2} dV \ , \ \rho \frac{d^2z}{dt^2} dV \ ,$$

due to the mass of the element.

The absolute coefficient of viscosity μ is dependent on the temperature and, because the viscosity forces are due to the shearing of the fluid, has the dimension $ML^{-1}T^{-1}$, where M, L and T are the units of mass, length and time, respectively.

The ratio $\frac{\mu}{\rho}$ is the kinematic coefficient of viscosity.

The pressure p is the arithmetic mean of the normal pressures acting on any three mutually perpendicular planes through the point (x,y,z).

After these preliminary remarks, the Navier-Stokes equations for the motion of a viscous fluid are written:

$$\left.\begin{aligned} \frac{du}{dt} - X &= -\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{1}{3}\frac{\mu}{\rho}\frac{\partial \delta}{\partial x} + \frac{\mu}{\rho}\nabla^2 u \quad , \\ \frac{dv}{dt} - Y &= -\frac{1}{\rho}\frac{\partial p}{\partial y} + \frac{1}{3}\frac{\mu}{\rho}\frac{\partial \delta}{\partial y} + \frac{\mu}{\rho}\nabla^2 v \quad , \\ \frac{dw}{dt} - Z &= -\frac{1}{\rho}\frac{\partial p}{\partial z} + \frac{1}{3}\frac{\mu}{\rho}\frac{\partial \delta}{\partial z} + \frac{\mu}{\rho}\nabla^2 w \quad , \end{aligned}\right\} \qquad (2.2a)$$

where

$$\delta = \operatorname{div} \vec{q} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}$$

and

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \quad .$$

If the fluid is assumed incompressible, $\operatorname{div} \vec{q} = 0$, and the Equations (2.2a) become

$$\left.\begin{aligned} \frac{du}{dt} - X &= -\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\mu}{\rho}\nabla^2 u \quad , \\ \frac{dv}{dt} - Y &= -\frac{1}{\rho}\frac{\partial p}{\partial y} + \frac{\mu}{\rho}\nabla^2 v \quad , \\ \frac{dw}{dt} - Z &= -\frac{1}{\rho}\frac{\partial p}{\partial z} + \frac{\mu}{\rho}\nabla^2 w \quad . \end{aligned}\right\} \qquad (2.2b)$$

For $\mu = 0$, the Euler equations result from Equations (2.2a)

$$\left.\begin{aligned} \frac{du}{dt} - X &= -\frac{1}{\rho}\frac{\partial p}{\partial x} \\ \frac{dv}{dt} - Y &= -\frac{1}{\rho}\frac{\partial p}{\partial y} \\ \frac{dw}{dt} - Z &= -\frac{1}{\rho}\frac{\partial p}{\partial z} \quad . \end{aligned}\right\} \qquad (2.2c)$$

In a majority of cases in fluid flow problems, the effect of the unit mass force can be neglected. In these cases the Euler Equations (2.2c) can be put into a useful vector form

$$\vec{q}_t + \text{grad}\,\frac{q^2}{2} - \vec{q} \times \text{curl}\,\vec{q} = -\frac{1}{\rho}\,\text{grad}\,p \quad . \qquad (2.2d)$$

Here $\vec{q}_t = \frac{\partial \vec{q}}{\partial t}$. It must be remembered that $\frac{d}{dt}$ is the total derivative operator. Thus, for example

$$u_t = \frac{\partial u}{\partial t}$$

but

$$\frac{du}{dt} = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial w}{\partial z} \quad .$$

In Equation (2.2d) curl $\vec{q}$ is a vector derived from $\vec{q}$ and is identical with the vorticity $\vec{\omega}$. In rectangular Cartesian coordinates, it has the components

$$\omega_x = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\,, \qquad \omega_y = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\,, \qquad \omega_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\,. \qquad (2.3)$$

See References: 2.2, pages 262 and 361; 2.3, page 571.

3. Thermodynamic Definitions and Relations

a. The general equation of state

The thermodynamic system here considered is a mass of a compressible fluid, e.g., a mass of a gas. The measurements made on the system are of the pressure p, the volume V, and the absolute temperature T. These are not independent quantities, but are functionally related by the equation of state:

$$f(p,V,T) = 0 \,.$$

A state of equilibrium of the fluid is a state that does not vary so long as the external conditions do not change.

A change of the fluid from one equilibrium state A to another such state B is said to be a reversible change if the transition from A to B is made through a continuous succession of states differing only infinitesimally from equilibrium states. Otherwise, the change from A to B is said to be irreversible.

If the state of the fluid is represented on the (p,V) diagram, such transformations are represented by continuous curves.

If the external pressure on the fluid is equal to the fluid pressure p, the system, during the transformation from A to B, can perform positive or negative external work. If W is the work done

$$dW = pdV$$

and

$$W = \int_A^B pdV \quad .$$

On the (p,V) diagram the work W is represented by the shaded area:

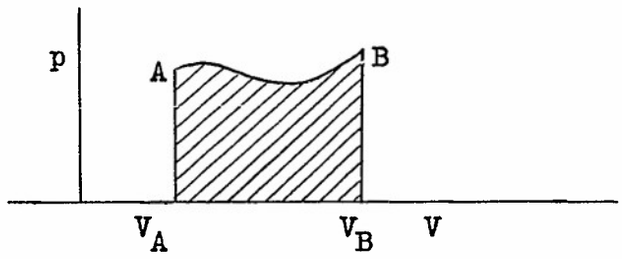


Fig. 2.2

The amount of work is dependent on the curve connecting A and B.

b. The equation of state for a perfect gas

Consider a mass m of a gas having the molecular weight N. The equation of state of this system is given approximately by

$$pV = \frac{m}{N} RT \quad , \qquad (2.4a)$$

where R is a constant for all gases; its value depends on the system of units employed. This equation is called the equation of state for a perfect gas; it includes the laws of Boyle, Gay-Lussac, and Avogadro.

For a mole of the gas, m = N, and

$$pV = RT \quad . \qquad (2.4b)$$

For unit mass of the gas, Equation (2.4a) may be written

$$p = \frac{\rho}{N} RT \quad . \qquad (2.4c)$$

c. Entropy

The thermodynamic system considered is a mass of compressible

fluid. Suppose this system is taken reversibly through a cycle from the equilibrium state A back to A in some system of coordinates, such as a (p,V) diagram. During this cycle the system absorbs heat reversibly from its external surroundings. Let dQ indicate the heat absorbed at the temperature T.

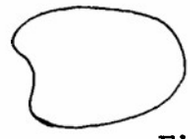


Fig. 2.3

It is demonstrated in treatises on thermodynamics that

$$\oint \frac{dQ}{T} = 0 \quad . \tag{2.5a}$$

where $\oint$ indicates the curvilinear integral over the path describing the cycle.

Consider now the integral

$$\int_A^B \frac{dQ}{T} \tag{2.5b}$$

where the transition from A to B is carried out reversibly. It follows from Equation (2.5a) that the Integral (2.5b) is independent of the path from A to B. For example, if the state of the system can be represented on the (p,V) diagram, the equation of the curve AB can be taken in the form $f(p,V) = 0$.

Since the value of the Integral (2.5b) depends only on the states A and B of the system, a new function of the state of the system can be defined in the following way:

A standard state 0 is selected for the system. Then the integral

$$S(A) = \int_0^A \frac{dQ}{T}$$

is independent of the reversible transformation from 0 to A. The quantity S(A) is called the entropy of the system in the state A.

From this definition, it follows for two states A and B of the system

$$S(B) - S(A) = \int_A^B \frac{dQ}{T} \quad .$$

The standard state 0 may be arbitrarily selected.

For an irreversible transformation from A to B

$$S(B) - S(A) \geqq \int_A^B \frac{dQ}{T} .$$

For a completely isolated system $dQ = 0$. Hence

$$S(B) - S(A) \geqq 0 ,$$

i.e., for any transformation occurring in an isolated system, the entropy can never decrease.

From here on only systems, the states of which can be described in terms of p, V, T and S, will be considered. These quantities are not independent, since it is a consequence of thermodynamics that any two of them can be selected as the independent state parameters. For the case of a compressible fluid where the external pressure is equal to the fluid pressure,

$$dQ = dE + pdV . \qquad (2.6a)$$

Here dQ is not necessarily an exact differential. For an infinitesimal reversible transformation

$$\frac{dQ}{T} = \frac{dE + pdV}{T} = dS$$

is an exact differential. It is equivalent to

$$dE + pdV = TdS . \qquad (2.6b)$$

As an example the entropy of a mole of a perfect gas may be computed. For a perfect gas

$$dQ = c_V dT + pdV . \qquad (2.6c)$$

where c_V is the specific heat at constant volume. Specific heats are assumed to be constants.

From the Equation of State (2.4b)

$$dQ = c_V dT + \frac{RT}{V} dV$$

$$dS = \frac{dQ}{T} = c_V \frac{dT}{T} + \frac{R}{V} dV .$$

Hence

$$S = c_V \log T + R \log V + \text{const.}$$

d. Adiabatic processes in a fluid

If S and ρ are selected as the independent variables specifying the state of a fluid, the pressure p may be written

$$p = p(\rho,S) \quad ; \tag{2.7a}$$

this relation may be regarded as an equation of state for the fluid. If along the path of a fluid particle S is constant, the changes in the fluid are said to be adiabatic. If S is initially constant throughout the fluid, it remains constant throughout an adiabatic process and

$$p = p(\rho) \quad . \tag{2.7b}$$

Such a process is called an isentropic process. An assumption justified by experiment is

$$p'(\rho) = \frac{dp}{d\rho} > 0 \quad .$$

For most gases the Relation (2.7a) can be written

$$p = A\rho^{\gamma} \quad . \tag{2.7c}$$

In this $\gamma = \frac{c_p}{c_v}$ is the adiabatic constant and A is related to the entropy by the formula

$$A = e^{\frac{S}{c_v}}$$

where c_v is the specific heat at constant volume, and c_p is the specific heat at constant pressure.

It should be noticed that in an adiabatic change in a gas, the effects of heat transfer and viscosity are neglected.

e. The enthalpy of a gas

The enthalpy per unit mass of a gas is defined by

$$h = E + pv \quad . \tag{2.8a}$$

From this

$$dh = dE + pdv + vdp = dQ + vdp \quad . \tag{2.8b}$$

Hence for constant pressure processes, the change in the enthalpy is equal to the heat input.

From Equations (2.6b)# and (2.8b),

$$dh - vdp = TdS \ . \qquad (2.8c)$$

This implies that in adiabatic processes

$$dh = vdp = \frac{dp}{\rho} = \frac{p'(\rho)\, d\rho}{\rho} \ , \qquad (2.8d)$$

$$h = \int_{\bar{\rho}}^{\rho} \frac{p'(\rho)\, d\rho}{\rho} = \int_{\bar{p}}^{p} \frac{dp}{\rho(p)} \ , \qquad (2.8e)$$

where $\bar{\rho}$ and $\bar{p}$ are arbitrarily selected values.

It is shown in treatises on hydrodynamics and on sound, that the quantity $p'(\rho)$ measures the local speed of sound. It is indicated by the symbol a:

$$a^2 = p'(\rho) \ .$$

See references: 2.4, 2.5 and 2.6

4. Bernoulli's Formulae

For a steady, non-viscous, isentropic flow, the Euler Equation (2.2d) can be put in the form

$$\frac{d\vec{q}}{dt} + \text{grad } h = 0 \ . \qquad (2.9a)$$

From this it follows

$$\vec{q} \cdot \frac{d\vec{q}}{dt} + \vec{q} \cdot \text{grad } h = \frac{d}{dt}\left(\tfrac{1}{2} q^2 + h\right) = 0$$

$$\tfrac{1}{2} q^2 + h = \tfrac{1}{2}(u^2 + v^2 + w^2) + h = \tfrac{1}{2} \hat{q}^2 \ , \qquad (2.9b)$$

where $\hat{q}$ is a constant along a streamline, but is not necessarily constant throughout the flow. $\hat{q}$ is interpreted as an ultimate or limiting speed. Relation (2.9b) is called Bernoulli's formula in the weak form. It is valid for steady, isentropic, but not necessarily irrotational, flow. If the limiting speed $\hat{q}$ is the same for all streamlines, Bernoulli's formula is said to be the strong form.

In irrotational isentropic flow, a velocity potential function $\phi(x,y,z,t)$ exists. The Euler Equation (2.2d) then can be put in the form $\text{grad } (\phi_t + \tfrac{1}{2} q^2 + h) = 0$,

#Equation (2.6b) may be written dE + pdv = TdS, where dE is the change in internal energy per unit mass and dS is the change in entropy per unit mass.

or

$$\tfrac{1}{2} q^2 + \phi_t + h = \tfrac{1}{2} (\phi_x^2 + \phi_y^2 + \phi_z^2) + \phi_t + h = \tfrac{1}{2} \hat{q}^2 . \quad (2.9c)$$

where the limiting speed $\hat{q}$ is constant throughout the fluid. Hence Bernoulli's formula in the strong form is valid for an irrotational isentropic, but not necessarily steady, flow.

See References: 2.6, Vol. II, page 981; 2.7.

5. Pressure-Velocity Relations from Bernoulli's Formula (2.9b) and the Adiabatic Formula $p = A\rho^\gamma$

a. The adiabatic relation for a perfect gas

The adiabatic relation will first be shown to exist for a perfect gas. For an adiabatic process in a perfect gas

$$dQ = 0 = pdV + c_v dT .$$

For a unit mass of a perfect gas

$$p = \frac{\rho R}{N} T , \quad v = \frac{1}{\rho} .$$

Hence

$$\frac{R}{N} \frac{dv}{v} + c_v \frac{dT}{T} = 0 .$$

Since $\frac{R}{N} = c_p - c_v$, an integration yields

$$\left(\frac{c_p}{c_v} - 1\right) \log v + \log T = \log K, \#$$

or

$$(\gamma - 1) \log v + \log T = \log K$$

$$T v^{\gamma-1} = K$$

or

$$\frac{pN}{\rho R} \cdot \frac{1}{\rho^{\gamma-1}} = K .$$

Hence

$$p = \frac{KR}{N} \rho^\gamma \text{ or } p = A\rho^\gamma .$$

The enthalpy h becomes, from Equation (2.8e)

$$h = \frac{\gamma}{\gamma - 1} \frac{p}{\rho} . \quad (2.10)$$

It can be shown that K is a function of the entropy.

$$a^2 = \gamma \frac{p}{\rho} . \tag{2.11}$$

Bernoulli's formula for steady flow, Equation (2.9b), now becomes

$$\tfrac{1}{2} q^2 + \frac{\gamma}{\gamma - 1} \frac{p}{\rho} = \tfrac{1}{2} \hat{q}^2 . \tag{2.12a}$$

b. The stagnation or reservoir pressure

Formula (2.12a) can be written in the form

$$\tfrac{1}{2} q^2 + \frac{\gamma}{\gamma - 1} \frac{p}{\rho} = \frac{\gamma}{\gamma - 1} \frac{p_o}{\rho_o} . \tag{2.12b}$$

The pressure p_o corresponds to $q = 0$. It is called the reservoir or stagnation pressure, since it is the pressure in a reservoir from which the fluid would issue and accelerate isentropically to the speed q and the pressure p.

At any point in a fluid flow a stagnation or reservoir state may be defined if the flow at that point is imagined to be decelerated isentropically to zero speed.

From Equations (2.11) and (2.12a), we have

$$q^2 + \frac{2}{\gamma - 1} a^2 = \hat{q}^2 , \tag{2.12c}$$

$$\hat{q} = \sqrt{\frac{2\gamma}{\gamma - 1} \frac{p_o}{\rho_o}} \tag{2.13}$$

$$q^2 = \frac{2\gamma}{\gamma - 1} \frac{p_o}{\rho_o} \left[1 - \left(\frac{p}{p_o} \right)^{\frac{\gamma-1}{\gamma}} \right] = \hat{q}^2 \left[1 - \left(\frac{p}{p_o} \right)^{\frac{\gamma-1}{\gamma}} \right] \tag{2.14}$$

c. The critical speed of sound

It can be shown that there exists a unique value of $a = a^*$ such that $q^2 - a^2 = 0$, i.e. $q = a^*$. This means that along a streamline in a steady flow there exists a state where the speed of the flow is equal to the speed of sound. This speed of sound, which may or may not be attained, is called the critical speed.

Putting $q = a$ in Equation (2.12c), we find for the critical speed of sound,

$$a^* = \sqrt{\frac{\gamma - 1}{\gamma + 1}} \hat{q} = \sqrt{\frac{2\gamma}{\gamma + 1} \left(\frac{p_o}{\rho_o} \right)} = a_o \sqrt{\frac{2}{\gamma + 1}} \tag{2.15}$$

$$a_o = \sqrt{\frac{\gamma - 1}{2}} \hat{q} = \sqrt{\gamma R T_o} \tag{2.16}$$

for a perfect gas.

$$p^* = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma-1}} p_o \quad , \tag{2.17}$$

$$\rho^* = \left(\frac{2}{\gamma + 1}\right)^{\frac{1}{\gamma-1}} \rho_o \quad , \tag{2.18}$$

$$T^* = \frac{2}{\gamma + 1} T_o \quad . \tag{2.19}$$

See Reference 2.8, Chapter 3.

6. The Mach Number (M)

By definition, $M = q/a$, where q and a are, respectively, the local velocity of the flow and the local speed of sound. For subsonic flow, $M < 1$, for supersonic flow $M > 1$ and for $a = a^*$, $M = 1$.

The angle μ defined by

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

is called the Mach angle.

Sometimes another number is defined with reference to the critical sound velocity a^* :

$$M^* = \frac{q}{a^*} \quad .$$

This sets up a direct proportion between the number M^* and q. For subsonic flow $M^* < 1$, for the critical sound velocity a^*, $M^* = 1$ and for supersonic flow, $M^* > 1$.

The numbers M and M^* are connected by the formulae:

$$M^{*2} = \frac{(\gamma + 1) M^2}{(\gamma - 1) M^2 + 2} \tag{2.20a}$$

$$M^2 = \frac{2M^{*2}}{(\gamma + 1) - (\gamma - 1) M^{*2}} = \frac{2q^2}{(\gamma + 1) a^{*2} - (\gamma - 1) q^2} \tag{2.20b}$$

From Equations (2.14), (2.15), (2.20a) and (2.20b) it follows that

$$\frac{p_o}{p} = \left[\frac{\gamma - 1}{2} M^2 + 1\right]^{\frac{\gamma}{\gamma-1}} = \left[\frac{\gamma + 1}{(\gamma + 1) - (\gamma - 1) M^{*2}}\right]^{\frac{\gamma}{\gamma-1}} \tag{2.21}$$

It should be noticed that for an incompressible flow, $a = \infty$, and $M = M^* = 0$. The Mach number is dimensionless, from its definition.

7. The Circulation of a Fluid. Irrotational Motion

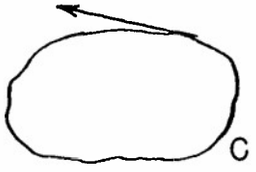


Fig. 2.4

The circulation of a fluid is defined by the curvilinear integral

$$\Gamma = \oint_C (udx + vdy + wdz) , \tag{2.22a}$$

where the integration is carried out over the closed curve C. This integral can be written very usefully in the vector form

$$\Gamma = \oint_C \vec{q} \cdot d\vec{\ell} ,$$

where the vector $d\vec{\ell}$ is the product of the element of length $d\ell$ and the unit tangent vector so directed that the inside of the circuit is to the left of the unit vector. $\vec{q} \cdot d\vec{\ell}$ denotes the scalar product of the vectors $\vec{q}$ and $d\vec{\ell}$.

Fundamental theorem on the circulation:

The value of Γ does not change if the closed curve C always is composed of the same fluid particles:

$$\frac{d\Gamma}{dt} = \frac{d}{dt} \oint_C (udx + vdy + wdz) = 0 . \tag{2.22b}$$

The circulation Γ is connected with the vorticity $\vec{\omega}$ by Stokes' Theorem:

$$\oint_C (u\,dx + v\,dy + w\,dz) = \iint_\Sigma (\omega_x \cos\alpha + \omega_y \cos\beta + \omega_z \cos\gamma)\, d\Sigma \,. \tag{2.22c}$$

where Σ is any sufficiently smooth surface bounded by C and $\cos\alpha$, $\cos\beta$, $\cos\gamma$ are the direction cosines of the normal to Σ.

If

$$\omega_x = \omega_y = \omega_z = 0 \quad , \tag{2.23}$$

the fluid flow is said to be irrotational.

It follows from Equations (2.22c) and (2.22b) that a continuous flow initially irrotational remains irrotational. Hence Equations (2.23) hold throughout the flow and a velocity potential $\phi(x,y,z.t)$ such that

$$u = \frac{\partial \phi}{\partial x} \,, \quad v = \frac{\partial \phi}{\partial y} \,, \quad w = \frac{\partial \phi}{\partial z}$$

exists.

See References: 2.1, 2.2 and 2.3.

8. Basic Partial Differential Equations for Isentropic Steady Flow

For a steady flow, Equation (2.2d) becomes

$$\text{grad}\,\frac{q^2}{2} - \vec{q} \times \text{curl}\,\vec{q} = -\frac{1}{\rho}\,\text{grad}\,p \,. \tag{2.24a}$$

This gives

$$\vec{q} \cdot \text{grad}\,\frac{q^2}{2} - \vec{q} \cdot \vec{q} \times \text{curl}\,\vec{q} = -\frac{1}{\rho}\,\vec{q} \cdot \text{grad}\,p = -\frac{a^2}{\rho}\,\vec{q} \cdot \text{grad}\,\rho \,. \tag{2.24b}$$

The continuity Equation (2.1c) can be written

$$\frac{a^2}{\rho}\left[u\frac{\partial \rho}{\partial x} + v\frac{\partial \rho}{\partial y} + w\frac{\partial \rho}{\partial z}\right] = \frac{a^2}{\rho}\,\vec{q} \cdot \text{grad}\,\rho = -a^2\,\text{div}\,\vec{q} \,. \tag{2.25}$$

From Equations (2.24b) and (2.25)

$$\vec{q} \cdot \text{grad}\,\frac{q^2}{2} - \vec{q} \cdot \vec{q} \times \text{curl}\,q - a^2\,\text{div}\,\vec{q} = 0 \,. \tag{2.26}$$

Equation (2.26) is a partial differential equation for steady, compressible flow which may be readily written explicitly for a given orthogonal system of coordinates. Some of the more common forms are given in the following section.

To facilitate its use, the expressions for the gradient, curl and divergence are given for an orthogonal curvilinear system of coordinates $\hat{e}_1$, $\hat{e}_2$, $\hat{e}_3$:

The gradient of a scalar function Φ ,

$$\nabla \Phi = \vec{e}_1 \frac{1}{e_1} \frac{\partial \Phi}{\partial \theta_1} + \vec{e}_2 \frac{1}{e_2} \frac{\partial \Phi}{\partial \theta_2} + \vec{e}_3 \frac{1}{e_3} \frac{\partial \Phi}{\partial \theta_3} \quad , \qquad (2.27)$$

where $\vec{e_1}$, $\vec{e_2}$, $\vec{e_3}$ are unit vectors in the direction of increase of θ_1, θ_2, θ_3.

The divergence of a vector function $\vec{A}$,

$$\text{div } \vec{A} = \frac{1}{e_1 e_2 e_3} \left[\frac{\partial A_1 e_2 e_3}{\partial \theta_1} + \frac{\partial A_2 e_1 e_3}{\partial \theta_2} + \frac{\partial A_3 e_1 e_2}{\partial \theta_3} \right] . \qquad (2.28)$$

The curl of a vector function $\vec{A}$,

$$\begin{aligned} \text{curl } \vec{A} = {} & \vec{e}_1 \frac{1}{e_2 e_3} \left[\frac{\partial (e_3 A_3)}{\partial \theta_2} - \frac{\partial (e_2 A_2)}{\partial \theta_3} \right] \\ & + \vec{e}_2 \frac{1}{e_3 e_1} \left[\frac{\partial (e_1 A_1)}{\partial \theta_3} - \frac{\partial (e_3 A_3)}{\partial \theta_1} \right] \\ & + \vec{e}_3 \frac{1}{e_1 e_2} \left[\frac{\partial (e_2 A_2)}{\partial \theta_1} - \frac{\partial (e_1 A_1)}{\partial \theta_2} \right] . \end{aligned} \qquad (2.29)$$

In Equations (2.27), (2.28) and (2.29), the quantities e_1 , e_2 , e_3 are determined from the relation

$$ds^2 = e_1^2 \, d\theta_1^2 + e_2^2 \, d\theta_2^2 + e_3^2 \, d\theta_3^2 \quad ,$$

where ds is the element of length in the coordinate system under consideration. Often e_1, e_2 and e_3 may be quickly read from a figure.

a. <u>The partial differential equation for steady, compressible flow</u>

For a rectangular Cartesian coordinate system, Equation (2.26) yields the equation

$$\left(1 - \frac{u^2}{a^2}\right)\frac{\partial u}{\partial x} + \left(1 - \frac{v^2}{a^2}\right)\frac{\partial v}{\partial y} + \left(1 - \frac{w^2}{a^2}\right)\frac{\partial w}{\partial z} + \frac{uv}{a^2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)$$

$$+ \frac{uw}{a^2}\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right) + \frac{vw}{a^2}\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right) = 0 \quad . \qquad (2.30)$$

b. The partial differential equations for steady, compressible, irrotational flow

If the flow is irrotational, a velocity potential ϕ exists such that

$$u = \phi_x, \quad v = \phi_y, \quad w = \phi_z,$$

and Equation (2.30) becomes

$$\left(1 - \frac{\phi_x^2}{a^2}\right)\phi_{xx} + \left(1 - \frac{\phi_y^2}{a^2}\right)\phi_{yy} + \left(1 - \frac{\phi_z^2}{a^2}\right)\phi_{zz}$$

$$- 2\phi_{yz}\frac{\phi_y\phi_z}{a^2} - 2\phi_{zx}\frac{\phi_z\phi_x}{a^2} - 2\phi_{xy}\frac{\phi_x\phi_y}{a^2} = 0 \quad . \qquad (2.31)$$

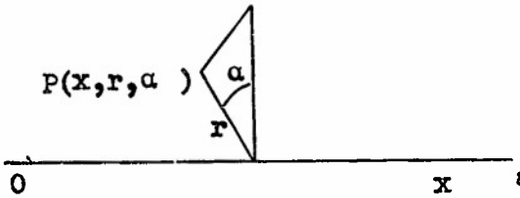


Fig. 2.5

For an irrotational flow in cylindrical coordinates

$$\theta_1 = x, \quad \theta_2 = r \quad \text{and} \quad \theta_3 = \alpha ;$$

$$e_1 = 1, \quad e_2 = 1, \quad e_3 = r$$

and the velocity components are

$$q_{\theta_1} = \phi_x , \quad q_{\theta_2} = \phi_r , \quad q_{\theta_3} = \frac{\phi_\alpha}{r} .$$

Equation (2.26) yields

$$\phi_{xx}\left(1 - \frac{\phi_x^2}{a^2}\right) + \phi_{rr}\left(1 - \frac{\phi_r^2}{a^2}\right) + \frac{\phi_{\alpha\alpha}}{r^2}\left(1 - \frac{\phi_\alpha^2}{r^2a^2}\right)$$

$$- 2\frac{\phi_x\phi_r}{a^2}\phi_{xr} - 2\frac{\phi_\alpha\phi_r}{r^2a^2}\phi_{\alpha r} - 2\frac{\phi_x\phi_\alpha}{r^2a^2}\phi_{x\alpha} + \frac{\phi_r}{r}\left(1 + \frac{\phi_\alpha^2}{a^2r^2}\right) = 0 \quad .$$

(2.32)

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For an irrotational flow in spherical coordinates (r, θ, α)

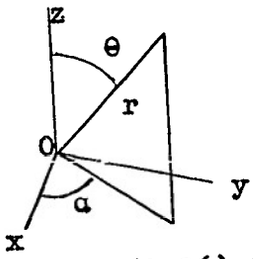


Fig.2.6

$$\theta_1 = r \qquad \theta_2 = \theta \qquad \theta_3 = \alpha$$

$$e_1 = 1 \qquad e_2 = r \qquad e_3 = r \sin\theta$$

$$q_{\theta_1} = \phi_r \qquad q_{\theta_2} = \frac{1}{r}\phi_\theta \qquad q_{\theta_3} = \frac{1}{r\sin\theta}\phi_\alpha$$

Equation (2.26) then gives for the velocity potential ϕ

$$\phi_{rr}\left(1 - \frac{\phi_r^2}{a^2}\right) + \frac{\phi_{\theta\theta}}{r^2}\left(1 - \frac{\phi_\theta^2}{r^2a^2}\right) + \frac{\phi_{\alpha\alpha}}{r^2\sin^2\theta}\left(1 - \frac{\phi_\alpha^2}{r^2a^2\sin^2\theta}\right)$$

$$- 2\frac{\phi_r\phi_\theta}{r^2a^2}\phi_{\theta r} - 2\frac{\phi_r\phi_\alpha}{r^2a^2\sin^2\theta}\phi_{\alpha r}$$

$$- 2\frac{\phi_\theta\phi_\alpha}{r^4a^2\sin^2\theta}\phi_{\theta\alpha} + 2\frac{\phi_r}{r} + \frac{\phi_r}{r^3a^2}\phi_\theta^2$$

$$+ \frac{\phi_\theta\cos\theta}{r^2\sin\theta} + \frac{\phi_r}{r^3a^2\sin^2\theta}\phi_\alpha^2 + \frac{\phi_\theta\cos\theta}{r^4a^2\sin^3\theta}\phi_\alpha^2 = 0 . \qquad (2.33)$$

c. <u>Equations for the velocity potential(ϕ)and the stream function(ψ)in axially symmetric flow</u>

In this type of flow, Equation (2.32) is independent of α. Hence

$$\phi_{xx}\left(1 - \frac{\phi_x^2}{a^2}\right) + \phi_{rr}\left(1 - \frac{\phi_r^2}{a^2}\right) - 2\phi_{xr}\frac{\phi_x\phi_r}{a^2} + \frac{\phi_r}{r} = 0 . \qquad (2.34)$$

If

$$u = \phi_x = \frac{1}{r}\frac{\rho_o}{\rho}\psi_r \quad , \quad v = \phi_r = -\frac{1}{r}\frac{\rho_o}{\rho}\psi_x$$

$$q^2 = u^2 + v^2 = \phi_x^2 + \phi_r^2 = \left(\frac{\rho_o}{\rho r}\right)^2\left(\psi_x^2 + \psi_r^2\right)$$

the function ψ is called the stream function. Its partial

differential equation is

$$\psi_{xx}\left[1-\left(\frac{\rho_o}{r\rho_a}\right)^2\psi_r^2\right]+\psi_{rr}\left[1-\left(\frac{\rho_o}{r\rho_a}\right)^2\psi_x^2\right]+2\left(\frac{\rho_o}{r\rho_a}\right)^2\psi_{xr}\,\psi_x\,\psi_r-\frac{\psi_r}{r}=0 \quad . \tag{2.35}$$

c. Equations for the velocity potential (ϕ) and the stream function (ψ) in plane flow

Plane flow is described in terms of two independent variables x and y. The equation for the velocity potential is

$$\phi_{xx}\left(1-\frac{\phi_x^2}{a^2}\right)+\phi_{yy}\left(1-\frac{\phi_y^2}{a^2}\right)-2\phi_{xy}\left(\frac{\phi_x\phi_y}{a^2}\right)=0 \quad . \tag{2.36}$$

The function ψ defined by the equations

$$u=\phi_x=\frac{\rho_o}{\rho}\psi_y \quad , \quad v=\phi_y=-\frac{\rho_o}{\rho}\psi_x$$

$$q^2=u^2+v^2=\phi_x^2+\phi_y^2=\left(\frac{\rho_o}{\rho}\right)^2\left(\psi_x^2+\psi_y^2\right) \tag{2.37}$$

is called the stream function. Its differential equation for plane flow is

$$\psi_{xx}\left[1-\left(\frac{\rho_o}{\rho a}\right)^2\psi_y^2\right]+\psi_{yy}\left[1-\left(\frac{\rho_o}{\rho a}\right)^2\psi_x^2\right]+2\left(\frac{\rho_o}{\rho a}\right)^2\psi_{xy}\,\psi_x\,\psi_y=0 \quad . \tag{2.38}$$

It should be noticed that for an incompressible fluid $\rho=\rho_o=$ constant, and the Equations (2.37) give

$$\phi_x=\psi_y$$

$$\phi_y=-\psi_x \quad .$$

These are precisely the Cauchy-Riemann equations of the theory of an analytic function of a complex variable. Thus for incompressible fluid flow ϕ and ψ are harmonic conjugates, and satisfy LaPlace's equation:

differential equation is

$$\psi_{xx}\left[1 - \left(\frac{\rho_o}{r\rho a}\right)^2 \psi_r^2\right] + \psi_{rr}\left[1 - \left(\frac{\rho_o}{r\rho a}\right)^2 \psi_x^2\right] + 2\left(\frac{\rho_o}{r\rho a}\right)^2 \psi_{xr}\,\psi_x\,\psi_r - \frac{\psi_r}{r} = 0 \quad . \tag{2.35}$$

d. Equations for the velocity potential (ϕ) and the stream function (ψ) in plane flow

Plane flow is described in terms of two independent variables x and y. The equation for the velocity potential is

$$\phi_{xx}\left(1 - \frac{\phi_x^2}{a^2}\right) + \phi_{yy}\left(1 - \frac{\phi_y^2}{a^2}\right) - 2\phi_{xy}\left(\frac{\phi_x\phi_y}{a^2}\right) = 0 \quad . \tag{2.36}$$

The function ψ defined by the equations

$$u = \phi_x = \frac{\rho_o}{\rho}\,\psi_y \quad , \quad v = \phi_y = -\frac{\rho_o}{\rho}\,\psi_x$$

$$q^2 = u^2 + v^2 = \phi_x^2 + \phi_y^2 = \left(\frac{\rho_o}{\rho}\right)^2\left(\psi_x^2 + \psi_y^2\right) \tag{2.37}$$

is called the stream function. Its differential equation for plane flow is

$$\psi_{xx}\left[1 - \left(\frac{\rho_o}{\rho a}\right)^2 \psi_y^2\right] + \psi_{yy}\left[1 - \left(\frac{\rho_o}{\rho a}\right)^2 \psi_x^2\right] + 2\left(\frac{\rho_o}{\rho a}\right)^2 \psi_{xy}\,\psi_x\,\psi_y = 0 \quad . \tag{2.38}$$

It should be noticed that for an incompressible fluid $\rho = \rho_o$ = constant, and the Equations (2.37) give

$$\phi_x = \psi_y$$

$$\phi_y = -\psi_x \quad .$$

These are precisely the Cauchy-Riemann equations of the theory of an analytic function of a complex variable. Thus for incompressible fluid flow ϕ and ψ are harmonic conjugates, and satisfy LaPlace's equation:

$$\phi_{xx} + \phi_{yy} = 0 \quad , \quad \psi_{xx} + \psi_{yy} = 0 \quad .$$

The stream function ψ can be interpreted in terms of mass flow in the cases of plane potential flow and axially symmetric flow. Consider the plane case. The equation for a stream line is obtained by setting ψ = a constant. Consider an arbitrary continuous curve joining the points A and B on the stream lines $\psi = \psi_A$ and $\psi = \psi_B$ where ψ_A and ψ_B are constants.

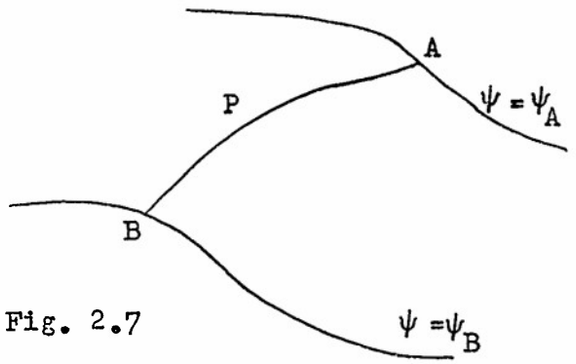


Fig. 2.7

If the direction cosines of the tangent to the curve AB at a point P are $\frac{dx}{ds}$, $\frac{dy}{ds}$. The direction cosines of the normal are $\frac{dy}{ds}$, $-\frac{dx}{ds}$ respectively.

The mass flow across the curve AB is then

$$\int_A^B \rho\left(u\frac{dy}{ds} - v\frac{dx}{ds}\right)ds = \int_A^B \rho(udy - vdx) = \rho_o \int_A^B d\psi = \rho_o\left[\psi_B - \psi_A\right]$$

Similarly, for an axially symmetric flow, the mass flow is

$$\int_A^B 2\pi r\rho_o d\psi = 2\pi\rho_o\left[\psi_B - \psi_A\right];$$

since, from the figure, the flow through the conical element is

$$2\pi r\rho q_n ds$$

$$= 2\pi r\rho\left(u\frac{dr}{ds} - v\frac{dx}{ds}\right)ds$$

$$= 2\pi r\rho\,(udr - vdx)$$

$$= 2\pi\rho_o d\psi \text{ , from the definition of } \psi \text{ .}$$

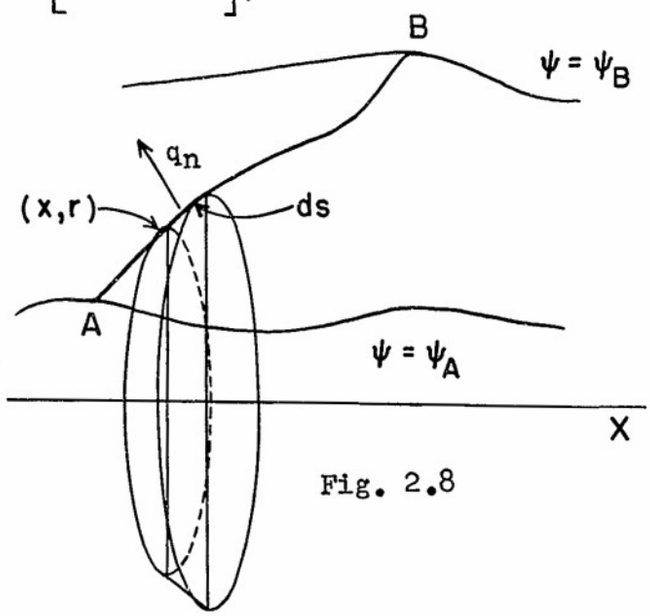


Fig. 2.8

e. The hodograph equations for the potential function(ϕ) and the stream function (ψ) in two-dimensional flow

Equations (2.36) and (2.38) can be linearized by changing from the independent variables x and y to the independent variables q and θ, where q is the velocity of flow at a given point and θ is the angle between $\vec{q}$ and a selected reference direction. Changing from (x,y) to (q, θ) amounts to setting up a correspondence between the flow plane (x,y) and the velocity plane (q,θ). It is assumed that this correspondence is a one-to-one reciprocal correspondence. This rules out cases such as expansion around a corner, where the map in the velocity plane would become a curve, and uniform parallel flow where the map in the velocity plane becomes a single point. Under these conditions the equations for ϕ and ψ become, respectively,

$$q^2\left(1-\frac{q^2}{a^2}\right)\phi_{qq}+q\left(1+\frac{\gamma q^4}{a^4}\right)\phi_q+\left(1-\frac{q^2}{a^2}\right)\phi_{\theta\theta}=0\ . \tag{2.39}$$

$$q^2\,\psi_{qq}+q\left(1+\frac{q^2}{a^2}\right)\psi_q+\left(1-\frac{q^2}{a^2}\right)\psi_{\theta\theta}=0\ . \tag{2.40}$$

See References: 2.2, 2.3 and 2.7.

9. Formulae for Isentropic Channel Flow

It is assumed that the flow is uniform across any cross-section of the channel, i.e., that the flow is determined by the value of a single variable taken along the center line of the channel.

These formulae are obtained from Bernoulli's equation for steady isentropic flow. The subscript o refers to the stagnation condition.

$$\frac{T_o}{T}=1+\frac{\gamma-1}{2}M^2 \tag{2.41}$$

$$\frac{T}{T_o}=1-\frac{\gamma-1}{2}\left(\frac{q}{a_o}\right)^2 \tag{2.42}$$

$$\frac{T}{T_o}=1-\frac{\gamma-1}{\gamma+1}M^{*2} \tag{2.43}$$

$$\frac{p_o}{p} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} \tag{2.44}$$

$$\frac{\rho_o}{\rho} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{1}{\gamma-1}} \tag{2.45}$$

$$\frac{p}{p_o} = \left[1 - \frac{\gamma - 1}{2}\left(\frac{q}{a_o}\right)^2\right]^{\frac{\gamma}{\gamma-1}} \tag{2.46}$$

$$\frac{\rho}{\rho_o} = \left[1 - \frac{\gamma - 1}{2}\left(\frac{q}{a_o}\right)^2\right]^{\frac{1}{\gamma-1}} \tag{2.47}$$

$$\frac{p}{p_o} = \left(1 - \frac{\gamma - 1}{\gamma + 1} M^{*2}\right)^{\frac{\gamma}{\gamma-1}} \tag{2.48}$$

$$\frac{\rho}{\rho_o} = \left(1 - \frac{\gamma - 1}{\gamma + 1} M^{*2}\right)^{\frac{1}{\gamma-1}} \tag{2.49}$$

10. Flow Relations Near the Speed of Sound

Bernoulli's Equation (2.9b) can be put in the form

$$q\,dq + a^2 \frac{d\rho}{\rho} = 0 \ .$$

For a one-dimensional flow, the continuity Equation (2.1e) becomes

$$\frac{d\rho}{\rho} + \frac{dq}{q} + \frac{dA}{A} = 0 \ ,$$

where A measures the cross-section of the channel at a given value of x.

Eliminating $d\rho/\rho$ between the given equations,

$$\frac{dq}{q}(1 - M^2) = -\frac{dA}{A} \ .$$

For low speeds, $M = 0$, approximately, and the situation for incompressible fluids results. For $M > 1$, the channel must expand as q increases; and for $M < 1$, the channel contracts as q increases.

For $\frac{dA}{A} = 0$, either (a) $M \neq 1$ and $\frac{dq}{q} = 0$

or (b) $M = 1$ and $\frac{dq}{q} \neq 0$. Case (a) corresponds to the incompressible case, where q reaches a maximum at the narrowest part of the channel. Case (b) is the case for compressible fluids, when q is equal to a* and will continue to increase beyond the constriction in a channel. Such a constriction in a channel is often called a <u>throat</u>.

The throat ratios of p, ρ and T to the corresponding reservoir quantities are of particular interest:

$$\left.\begin{aligned} \frac{p^*}{p_o} &= \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} = 0.528 \quad \text{for} \quad \gamma = 1.400, \\ \frac{\rho^*}{\rho_o} &= \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} = 0.634 \quad \text{for} \quad \gamma = 1.400, \\ \frac{T^*}{T_o} &= \frac{2}{\gamma+1} = 0.833 \quad \text{for} \quad \gamma = 1.400. \end{aligned}\right\} \quad (2.50)$$

11. Laval Nozzle Equations

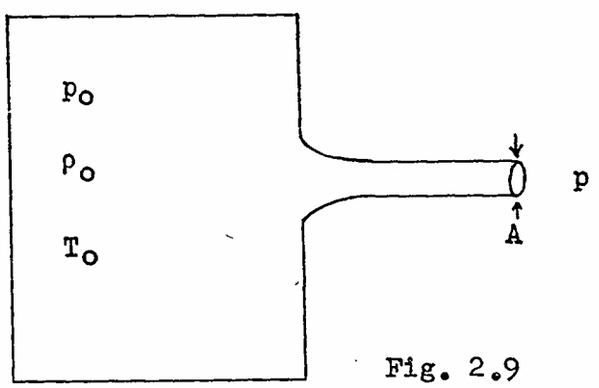


Fig. 2.9

Suppose a reservoir of compressible fluid at the pressure p_o, density ρ_o and temperature T_o discharges into a region at the pressure p. Let the terminal cross-section area and velocity be respectively A and q. Then the mass flow is

$$m = \rho q A$$

which may be written in the form

$$m = A\sqrt{\frac{2\gamma}{\gamma-1}p_o\rho_o\left(\frac{p}{p_o}\right)^{2/\gamma}\left[1-\left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}}\right]} \qquad (2.51)$$

If $\frac{p}{p_o}$ is chosen as the independent variable, m reaches a maximum value for

$$\frac{p}{p_o} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} .$$

For smaller values, m, mathematically, should decrease. This is physically unreasonable, therefore further decreases in p will not result in changing m. It will be noticed from Equation (2.50) that this value for $\frac{p}{p_o}$ is exactly the critical value. The mass flow remains constant for all lower values of $\frac{p}{p_o}$.

An expanding section may be added to the exit channel to obtain lower pressures and higher velocities than in the channel itself. Then Equation (2.51) can be written

$$A = \frac{m}{\sqrt{\frac{2\gamma}{\gamma-1}p_o\rho_o\left(\frac{p}{p_o}\right)^{\frac{2}{\gamma}}\left[1-\left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}}\right]}} \qquad (2.52)$$

which may be made dimensionless by writing

$$m = \rho^* q^* A^*$$

Since

$$\frac{\rho^*}{\rho_o} = \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}, \quad a^* = \sqrt{\gamma RT^*} = \sqrt{\gamma RT_o\frac{2}{\gamma+1}},$$

it follows that

$$\left(\frac{A}{A^*}\right)^2 = \frac{\gamma-1}{2}\frac{\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}}{\left(\frac{p}{p_o}\right)^{\frac{2}{\gamma}}\left[1-\left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}}\right]}, \qquad (2.53)$$

or in terms of M,

$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2}\left[\frac{2}{\gamma+1}\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{\frac{\gamma+1}{\gamma-1}} . \qquad (2.54)$$

See References: 2.7; 2.8, page 23.

12. Prandtl-Meyer Flow

a. Prandtl-Meyer two-dimensional steady flow around a convex corner

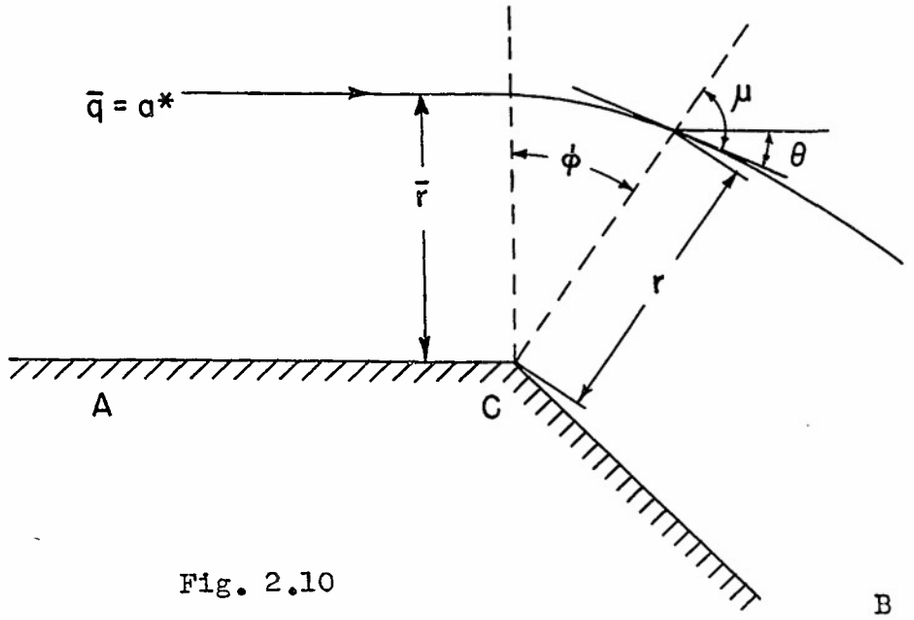


Fig. 2.10

The convex corner is at C . The flow before C is a uniform steady flow with M = 1, parallel to the plane surface AC . The flow expands around the edge C to become a uniform steady flow parallel to the plane CB. The flow connecting these two plane flows is a centered expansion wave. It is characterized by the property that along radial lines from C, the velocity $\bar{q}$ is constant, and as a result, the Mach number is a constant. Hence the flow formulae in the expansion wave can be expressed in terms of the single variable ϕ . The essential formulae are:

$$q_r = \hat{q} \sin\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\,\phi\right) \tag{2.55}$$

$$q_n = a^* \cos\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\,\phi\right) \tag{2.56}$$

$$M^2 = \frac{(\gamma + 1) - 2\cos^2\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\,\phi\right)}{(\gamma - 1)\cos^2\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\,\phi\right)} \tag{2.57}$$

$$M^{*2} = 1 + \frac{2}{\gamma - 1}\sin^2\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\,\phi\right) \tag{2.58}$$

$$\frac{p_o}{p} = \left[\frac{\gamma + 1}{2}\,\frac{1}{\cos^2\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\,\phi\right)}\right]^{\frac{\gamma}{\gamma-1}} \tag{2.59}$$

$$2\theta = \arccos\left[\gamma - (\gamma+1)\frac{1}{M^{*2}}\right] + \sqrt{\frac{\gamma+1}{\gamma-1}}\arccos\left[\gamma - (\gamma-1)M^{*2}\right] - \Pi\ . \tag{2.60}$$

The equation for the streamlines in the expansion wave

$$r = \bar{r}\left[\cos\left(\sqrt{\frac{\gamma - 1}{\gamma + 1}}\,\phi\right)\right]^{-\frac{\gamma+1}{\gamma-1}}\ . \tag{2.61}$$

From Equations (2.57), (2.58) and (2.59), it follows that

$$\phi_{max} = \frac{\Pi}{2}\sqrt{\frac{\gamma + 1}{\gamma - 1}}\ , \quad \theta_{max} = \phi_{max} - \frac{\Pi}{2}\ . \tag{2.62}$$

In these formulae, the quantities $\hat{q}$ and a^* are determined by the stagnation values p_o and ρ_o, as indicated by formulae (2.13) and (2.15). The angle ϕ is referred to the Mach line corresponding to $q = a^*$; i.e., to a Mach line perpendicular to the undisturbed flow. The expansion from $\phi = 0$ to $\phi = \phi_{max}$ or $\theta = 0$ to θ_{max} is called a <u>complete</u> wave. If the uniform flow along the plane AC is supersonic with the Mach number M_1, and expands around C to a second uniform supersonic

flow with the Mach number M_2 , $M_2 > M_1$, the expansion wave can be regarded as a part of a complete expansion wave. The initial conditions for the partial wave can be determined from the Mach number M_1. The final conditions for the partial expansion are determined by the direction of the second uniform flow having the Mach number M_2, if the values $\phi = \phi_{max}$ and $\theta = \theta_{max}$ are not attained. The values $\phi = \phi_{max}$ and $\theta = \theta_{max}$ set the upper bounds for the expansion wave. The initial and final conditions for the partial expansion wave, and the flow quantities inside the wave are determined from the above formulae, or more conveniently by tables computed from these formulae. For example, the table given on Page 57 of the German edition of Sauer (Ref. 2.7) might be used.

b. Flow over a two-dimensional curved surface

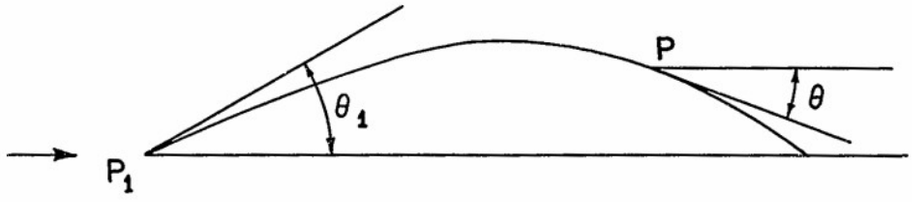


Fig. 2.11

All formulae are based on the assumption of shock-free flow. The flow quantities associated with P_1 in the figure are those back of any shock wave that may be attached to the leading edge of the surface.

The formula connecting the change in Mach number with the change in the deflection angle of the flow is

$$\theta_1 - \theta = f(\mu_1) - f(\mu) \tag{2.63}$$

where

$$f(\mu) = \sqrt{\frac{\gamma+1}{\gamma-1}} \tan^{-1}\left(\sqrt{\frac{\gamma+1}{\gamma-1}} \tan \mu\right) - \mu \, . \tag{2.64}$$

The static pressure ratio is determined by

$$\frac{p}{p_1} = \frac{g(\mu)}{g(\mu_1)} \tag{2.65}$$

where p_1 is the static pressure at P_1 and p is the static pressure at P. The function $g(\mu)$ is determined by

$$g(\mu) = \left(\frac{\sin^2 \mu}{\gamma - \cos^2 \mu}\right)^{\frac{\gamma}{\gamma-1}} \qquad (2.66)$$

The values of $f(\mu)$ and $g(\mu)$ have been calculated and compiled into tables (Ref. 2.9). The angles θ and θ_1 are determined from the geometry of the cross-section of the surface.

See References: 2.7, page 54; 2.8, page 210; and 2.9.

13. Plane Shock Wave Relations for Two-Dimensional Steady Flow

A perfect gas is assumed.

Experimentally, it is found that discontinuities in the pressure, the temperature, the density and the entropy may occur in supersonic flow of gases approximating a perfect gas. The following situations are typical examples where such discontinuities occur:

a. If the flow impinges on a two-dimensional wedge ABC and if the Mach number is sufficiently high, the flow is turned parallel to the plane wedge surfaces AB and BC by compression through the surfaces of discontinuity BD and BE, as shown in Figure 2.12a. If the flow is supersonic, but the Mach number is not sufficiently high relative to the wedge angle ABC, the discontinuity surface will be detached from the edge of the wedge, as in Figure 2.12b, where DEF is the surface of discontinuity.

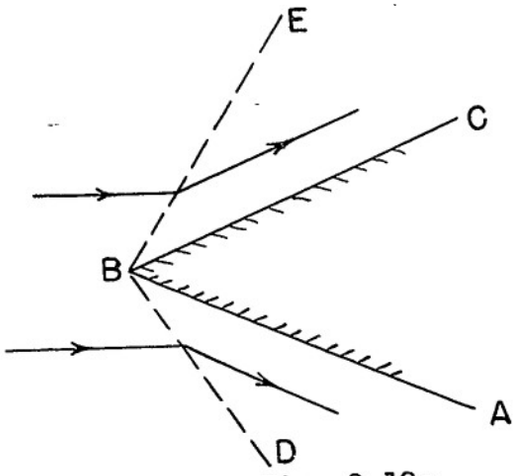


Fig. 2.12a

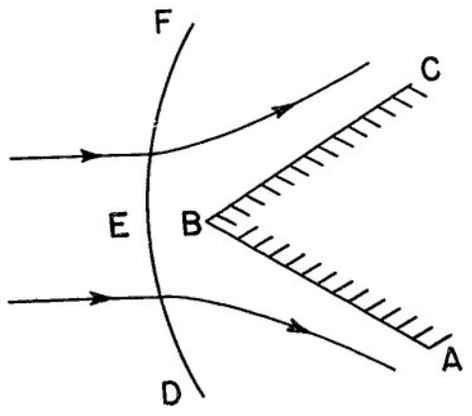


Fig. 2.12b

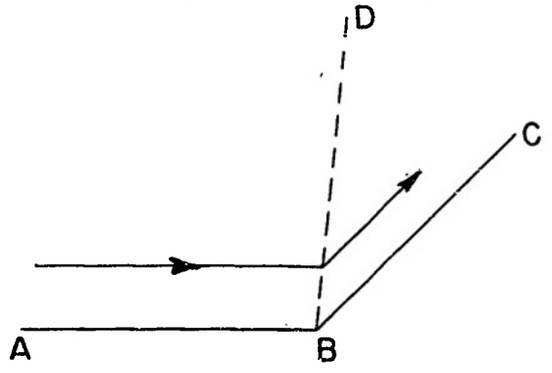


Fig. 2.13

b. Since the two-dimensional flow in a convex corner ABC is equivalent to the flow over one surface of a wedge, it can be obtained as a special case by considering half of the flow over the wedge in the example just given.

c. If a cone is immersed, with its axis parallel to the direction of flow, in a supersonic flow, the direction of flow will be changed through a surface of discontinuity. As in the case of the wedge, the surface of discontinuity may be attached to the vertex of the cone or it may be detached, according to the bluntness of the cone. If the surface of discontinuity is attached it has approximately the shape of a cone. In a great many cases it can be taken as a cone with no serious loss in accuracy.

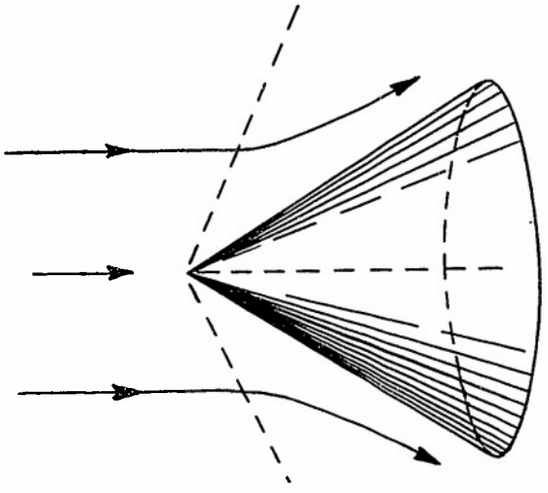


Fig. 2.14a

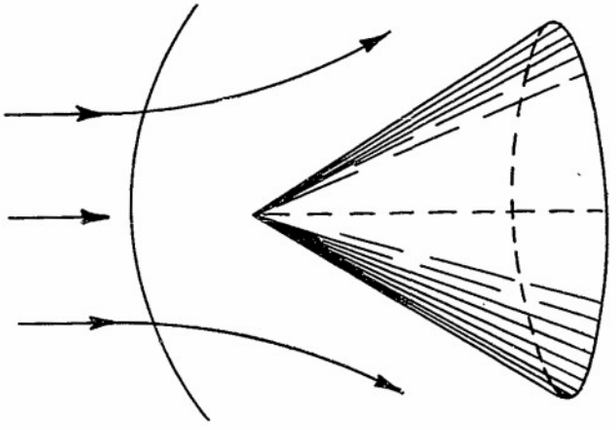


Fig. 2.14b

d. A supersonic flow in a channel in the part C may, because of friction and heat transfer effects, change to a subsonic flow in part D, through a discontinuity surface AB, perpendicular to the flow direction.

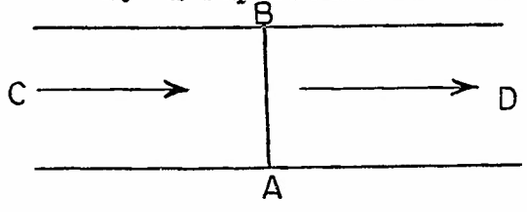


Fig. 2.15

It is found compatible with experiment to assume that these discontinuities in supersonic flow are mathematical surfaces of discontinuity for the flow quantities. These surfaces of discontinuity are called shock waves or shock fronts. By the Gallileo principle of relativity, it is sufficient to assume the shock wave stationary since the laws are the same for systems of axes moving uniformly relative to each other. The shock wave surface is in general not plane; however, it can be assumed plane "in the small". Under these assumptions the principles of the conservation of mass, of momentum and of energy, can be used to get the flow relations through the shock front by algebraic methods.

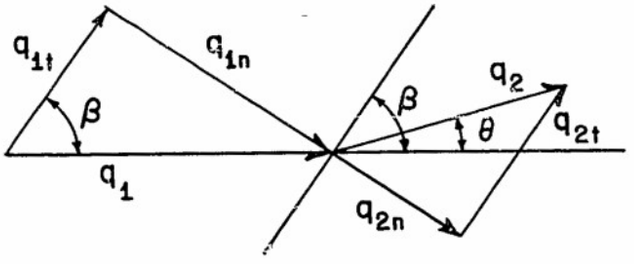


Fig. 2.16

Assume a plane shock front AB. The flow variables to the left or front of AB will be indicated by the subscript 1, those to the right or back of AB by the subscript 2.

From the continuity equation (conservation of mass):

$$\rho_1 q_{1n} = \rho_2 q_{2n} \,. \tag{2.67}$$

From the conservation of momentum law (Newton's Second Law):

$$\rho_1 q_{1n}^2 + p_1 = \rho_2 q_{2n}^2 + p_2 \tag{2.68}$$

for the direction normal to AB, and

$$\rho_1 \, q_{1n} \, q_{1t} = \rho_2 \, q_{2n} \, q_{2t} \,, \tag{2.69}$$

for the direction parallel to AB.

From Equations (2.67) and (2.69),

$$q_{1t} = q_{2t} \tag{2.70}$$

i.e., the velocity component parallel to AB does not change across AB.

From Bernoulli's Formula (2.9b) and Equation (2.70),

$$h_1 + \tfrac{1}{2} q_{1n}^2 = h_2 + \tfrac{1}{2} q_{2n}^2 \,. \tag{2.71}$$

From Equations (2.67) and (2.68),

$$\left.\begin{aligned} q_{1n}^2 &= \frac{\rho_2}{\rho_1}\left(\frac{p_2 - p_1}{\rho_2 - \rho_1}\right) = \frac{\rho_2}{\rho_1}\frac{\Delta p}{\Delta \rho} \\ q_{2n}^2 &= \frac{\rho_1}{\rho_2}\frac{\Delta p}{\Delta \rho} \\ q_{1n}\, q_{2n} &= \frac{\Delta p}{\Delta \rho} \\ \Delta p &= -\rho_1 q_{1n}(q_{2n} - q_{1n}) = -\rho_1 q_{1n}\Delta q_n \end{aligned}\right\} \quad (2.72)$$

For a perfect gas it follows from Equation (2.71) that if the flow is isentropically brought to rest on each side of the shock front

$$h_{1o} = h_{2o}\ , \quad T_{1o} = T_{2o}\ , \quad \frac{p_{1o}}{\rho_{1o}} = \frac{p_{2o}}{\rho_{2o}}\ ,$$

and that the critical velocity a^* is the same on each side of AB.

The pressure ratio $\frac{p_2}{p_1}$ and the density ratio $\frac{\rho_2}{\rho_1}$

are determined by the Rankine-Hugoniot relation:

$$\frac{p_2}{p_1} = \frac{(\gamma + 1)\rho_2 - (\gamma - 1)\rho_1}{(\gamma + 1)\rho_1 - (\gamma - 1)\rho_2} \quad (2.73)$$

or

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma + 1)p_2 + (\gamma - 1)p_1}{(\gamma - 1)p_2 + (\gamma + 1)p_1}\ . \quad (2.74)$$

The angle β between the shock front AB and the flow in front of AB is given in terms of the static pressure before and after the shock by

$$\sin^2\beta = \frac{\left[(\gamma - 1) + (\gamma + 1)\frac{p_2}{p_1}\right](\gamma - 1)}{4\gamma\left[\left(\frac{p_{1o}}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \quad (2.75)$$

or

$$\tan \beta = \frac{(\gamma - 1)\, p_1 + (\gamma + 1)\, p_2}{(\gamma - 1)\, p_2 + (\gamma + 1)\, p_1} \tan (\beta - \theta) \qquad (2.76)$$

where θ is the angle between the flow direction after AB and the flow direction before AB.

The quantities describing the flow after the shock can be calculated in terms of the flow quantities before the shock by the formulae:

$$q_{1n}\, q_{2n} = \frac{\Delta p}{\Delta \rho} = a^{*2} - \frac{\gamma - 1}{\gamma + 1} q_t^2 \qquad (2.77)$$

$$\frac{p_2}{p_{1o}} = \frac{\gamma+1}{\gamma-1} \left(\frac{p_1}{p_{1o}}\right)^{\frac{1}{\gamma}} \left[\frac{4\gamma \sin^2\beta}{(\gamma+1)^2} - \left(\frac{\gamma-1}{\gamma+1}\right)^2 \left(1 + \frac{4\gamma \sin^2\beta}{(\gamma-1)^2}\right) \left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right] \qquad (2.78)$$

$$\frac{\rho_2}{\rho_{1o}} = \left(\frac{\gamma + 1}{\gamma - 1}\right) \frac{\rho_1}{\rho_{1o}} \frac{1 - \left(\frac{\rho_1}{\rho_{1o}}\right)^{\gamma-1}}{1 + \left(\frac{\rho_1}{\rho_{1o}}\right)^{\gamma-1} \left(\cot^2\beta\right)} \qquad (2.79)$$

$$\frac{T_2}{T_{1o}} = \frac{1 + \frac{T_1}{T_{1o}} \cot^2\beta}{1 - \frac{T_1}{T_{1o}}} \left[\frac{4\gamma \sin^2\beta}{(\gamma+1)^2} - \left(\frac{\gamma-1}{\gamma+1}\right)^2 \left(1 + \frac{4\gamma \sin^2\beta}{(\gamma-1)^2}\right) \frac{T_1}{T_{1o}}\right]. \qquad (2.80)$$

The value $\beta = \frac{\Pi}{2}$ corresponds to the case of the <u>normal</u> shock. For this case $q_t = 0$, and the above formulae are easily specialized to the normal shock. The Prandtl relation

$$q_1\, q_2 = a^{*2} \qquad (2.81)$$

will be the only normal shock relation explicitly mentioned. It is seen from this relation that the flow after a normal shock is subsonic.

The entropy change through the shock is computed by integrating

$$dS = \frac{dQ}{T} = c_v \frac{dT}{T} - R \frac{d\rho}{\rho}$$

from the stagnation pressure p_{1o} to the stagnation pressure p_{2o}, and using the relation $T_{2o} = T_{1o}$, with the result

$$S_2 - S_1 = R\ell n\left(\frac{p_{1o}}{p_{2o}}\right) . \qquad (2.82)$$

Since it can be demonstrated that the stagnation pressure changes through the shock, $S_2 - S_1 \neq 0$, and, by the Second Law of Thermodynamics, this entropy change cannot be negative. Hence $S_2 - S_1 > 0$ and $p_{1o} > p_{2o}$, i.e., the transition through the shock front causes a loss in stagnation pressure.

The stagnation pressure ratio through the shock front is given by the formula

$$\frac{p_{2o}}{p_{1o}} = \frac{\gamma+1}{\gamma-1} \frac{\left(\frac{p_1}{p_{1o}}\right)^{\frac{1}{\gamma}} \left[1 - \left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}}{\left[1+\left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}} \cot^2\beta\right]^{\frac{\gamma}{\gamma-1}} \left[\frac{4\gamma\sin^2\beta}{(\gamma+1)^2} - \left(\frac{\gamma-1}{\gamma+1}\right)^2 \left(1+\frac{4\gamma\sin^2\beta}{(\gamma-1)^2}\right)\left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{1}{\gamma-1}}} . \qquad (2.83)$$

For the normal shock $\beta = \frac{\Pi}{2}$ and

$$\frac{p_{2o}}{p_{1o}} = \frac{\gamma+1}{\gamma-1}\left(\frac{p_1}{p_{1o}}\right)^{\frac{1}{\gamma}} \frac{\left[1 - \left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}}{\left[\frac{4\gamma}{(\gamma+1)^2} - \left(\frac{p_1}{p_{1o}}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{1}{\gamma-1}}} , \qquad (2.84)$$

or in terms of the Mach number M_1 or the number M_1^* of the flow to the left of the shock surface

$$\frac{p_{2o}}{p_{1o}} = \left[\frac{\frac{\gamma+1}{2}M_1^2}{\frac{\gamma-1}{2}M_1^2+1}\right]^{\frac{\gamma}{\gamma-1}} \left[\frac{\frac{\gamma+1}{2}}{\gamma M_1^2 - \frac{\gamma-1}{2}}\right]^{\frac{1}{\gamma-1}} = M_1^{*\frac{2\gamma}{\gamma-1}} \left[\frac{1-\frac{\gamma-1}{\gamma+1}M_1^{*2}}{M_1^{*2} - \frac{\gamma-1}{\gamma+1}}\right]^{\frac{1}{\gamma-1}} . \qquad (2.85)$$

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The use of these formulae is greatly facilitated by curves and tables found in Section 5 of the Handbook of Supersonic Aerodynamics.

The Pitot tube is an instrument commonly used for measuring pressures in gaseous flows. Usually the end of the tube presented to the oncoming flow is so blunt that in a supersonic stream a detached shock wave is formed, as in the figure.

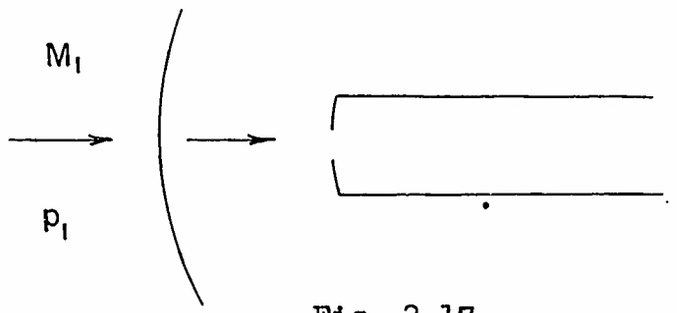


Fig. 2.17

The Pitot tube reading must be corrected because of the presence of the detached shock. This can be done on the assumption that the part of the shock front immediately in front of the tube is normal to the direction of the flow. The formula connecting the static pressure in front of the shock with the stagnation pressure in the tube is obtained by calculating the transition through the shock by the normal shock formula and then assuming the flow is brought to rest isentropically. The resulting formula is the Rayleigh Pitot Tube Formula:

$$\frac{p_1}{p_{2o}} = \frac{\left(\frac{2\gamma}{\gamma+1} M_1^2 - \frac{\gamma-1}{\gamma+1}\right)^{\frac{1}{\gamma-1}}}{\left(\frac{\gamma+1}{2} M_1^2\right)^{\frac{\gamma}{\gamma-1}}} \qquad (2.86)$$

where p_{2o} is the stagnation pressure measured by the tube and p_1 is, as before, the free stream static pressure.

It should be pointed out that a static pressure measurement made on the impact tube or in its vicinity is not the free stream static pressure because of the presence of the shock wave.

See References: 2.7, page 61; 2.8, chapters 4 and 5.

14. Two Flow Functions

a. A flow density formula

An explicit formulation of the stream density ρq in terms of the static pressure p and the stagnation pressure p_o or in terms of the Mach number of the flow is useful. The stream density is made dimensionless by dividing by $\rho^* q^* = \rho^* a^*$ and is denoted by Θ :

$$\Theta = \frac{\rho q}{\rho^* q^*} = \left[\frac{\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}}}{\frac{\gamma-1}{2}}\right]^{\frac{1}{2}} \left(\frac{p}{p_o}\right)^{\frac{1}{\gamma}} \left[1 - \left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{1}{2}} = \left[\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}}\right]^{\frac{1}{2}} \frac{M}{\left(\frac{\gamma-1}{2}M^2+1\right)^{\frac{\gamma+1}{2(\gamma-1)}}} \tag{2.87}$$

This relation has been implicitly used in Formulae (2.51) and (2.52).

b. The mass flow function $\overset{o}{m}$

Write

$$m = \rho q A = g\frac{p}{RT} M\sqrt{\gamma RT}\cdot A$$

$$= Apg M\left(\frac{\gamma}{R}\right)^{\frac{1}{2}} T^{-\frac{1}{2}} \quad \text{, by Equation (2.41),}$$

$$= Apg\sqrt{\gamma/R}\cdot M\left[1+\frac{\gamma-1}{2}M^2\right]^{\frac{1}{2}} T_o^{-\frac{1}{2}} .$$

Now let $\overset{o}{m}$ be defined by $m = Ap\overset{o}{m}T_o^{-\frac{1}{2}}$,

then

$$\overset{o}{m} = g\sqrt{\gamma/R}\cdot M\left[1+\frac{\gamma-1}{2}M^2\right]^{\frac{1}{2}} \tag{2.88}$$

Values of this function are tabulated in Section 5 of the Handbook of Supersonic Aerodynamics.

See Reference: 2.7.

SECTION 3 - GENERAL ATMOSPHERIC DATA

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SECTION 3 - GENERAL ATMOSPHERIC DATA

ERRATA

The information on Errata Pages 3-1 to 3-4 is taken from Errata Sheets issued by the RAND Corporation for RAND Report R-105, "Analysis of Temperature, Pressure, and Density of the Atmosphere Extending to Extreme Altitudes". RAND Report R-105 was used in the preparation of pages 3-52 to 3-123 of this Handbook. The RAND Errata Sheets indicate that an error exists in one of the basic formulae used in computing the data presented in the RAND report. Consequently, small errors exist in Handbook Tables 3.15, 3.16, 3.19, 3.20, 3.23, 3.24, 3.27 and 3.28.

Errata Tables and a discussion of the errors involved, taken from the Errata Sheets prepared by the RAND Corporation, appear on Errata Pages 3-1, 3-2, 3-3 and 3-4.

Errata - Through an oversight, the formula

$$g' = g_0 \left(r_0/r\right)^2 - r\Omega^2 \cos\,\theta$$

was used for the apparent gravity instead of the correct formula

$$g' = g_0 \left(r_0/r\right)^2 - r\Omega^2 \cos^2\theta.$$

(Ω denotes the constant angular velocity of rotation of the earth's atmosphere, r denotes the distance from the center of the earth to a point in the earth's atmosphere, and θ denotes latitude). As far as the results for latitude 0° are concerned, this introduces no error. At latitude 45° the values for g' (and $\emptyset$) are low, but the error is extremely small. The corresponding errors produced in the pressure and density, etc., are entirely negligible and are insignificant in comparison with the uncertainties which exist in the temperature and molecular weight. From the hydrostatic relation

$$\log \frac{p}{p_1} = -\int_{h_1}^{h} \frac{1}{H}\, dh \equiv \int_{h_1}^{h} \frac{Mg'}{RT}\, dh$$

it is seen that if new values for g' are introduced, the calculated values of pressure and density, etc., remain unchanged if they are interpreted as corresponding to slightly different temperatures (T_{new}), which are related to the temperatures given in the tables (T_{old}) by the ratio $T_{new}/T_{old} = g'_{correct}/g'_{old}$. The correct values of g' at latitude 45° and the ratios which they form with the old values are shown in the tables on Errata Pages 3.2, 3.3 and 3.4. These tables are reproduced from RAND errata sheets.

Height, h			Apparent Gravity, g'		Height, h			Apparent Gravity, g'		Height, h			Apparent Gravity, g'	
feet	miles	km	ft/sec²	cm/sec²	feet	miles	km	ft/sec²	cm/sec²	feet	miles	km	ft/sec²	cm/sec²
0	0	0	32.196	981.32	160,000	30.303	48.769	31.707	966.43	310,000	58.712	94.489	31.258	952.74
5,000	.947	1.524	32.180	980.85	164,040	31.068	50.000	31.694	966.03	315,000	59.659	96.013	31.244	952.32
10,000	1.894	3.048	32.165	980.38	165,000	31.250	50.293	31.692	965.97	320,000	60.606	97.537	31.229	951.86
15,000	2.841	4.572	32.149	979.91	170,000	32.197	51.817	31.676	965.48	325,000	61.553	99.061	31.214	951.40
20,000	3.788	6.096	31.134	979.44	175,000	33.144	53.341	31.662	965.06	330,000	62.500	100.58	31.199	950.95
25,000	4.735	7.620	32.118	978.97	180,000	34.091	54.865	31.646	964.57	335,000	63.447	102.11	31.184	950.49
30,000	5.682	9.144	32.103	978.50	185,000	35.038	56.389	31.631	964.11	340,000	64.394	103.63	31.170	950.06
35,000	6.629	10.668	32.088	978.03	190,000	35.985	57.913	31.616	963.66	345,000	65.341	105.16	31.155	949.60
35,332	6.692	10.769	32.086	977.98	195,000	36.932	59.437	31.601	963.20	350,000	66.288	106.68	31.140	949.15
40,000	7.576	12.192	32.072	977.55	196,848	37.282	60.000	31.596	963.05	355,000	67.235	108.20	31.126	948.72
45,000	8.523	13.716	32.057	977.10	200,000	37.879	60.961	31.586	962.74	360,000	68.182	109.73	31.111	948.26
50,000	9.470	15.240	32.042	976.64	205,000	38.826	62.485	31.571	962.28	365,000	69.129	111.25	31.096	947.81
55,000	10.417	16.764	32.026	976.15	210,000	39.773	64.009	31.556	961.83	370,000	70.076	112.78	31.082	947.38
60,000	11.364	18.288	32.011	975.70	215,000	40.720	65.553	31.541	961.37	375,000	71.023	114.30	31.067	946.92
65,000	12.311	19.812	31.996	975.24	220,000	41.667	67.057	31.526	960.91	380,000	71.970	115.82	31.052	946.46
70,000	13.258	21.336	31.980	974.75	225,000	42.614	68.581	31.511	960.46	385,000	72.917	117.35	31.038	946.04
75,000	14.205	22.860	31.965	974.29	230,000	43.561	70.105	31.496	960.00	390,000	73.864	118.87	31.023	945.58
80,000	15.152	24.384	31.950	973.84	235,000	44.508	71.629	31.481	959.54	393,696	74.564	120.00	31.012	945.25
85,000	16.098	25.098	31.934	973.35	240,000	45.455	73.153	31.466	959.08	395,000	74.811	120.40	31.009	945.15
90,000	17.045	27.432	31.919	972.89	245,000	46.402	74.677	31.451	958.63	400,000	75.758	121.92	30.994	944.70
95,000	17.992	28.956	31.904	972.43	250,000	47.349	76.201	31.436	958.17	4.500×10^5	85.227	137.16	30.848	940.25
100,000	18.939	30.480	31.889	971.98	255,000	48.295	77.725	31.422	957.74	5.000×10^5	94.697	152.40	30.703	935.83
104,986	19.884	32.000	31.874	971.50	255,902	48.466	78.000	31.419	957.65	5.280×10^5	100.00	160.94	30.624	933.42
105,000	19.886	32.004	31.873	971.50	260,000	49.242	79.249	31.407	957.29	5.500×10^5	104.17	167.64	30.561	931.50
110,000	20.883	33.528	31.858	971.03	265,000	50.189	80.773	31.392	956.83	6.000×10^5	113.64	182.88	30.418	927.14
115,000	21.780	35.052	31.843	970.57	270,000	51.136	82.297	31.377	956.37	6.500×10^5	123.11	198.12	30.277	922.84
120,000	22.727	36.576	31.828	970.12	272,306	51.573	83.000	31.370	956.16	7.000×10^5	132.58	213.36	30.136	918.55
125,000	23.674	38.100	31.813	969.66	275,000	52.083	83.821	31.362	955.91	7.500×10^5	142.05	228.60	29.997	914.31
130,000	24.621	39.624	31.797	969.17	280,000	53.030	85.345	31.347	955.46	8.000×10^5	151.57	243.84	29.858	910.07
135,000	25.568	41.148	31.782	968.72	285,000	53.977	86.869	31.332	955.00	8.500×10^5	160.98	259.08	29.721	905.90
140,000	26.515	42.673	31.767	968.26	290,000	54.924	88.393	31.318	954.57	9.000×10^5	170.45	274.32	29.584	901.72
145,000	27.462	44.197	31.752	967.80	295,000	55.871	89.917	31.303	954.12	9.500×10^5	179.92	289.56	29.448	897.58
150,000	28.409	45.721	31.737	967.34	300,000	56.818	91.441	31.288	953.66	9.842×10^6	186.41	300.00	29.356	894.77
155,000	29.356	47.245	31.722	966.89	305,000	57.765	92.965	31.273	953.20					

Errata Table 3.1 CORRECT VALUES FOR APPARENT GRAVITY (g') SEA LEVEL TO THE F_2-LAYER AT LATITUDE 45°. $g'_{correct}/g'_{old} = 1.0007 \pm 0.00005$ at all levels. Table from RAND Errata Sheets.

Height, h			Apparent Gravity, g'		$\frac{g'_{correct}}{g'_{old}}$	Height, h			Apparent Gravity, g'		$\frac{g'_{correct}}{g'_{old}}$	Height, h			Apparent Gravity, g'		$\frac{g'_{correct}}{g'_{old}}$
feet	miles	km	ft/sec^2	cm/sec^2		feet	miles	km	ft/sec^2	cm/sec^2		feet	miles	km	ft/sec^2	cm/sec^2	
9.842×10^5	186.41	300.0	29.364	895.03	1.0007	3.168×10^6	600	965.6	24.278	739.99	1.0006	1.320×10^7	2500	4023	12.100	368.81	1.0004
1.056×10^6	200	321.9	29.173	889.19	1.0007	3.696×10^6	700	1127	23.247	708.57	1.0006	1.584×10^7	3000	4828	10.426	317.78	1.0004
1.188×10^6	225	362.1	28.825	878.59	1.0006	4.224×10^6	800	1288	22.281	679.12	1.0006	1.848×10^7	3500	5633	9.076	276.64	1.0003
1.320×10^6	250	402.3	28.484	868.19	1.0006	4.752×10^6	900	1448	21.373	651.45	1.0006	2.112×10^7	4000	6437	7.973	243.00	1.0002
1.425×10^6	275	442.6	28.148	857.95	1.0006	5.280×10^6	1000	1609	20.520	625.45	1.0006	2.376×10^7	4500	7242	7.059	215.15	1.0001
1.584×10^6	300	482.8	27.819	847.92	1.0006	6.336×10^6	1200	1931	18.961	577.93	1.0006	2.640×10^7	5000	8047	6.293	191.82	1.0001
1.848×10^6	350	563.3	27.177	828.35	1.0006	7.392×10^6	1400	2253	17.572	535.59	1.0006	2.904×10^7	5500	8852	5.646	172.08	1.0000
2.112×10^6	400	643.8	26.557	809.46	1.0006	7.920×10^6	1500	2414	16.935	516.18	1.0006	3.006×10^7	5693.5	9161	5.422	165.25	1.0000
2.376×10^6	450	724.2	25.958	791.20	1.0006	9.240×10^6	1750	2816	15.485	471.98	1.0005						
2.640×10^6	500	804.7	25.379	773.55	1.0006	1.056×10^7	2000	3219	14.214	433.24	1.0005						

Errata Table 3.2 CORRECT VALUES FOR APPARENT GRAVITY (g') ABOVE THE F_2-LAYER AT LATITUDE 45°. ATMOSPHERIC MODEL I. Table from RAND Errata Sheets.

Height, h			Apparent Gravity, g'		$\frac{g'_{correct}}{g'_{old}}$	Height, h			Apparent Gravity, g'		$\frac{g'_{correct}}{g'_{old}}$	Height, h			Apparent Gravity, g'		$\frac{g'_{correct}}{g'_{old}}$
feet	miles	km	ft/sec^2	cm/sec^2		feet	miles	km	ft/sec^2	cm/sec^2		feet	miles	km	ft/sec^2	cm/sec^2	
9.842×10^5	186.41	300	29.363	894.98	1.0010	2.376×10^6	450	724	25.942	790.71	1.0009	7.920×10^6	1500	2414	16.926	515.90	1.0007
1.056×10^6	200	322	29.170	889.10	1.0010	2.508×10^6	475	765	25.650	781.81	1.0009	9.240×10^6	1750	2816	15.477	471.74	1.0007
1.188×10^6	225	362	28.821	878.46	1.0010	2.640×10^6	500	805	25.364	773.09	1.0009	1.056×10^7	2000	3219	14.206	433.00	1.0006
1.320×10^6	250	402	28.478	868.01	1.0010	2.940×10^6	550	835	24.804	756.03	1.0009	1.320×10^7	2500	4023	12.092	368.56	1.0006
1.452×10^6	275	443	28.139	857.68	1.0009	3.168×10^6	600	966	24.264	739.57	1.0009	1.584×10^7	3000	4828	10.418	317.54	1.0006
1.584×10^6	300	483	27.807	847.56	1.0009	3.696×10^6	700	1127	23.234	708.17	1.0008	1.848×10^7	3500	5633	9.068	276.40	1.0005
1.716×10^6	325	523	27.482	837.65	1.0009	4.224×10^6	800	1288	22.268	678.73	1.0008	2.112×10^7	4000	6438	7.965	242.77	1.0005
1.848×10^6	350	563	27.163	827.93	1.0009	4.752×10^6	900	1448	21.361	651.08	1.0008	2.376×10^7	4500	7242	7.052	214.93	1.0004
1.980×10^6	375	604	26.849	818.36	1.0009	5.280×10^6	1000	1609	20.509	625.11	1.0008	2.640×10^7	5000	8047	6.287	191.62	1.0004
2.064×10^6	391	630	26.649	812.26	1.0009	6.336×10^6	1200	1931	18.951	577.63	1.0007	2.904×10^7	5500	8851	5.640	171.90	1.0004
2.112×10^6	400	644	26.540	808.94	1.0009	7.392×10^6	1400	2253	17.563	535.32	1.0007						

Errata Table 3.3 CORRECT VALUES FOR APPARENT GRAVITY (g') ABOVE THE F_2-LAYER AT LATITUDE 45°. ATMOSPHERIC MODEL II. Table from RAND Errata Sheets.

Height, h			Apparent Gravity, g′		$\frac{g'_{correct}}{g'_{old}}$	Height, h			Apparent Gravity, g′		$\frac{g'_{correct}}{g'_{old}}$	Height, h			Apparent Gravity, g′		$\frac{g'_{correct}}{g'_{old}}$
feet	miles	km	ft/sec²	cm/sec²		feet	miles	km	ft/sec²	cm/sec²		feet	miles	km	ft/sec²	cm/sec²	
9.842×10^5	186.4	300	29.359	894.87	1.0009	2.789×10^6	528.2	850	25.046	763.39	1.0009	1.968×10^7	3728	6000	8.538	260.23	1.0005
1.066×10^6	201.9	325	29.139	888.17	1.0009	2.953×10^6	559.2	900	24.703	752.94	1.0009	2.297×10^7	4350	7000	7.309	222.78	1.0004
1.148×10^6	217.5	350	28.922	881.54	1.0009	3.117×10^6	590.3	950	24.366	742.69	1.0009	2.625×10^7	4971	8000	6.327	192.86	1.0004
1.230×10^6	233.0	375	28.707	874.98	1.0009	3.281×10^6	621.4	1000	24.037	732.66	1.0008	2.953×10^7	5592	9000	5.531	168.59	1.0004
1.312×10^6	248.5	400	28.494	868.51	1.0009	3.609×10^6	683.5	1100	23.399	713.19	1.0008	3.281×10^7	6214	10,000	4.876	148.63	1.0003
1.394×10^6	264.1	425	28.284	862.10	1.0009	3.937×10^6	745.6	1200	22.785	694.48	1.0008	4.921×10^7	9320	15,000	2.862	87.23	1.0003
1.476×10^6	279.6	450	28.076	855.76	1.0009	4.265×10^6	807.8	1300	22.195	676.51	1.0008	6.562×10^7	12,427	20,000	1.880	57.29	1.0002
1.558×10^6	295.1	475	27.870	849.49	1.0009	4.593×10^6	869.9	1400	21.628	659.22	1.0008	8.202×10^7	15,534	25,000	1.328	40.49	1.0002
1.640×10^6	310.7	500	27.674	843.49	1.0009	4.921×10^6	932.0	1500	21.082	642.58	1.0008	9.842×10^7	18,641	30,000	0.988	30.12	1.0001
1.722×10^6	326.2	525	27.466	837.15	1.0009	5.249×10^6	994.2	1600	20.557	626.57	1.0008	1.148×10^8	21,748	35,000	0.764	23.28	1.0001
1.804×10^6	341.8	550	27.267	831.09	1.0009	5.577×10^6	1056	1700	20.051	611.15	1.0008	1.312×10^8	24,855	40,000	0.608	18.53	1.0001
1.886×10^6	357.3	575	27.070	825.08	1.0009	6.562×10^6	1243	2000	18.640	568.15	1.0007	1.476×10^8	27,961	45,000	0.495	15.10	1.0001
1.968×10^6	372.8	600	26.908	820.15	1.0009	8.202×10^6	1553	2500	16.599	505.94	1.0007	1.640×10^8	31,068	50,000	0.411	12.54	1.0001
2.050×10^6	388.4	625	26.682	813.27	1.0009	9.842×10^6	1864	3000	14.876	453.42	1.0007	1.804×10^8	34,175	55,000	0.347	10.58	1.0000
2.133×10^6	403.9	650	26.492	807.47	1.0009	1.148×10^7	2175	3500	13.408	408.67	1.0006	1.968×10^8	37,282	60,000	0.297	9.05	1.0000
2.297×10^6	435.0	700	26.119	796.10	1.0009	1.312×10^7	2485	4000	12.147	370.23	1.0006	2.297×10^8	43,496	70,000	0.224	6.83	1.0000
2.461×10^6	466.0	750	25.754	784.97	1.0009	1.476×10^7	2796	4500	11.055	336.97	1.0006						
2.625×10^6	497.1	800	25.396	774.07	1.0009	1.640×10^7	3107	5000	10.105	308.00	1.0005						

Errata Table 3.4 CORRECT VALUES FOR APPARENT GRAVITY (g′) ABOVE THE F_2-LAYER AT LATITUDE 45°. ATMOSPHERIC MODEL III. Table from RAND Errata Sheets.

SECTION 3 - GENERAL ATMOSPHERIC DATA

SYMBOLS

The following symbols are used in the material appearing on pages 3-1 to 3-121.

a = speed of sound

C = Avogadro's number

d = mean particle diameter

f = mean collision frequency of atmospheric gas particles

g = acceleration due to gravity

g' = apparent acceleration of gravity at any height

h = height above sea level

H = scale height = RT/Mg'

k = molecular gas constant

m = mass of a molecule

M = mean molecular weight

n = number of atmospheric gas particles per unit volume

p = pressure

R = universal gas constant

t = temperature

T = absolute temperature

v = volume of molecular oxygen in an initial unit volume of normal air, at the same temperature and pressure

V = mean particle velocity

w = specific weight

γ = ratio of specific heats

λ = mean free path of atmospheric gas particles

μ = coefficient of viscosity

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ν = kinematic viscosity (μ/ρ)

ρ = density

σ = density ratio (ρ/ρ_0)

ϕ = apparent gravity potential function

Subscripts denote the conditions indicated:

0 = sea level

air = mixture of molecules in atmosphere

d = base of region of diffusion equilibrium

L = outer limit of the atmosphere

m = base of region of dissociation, where oxygen is all molecular

n = nitrogen molecules

o = oxygen molecules

ϕ = latitude

* = base of the exosphere (dynamical orbit region)

SECTION 3 - GENERAL ATMOSPHERIC DATA

The material on the Lower Atmosphere presented herein on pages 3-1 to 3-11 was originally compiled by A. W. Lemmon+, and that on the Upper Atmosphere on pages 3-12 to 3-27 was prepared by H. F. Kelsey, of the Applied Physics Laboratory Staff. Subsequent additions and revisions to this section have been made by the APL Handbook Staff and the Reviewing Committee.

The information on pages 3-28 to 3-51 was taken from the 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. This material is being reproduced here with the full permission of the author and the National Advisory Committee for Aeronautics.

The information on pages 3-52 to 3-123 was taken from the RAND Corporation Project RAND Report No. R-105, "Analysis of Temperature, Pressure and Density of the Atmosphere Extending to Extreme Altitudes", by G. Grimminger, dated November 1, 1948. This material is being used with the full permission of the author and the RAND Corporation.

1. Lower Atmosphere

Knowledge of certain fundamental constants with respect to atmospheric conditions at various altitudes is necessary for the evaluation of any aerodynamic design or performance problem. In this sub-section on the lower atmosphere, sea level composition and properties are first presented, followed by data on the atmosphere extending to an altitude of approximately 100,000 feet.

The composition of the atmosphere at sea level as first presented by Paneth (Ref. 3.15) and as recorded by Regener (Ref. 3.1) and by Humphreys (Ref. 3.2) is shown in Table 3.1.

The physical properties of the atmosphere at sea level as given by Warfield (Ref. 3.3) are shown in Table 3.2. The values are listed for each of three specified atmospheres and in some instances the quantity is expressed in more than one unit in either the metric or the British system. The values listed in Table 3.2 for the standard atmosphere at sea level are identical with those used by Diehl (Ref. 3.4) and Aiken (Ref. 3.5) except in a few instances. The exceptions are noted and explained in Appendix E of Reference 3.3.

The National Advisory Committee for Aeronautics (Refs. 3.4 and 3.5) has developed a series of empirical equations and tables which define the temperature (t), pressure (p) and density (ρ) of air as a function of the altitude. A table of the properties of the standard atmosphere up to an altitude of 65,000 feet (from

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Ref. 3.5) is reproduced here as Table 3.3. Figures 3.1, 3.2, 3.3, 3.4, 3.5 and 3.6 show temperature (t), pressure (p) and density (ρ) as functions of altitude (h) from 0 to 100,000 feet based on the data contained in References 3.4 and 3.5. The reliability of the data above 65,000 feet has not been finally standardized as yet.

Figures 3.7 and 3.8 show the atmospheric density (ρ) and pressure (p), respectively, as functions of altitude (h) for winter and summer. These figures are based on data, given by Humphreys (Ref. 3.2, page 78), which take into account the effect of water vapor and of changes in gravity with latitude and altitude, but possible variation with altitude of the composition of the atmosphere is not accounted for in these data.

No.1	No.2	No.3	No.4	No.5
GAS	SYM.	PERCENT COMPOSITION-VOLUME		
Nitrogen	N_2	78.09	78.09	78.09
Oxygen	O_2	20.95	20.95	20.95
Argon	A	.93	.93	.93
Carbon Dioxide	CO_2	.03	.03	0.02 - 0.04
Neon	NE	1.8×10^{-3}	18.0×10^{-4}	18.00×10^{-4}
Helium	HE	5.24×10^{-4}	5.3×10^{-4}	5.30×10^{-4}
Krypton	KR	1×10^{-4}	1.0×10^{-4}	1.10×10^{-4}
Hydrogen	H_2	5×10^{-5}	0.50×10^{-4}	0.50×10^{-4}
Xenon	X	8×10^{-6}	0.08×10^{-4}	0.08×10^{-4}
Ozone	O_3	1×10^{-6} increases with altitude		0.02×10^{-4} increases with altitude
Radon	RN	6×10^{-18} decreases with altitude		7.0×10^{-18} decreases with altitude
Water Vapor	H_2O			0.02 - 4.0 variable

Column No. 3 - Sea Level Composition Presented by Paneth (Ref. 3.15)
Column No. 4 - Sea Level Composition Recorded by Humphreys (Ref. 3.2)
Column No. 5 - Sea Level Composition Recorded by Regener (Ref. 3.1)

Table 3.1 COMPOSITION OF THE ATMOSPHERE AT SEA LEVEL
Data from Various Authorities as Shown

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 tempsrature
Temperature	t_0	^oC	-48.0	15.0	47.0	^oF	-54.5	59.0	116.6
Absolute temperature	T_0	^oK	225.0	288.0	320.0	^oF 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	$\rho_0 = \frac{w_0}{g_0}$	$kg\text{-}sec^2/m^4$	0.15995	0.124966	0.11247	$slugs/ft^3$	0.0030437	0.0023779	0.0021401
Coefficient of viscosity	μ_0	$kg\text{-}sec/m^2$	1.4852×10^{-6}	1.8187×10^{-6}	1.9751×10^{-6}	$lb\text{-}sec/ft^2$	3.0420×10^{-7}	3.7250×10^{-7}	4.0455×10^{-7}
		poise ($dyne\text{-}sec/cm^2$)	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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Table 3.2 PROPERTIES OF THE ATMOSPHERE AT SEA LEVEL - Table I of Ref. 3.3.

Altitude, h (ft)	Pressure, p (lb/ft²)	Pressure, p (in. H_2O)	Pressure, p (in. Hg)	Density, ρ (slugs/ft³)	Density ratio, $\sigma = \rho/\rho_0$	$\frac{1}{\sqrt{\sigma}}$	Temperature, T (°F abs.)	Speed of sound, a (mph)	Coefficient of viscosity, μ (slugs/ft sec)	Kinematic viscosity, ν (ft²/sec)
0	2116	407.1	29.92	0.002378	1.0000	1.0000	518.4	760.9	3.725×10^{-7}	1.566×10^{-4}
500	2078	399.8	29.38	.002343	.9855	1.007	516.6	759.6	3.718	1.586
1000	2041	392.6	28.86	.002309	.9710	1.015	514.8	758.3	3.705	1.604
1500	2004	385.5	28.33	.002275	.9568	1.022	513.0	757.0	3.695	1.624
2000	1968	378.5	27.82	.002242	.9428	1.030	511.2	755.7	3.685	1.644
2500	1932	371.6	27.31	.002209	.9288	1.038	509.5	754.3	3.674	1.665
3000	1896	364.8	26.81	.002176	.9151	1.045	507.7	753.0	3.664	1.684
3500	1862	358.2	26.32	.002144	.9015	1.053	505.9	751.7	3.654	1.704
4000	1828	351.6	25.84	.002112	.8881	1.061	504.1	750.4	3.644	1.725
4500	1794	345.1	25.36	.002080	.8748	1.069	502.4	749.1	3.633	1.747
5000	1760	338.7	24.89	.002049	.8616	1.077	500.6	747.7	3.623	1.768
5500	1728	332.4	24.43	.002018	.8487	1.085	498.8	746.4	3.612	1.790
6000	1696	326.2	23.98	.001988	.8358	1.094	497.0	745.1	3.602	1.812
6500	1664	320.1	23.53	.001957	.8232	1.102	495.2	743.7	3.592	1.835
7000	1633	314.1	23.09	.001928	.8106	1.111	493.4	742.3	3.581	1.857
7500	1602	308.2	22.65	.001898	.7982	1.119	491.7	741.0	3.571	1.881
8000	1572	302.4	22.22	.001869	.7859	1.128	489.9	739.7	3.561	1.905
8500	1542	296.6	21.80	.001840	.7738	1.137	488.1	738.3	3.550	1.929
9000	1512	291.0	21.38	.001812	.7619	1.146	486.3	737.0	3.540	1.954
9500	1483	285.4	20.98	.001784	.7501	1.155	484.5	735.6	3.529	1.978
10,000	1455	279.9	20.58	.001756	.7384	1.164	482.7	734.3	3.519	2.004
10,500	1427	274.5	20.18	.001728	.7269	1.173	481.0	732.9	3.508	2.030
11,000	1399	269.2	19.79	.001702	.7154	1.182	479.2	731.6	3.498	2.055
11,500	1372	264.0	19.40	.001675	.7042	1.192	477.4	730.2	3.487	2.082
12,000	1346	258.9	19.03	.001648	.6931	1.201	475.6	728.8	3.476	2.109
12,500	1319	253.8	18.65	.001622	.6821	1.211	473.8	727.5	3.466	2.137
13,000	1293	248.8	18.29	.001596	.6712	1.220	472.0	726.1	3.455	2.165
13,500	1268	243.9	17.93	.001570	.6605	1.230	470.3	724.7	3.445	2.194
14,000	1243	239.1	17.57	.001545	.6499	1.240	468.5	723.4	3.434	2.223
14,500	1218	234.4	17.22	.001520	.6394	1.250	466.7	722.0	3.423	2.252
15,000	1194	229.7	16.88	.001496	.6291	1.261	464.9	720.6	3.413	2.281
15,500	1170	225.1	16.54	.001472	.6189	1.271	463.1	719.2	3.402	2.311
16,000	1146	220.6	16.21	.001448	.6088	1.282	461.3	717.8	3.391	2.342
16,500	1123	216.1	15.89	.001424	.5988	1.292	459.6	716.4	3.380	2.374
17,000	1101	211.8	15.56	.001402	.5891	1.303	457.8	715.0	3.370	2.405
17,500	1078	207.5	15.25	.001378	.5793	1.314	456.0	713.6	3.359	2.438
18,000	1056	203.2	14.94	.001355	.5698	1.325	454.2	712.2	3.348	2.471
18,500	1035	199.1	14.63	.001333	.5603	1.336	452.4	710.8	3.337	2.503
19,000	1014	195.0	14.33	.001311	.5509	1.347	450.6	709.4	3.326	2.537
19,500	992.6	191.0	14.04	.001289	.5418	1.358	448.9	708.0	3.316	2.572
20,000	972.1	187.0	13.75	.001267	.5327	1.370	447.1	706.6	3.305	2.608
20,500	951.9	183.1	13.46	.001246	.5237	1.382	445.3	705.2	3.294	2.644
21,000	932.0	179.3	13.18	.001225	.5148	1.394	443.5	703.8	3.283	2.680
21,500	912.5	175.6	12.90	.001204	.5061	1.406	441.7	702.4	3.272	2.718
22,000	893.3	171.9	12.63	.001183	.4974	1.418	439.9	701.0	3.261	2.756
22,500	874.4	168.2	12.36	.001163	.4889	1.430	438.2	699.6	3.250	2.794
23,000	855.9	164.7	12.10	.001143	.4805	1.443	436.4	698.1	3.239	2.834
23,500	837.7	161.2	11.84	.001123	.4721	1.455	434.6	696.7	3.228	2.874
24,000	819.8	157.7	11.59	.001103	.4640	1.468	432.8	695.3	3.217	2.916
24,500	802.2	154.3	11.34	.001085	.4559	1.481	431.0	693.8	3.206	2.955
25,000	784.9	151.0	11.10	.001065	.4480	1.494	429.2	692.4	3.195	3.000
25,500	767.9	147.7	10.86	.001046	.4401	1.507	427.5	691.0	3.184	3.044
26,000	751.2	144.5	10.62	.001028	.4323	1.521	425.7	689.5	3.173	3.088
26,500	734.8	141.4	10.39	.001010	.4247	1.534	423.9	688.1	3.162	3.131
27,000	718.7	138.3	10.16	.000992	.4171	1.548	422.1	686.6	3.150	3.175
27,500	702.9	135.2	9.939	.000974	.4097	1.562	420.3	685.2	3.139	3.223
28,000	687.4	132.2	9.720	.000957	.4023	1.577	418.5	683.7	3.128	3.268
28,500	672.1	129.3	9.504	.000940	.3951	1.591	416.8	682.3	3.117	3.316
29,000	657.1	126.4	9.293	.000922	.3879	1.606	415.0	680.8	3.106	3.369
29,500	642.4	123.6	9.085	.000906	.3809	1.620	413.2	679.3	3.094	3.415
30,000	628.0	120.8	8.880	.000889	.3740	1.635	411.4	677.9	3.083	3.468
30,500	613.8	118.0	8.680	.000873	.3671	1.650	409.6	676.4	3.072	3.519
31,000	599.9	115.4	8.483	.000857	.3603	1.666	407.8	674.9	3.060	3.570
31,500	586.3	112.8	8.290	.000842	.3537	1.682	406.1	673.4	3.049	3.621
32,000	572.9	110.2	8.101	.000826	.3472	1.697	404.3	672.0	3.038	3.678
32,500	559.7	107.6	7.915	.000810	.3406	1.713	402.5	670.5	3.026	3.736
33,000	546.8	105.2	7.732	.000795	.3343	1.730	400.7	669.0	3.015	3.792
33,500	534.1	102.8	7.554	.000780	.3280	1.746	399.0	667.5	3.004	3.851
34,000	521.7	100.4	7.377	.000765	.3218	1.763	397.2	666.0	2.992	3.911
34,500	509.5	98.03	7.205	.000750	.3158	1.777	395.4	664.5	2.981	3.975

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Table 3.3 PROPERTIES OF THE ATMOSPHERE (NACA STANDARD) - 0 TO 65,000 FT. - Table VII of Ref. 3.5.

Altitude, h (ft)	Pressure, p (lb/ft²)	Pressure, p (in. H_2O)	Pressure, p (in. Hg)	Density, ρ (slugs/ft³)	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	$\frac{1}{\sqrt{\sigma}}$	Temperature, T (°F abs.)	Speed of sound, a (mph)	Coefficient of viscosity, μ (slugs/ft-sec)	Kinematic viscosity, ν (ft²/sec)
35,000	497.6	95.75	7.036	0.000736	0.3098	1.797	393.6	663.0	2.969×10^{-7}	4.034×10^{-4}
35,332	489.8	94.24	6.926	.000727	.3058	1.808	392.4	662.0	2.962	4.073
35,500	485.8	93.51	6.873	.000721	.3034	1.816	392.4	662.0	2.962	4.105
36,000	474.4	91.31	6.711	.000705	.2963	1.837	392.4	662.0	2.962	4.204
36,500	463.2	89.15	6.552	.000688	.2893	1.859	392.4	662.0	2.962	4.306
37,000	452.2	87.04	6.397	.000672	.2824	1.881	392.4	662.0	2.962	4.410
37,500	441.6	85.00	6.247	.000656	.2758	1.904	392.4	662.0	2.962	4.516
38,000	431.1	82.97	6.098	.000640	.2692	1.927	392.4	662.0	2.962	4.625
38,500	421.0	81.01	5.954	.000625	.2629	1.950	392.4	662.0	2.962	4.737
39,000	411.0	79.10	5.813	.000610	.2567	1.974	392.4	662.0	2.962	4.852
39,500	401.3	77.23	5.676	.000596	.2506	1.998	392.4	662.0	2.962	4.969
40,000	391.9	75.44	5.544	.000582	.2448	2.021	392.4	662.0	2.962	5.089
40,500	382.7	73.64	5.412	.000568	.2390	2.045	392.4	662.0	2.962	5.212
41,000	373.6	71.89	5.284	.000555	.2333	2.070	392.4	662.0	2.962	5.338
41,500	364.8	70.18	5.158	.000542	.2278	2.095	392.4	662.0	2.962	5.467
42,000	356.2	68.56	5.038	.000529	.2225	2.120	392.4	662.0	2.962	5.599
42,500	347.8	66.93	4.919	.000516	.2172	2.146	392.4	662.0	2.962	5.735
43,000	339.6	65.34	4.802	.000504	.2120	2.172	392.4	662.0	2.962	5.873
43,500	331.5	63.79	4.688	.000492	.2070	2.198	392.4	662.0	2.962	6.015
44,000	323.7	62.29	4.576	.000480	.2021	2.224	392.4	662.0	2.962	6.161
44,500	316.1	60.82	4.470	.000469	.1974	2.251	392.4	662.0	2.962	6.310
45,000	308.6	59.40	4.365	.000458	.1927	2.276	392.4	662.0	2.962	6.462
45,500	301.3	58.01	4.265	.000448	.1882	2.305	392.4	662.0	2.962	6.618
46,000	294.2	56.63	4.162	.000437	.1838	2.335	392.4	662.0	2.962	6.778
46,500	287.3	55.28	4.065	.000427	.1794	2.361	392.4	662.0	2.962	6.942
47,000	280.5	53.98	3.967	.000417	.1752	2.389	392.4	662.0	2.962	7.110
47,500	273.9	52.72	3.875	.000407	.1711	2.418	392.4	662.0	2.962	7.282
48,000	267.4	51.46	3.782	.000397	.1670	2.447	392.4	662.0	2.962	7.459
48,500	261.1	50.24	3.692	.000388	.1630	2.477	392.4	662.0	2.962	7.640
49,000	255.0	49.06	3.605	.000379	.1592	2.506	392.4	662.0	2.962	7.824
49,500	248.9	47.92	3.522	.000370	.1555	2.536	392.4	662.0	2.962	8.012
50,000	243.1	46.78	3.438	.000361	.1518	2.567	392.4	662.0	2.962	8.206
50,500	237.3	45.67	3.357	.000352	.1482	2.598	392.4	662.0	2.962	8.404
51,000	231.7	44.60	3.276	.000344	.1447	2.629	392.4	662.0	2.962	8.607
51,500	226.3	43.54	3.200	.000336	.1413	2.660	392.4	662.0	2.962	8.815
52,000	220.9	42.52	3.124	.000328	.1379	2.692	392.4	662.0	2.962	9.028
52,500	215.7	41.51	3.051	.000320	.1347	2.725	392.4	662.0	2.962	9.246
53,000	210.6	40.53	2.979	.000313	.1315	2.758	392.4	662.0	2.962	9.470
53,500	205.6	39.57	2.908	.000305	.1284	2.791	392.4	662.0	2.962	9.699
54,000	200.8	38.64	2.840	.000298	.1254	2.824	392.4	662.0	2.962	9.933
54,500	196.1	37.73	2.773	.000291	.1224	2.858	392.4	662.0	2.962	10.17
55,000	191.4	36.84	2.707	.000284	.1195	2.893	392.4	662.0	2.962	10.42
55,500	186.9	35.97	2.641	.000278	.1167	2.927	392.4	662.0	2.962	10.67
56,000	182.5	35.12	2.581	.000271	.1140	2.962	392.4	662.0	2.962	10.93
56,500	178.2	34.29	2.520	.000264	.1113	2.997	392.4	662.0	2.962	11.19
57,000	174.0	33.48	2.461	.000258	.1087	3.033	392.4	662.0	2.962	11.46
57,500	169.9	32.69	2.403	.000252	.1061	3.070	392.4	662.0	2.962	11.74
58,000	165.9	31.92	2.346	.000246	.1036	3.107	392.4	662.0	2.962	12.02
58,500	162.0	31.17	2.291	.000240	.1011	3.145	392.4	662.0	2.962	12.32
59,000	158.1	30.43	2.236	.000235	.09875	3.182	392.4	662.0	2.962	12.61
59,500	154.4	29.71	2.184	.000229	.09643	3.220	392.4	662.0	2.962	12.92
60,000	150.8	29.01	2.132	.000224	.09415	3.259	392.4	662.0	2.962	13.23
60,500	147.2	28.33	2.082	.000218	.09193	3.298	392.4	662.0	2.962	13.55
61,000	143.8	27.66	2.033	.000213	.08976	3.338	392.4	662.0	2.962	13.88
61,500	140.4	27.01	1.985	.000208	.08764	3.378	392.4	662.0	2.962	14.21
62,000	137.1	26.37	1.938	.000203	.08557	3.419	392.4	662.0	2.962	14.56
62,500	133.8	25.74	1.892	.000197	.08355	3.460	392.4	662.0	2.962	14.91
63,000	130.7	25.14	1.848	.000192	.08158	3.501	392.4	662.0	2.962	15.27
63,500	127.6	24.54	1.804	.000187	.07965	3.543	392.4	662.0	2.962	15.64
64,000	124.6	23.96	1.761	.000182	.07777	3.586	392.4	662.0	2.962	16.02
64,500	121.6	23.40	1.720	.000177	.07594	3.629	392.4	662.0	2.962	16.40
65,000	118.7	22.85	1.679	.000172	.07414	3.672	392.4	662.0	2.962	16.80

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Table 3.3 PROPERTIES OF THE ATMOSPHERE (NACA STANDARD) - 0 TO 65,000 FT. - Table VII of Ref. 3.5. (Concluded)

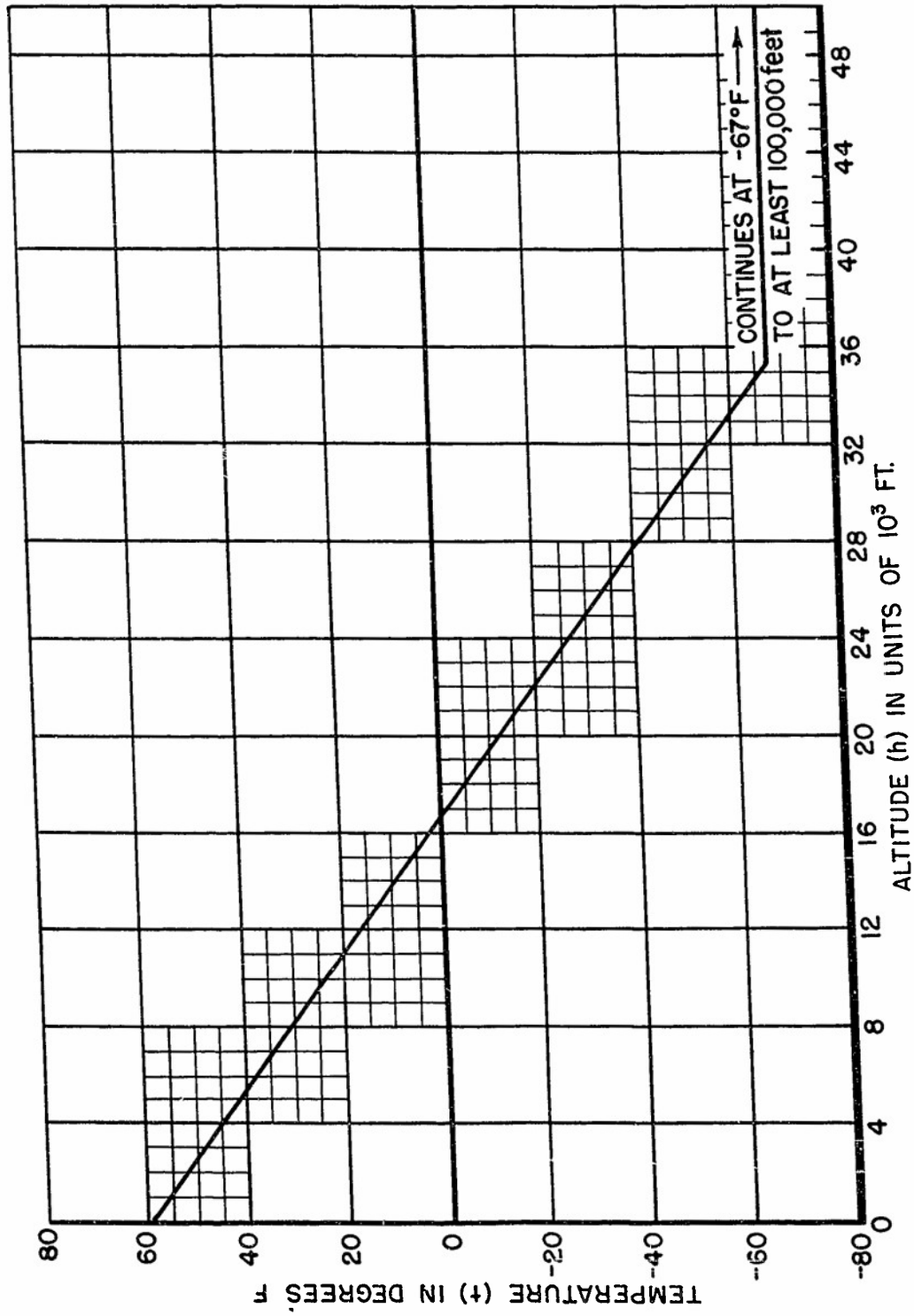


Fig. 3.1 TEMPERATURE OF THE ATMOSPHERE (NACA STANDARD) VS ALTITUDE - 0 TO 50,000 FT. - Data from Diehl (Ref. 3.4).

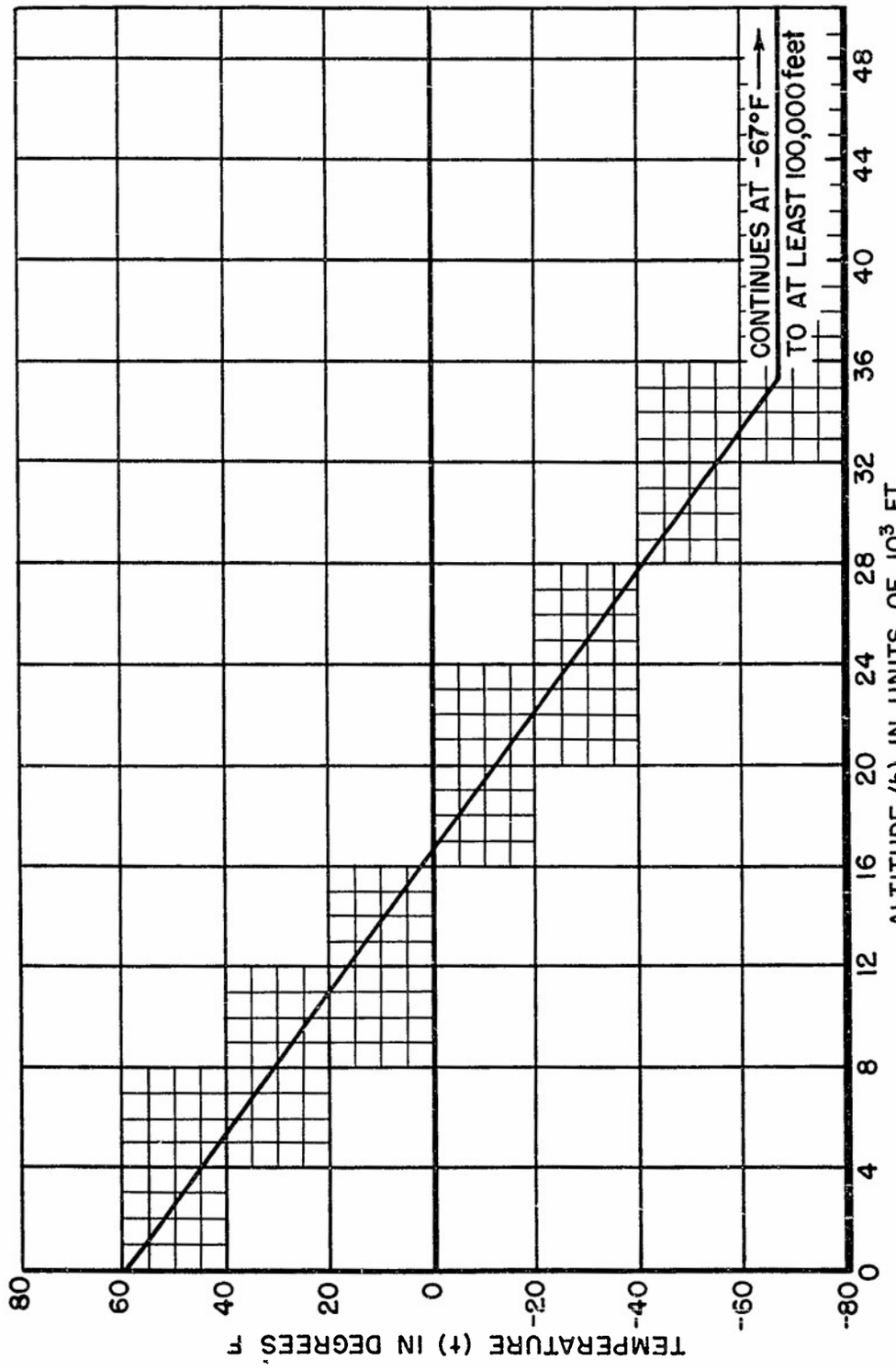


Fig. 3.1 TEMPERATURE OF THE ATMOSPHERE (NACA STANDARD) VS ALTITUDE - 0 TO 50,000 FT. - Data from Diehl (Ref. 3.4).

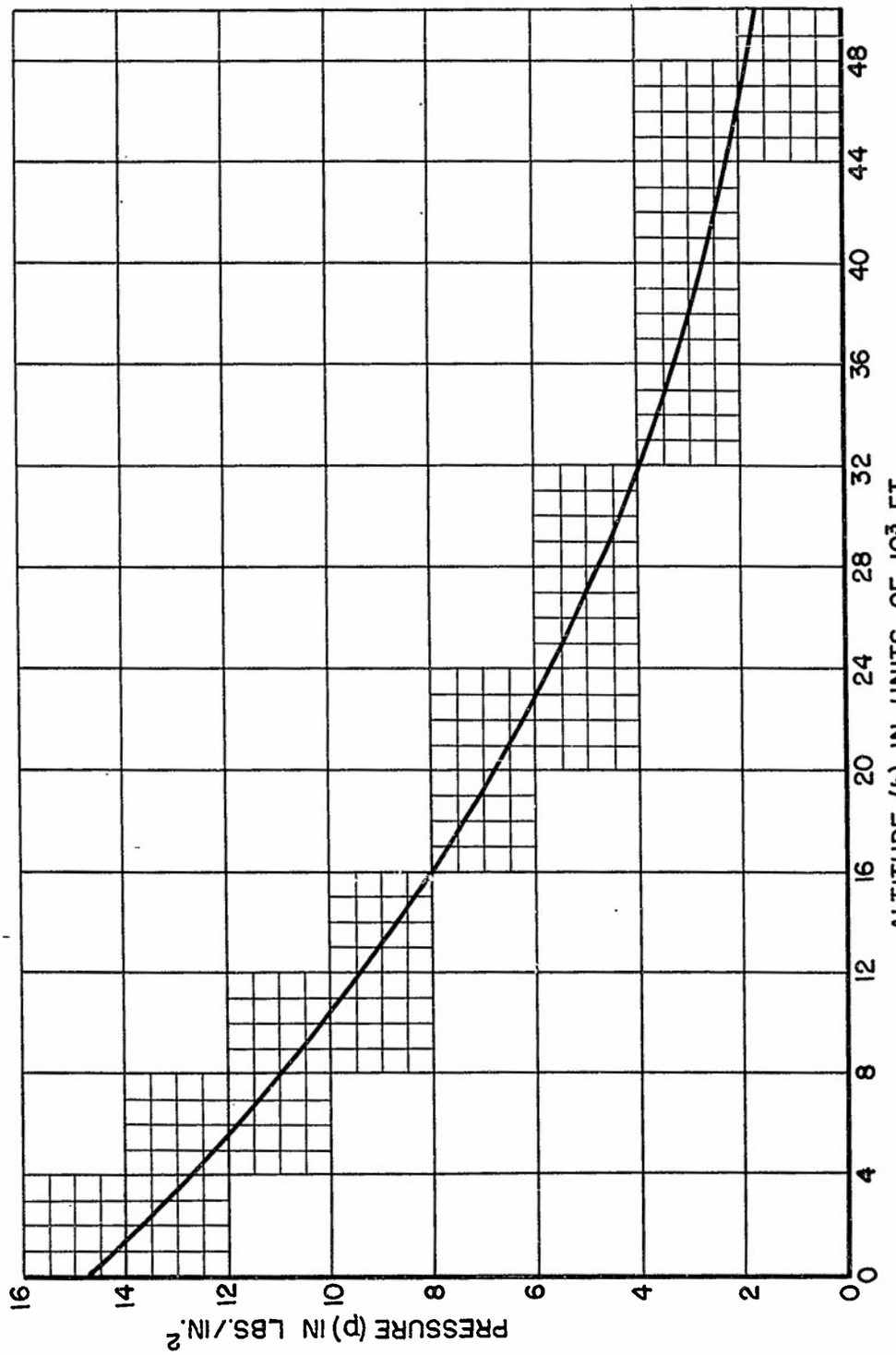


Fig. 3.2 PRESSURE OF THE ATMOSPHERE (NACA STANDARD) VS ALTITUDE - 0 TO 50,000 FT. - Data from Diehl (Ref. 3.4).

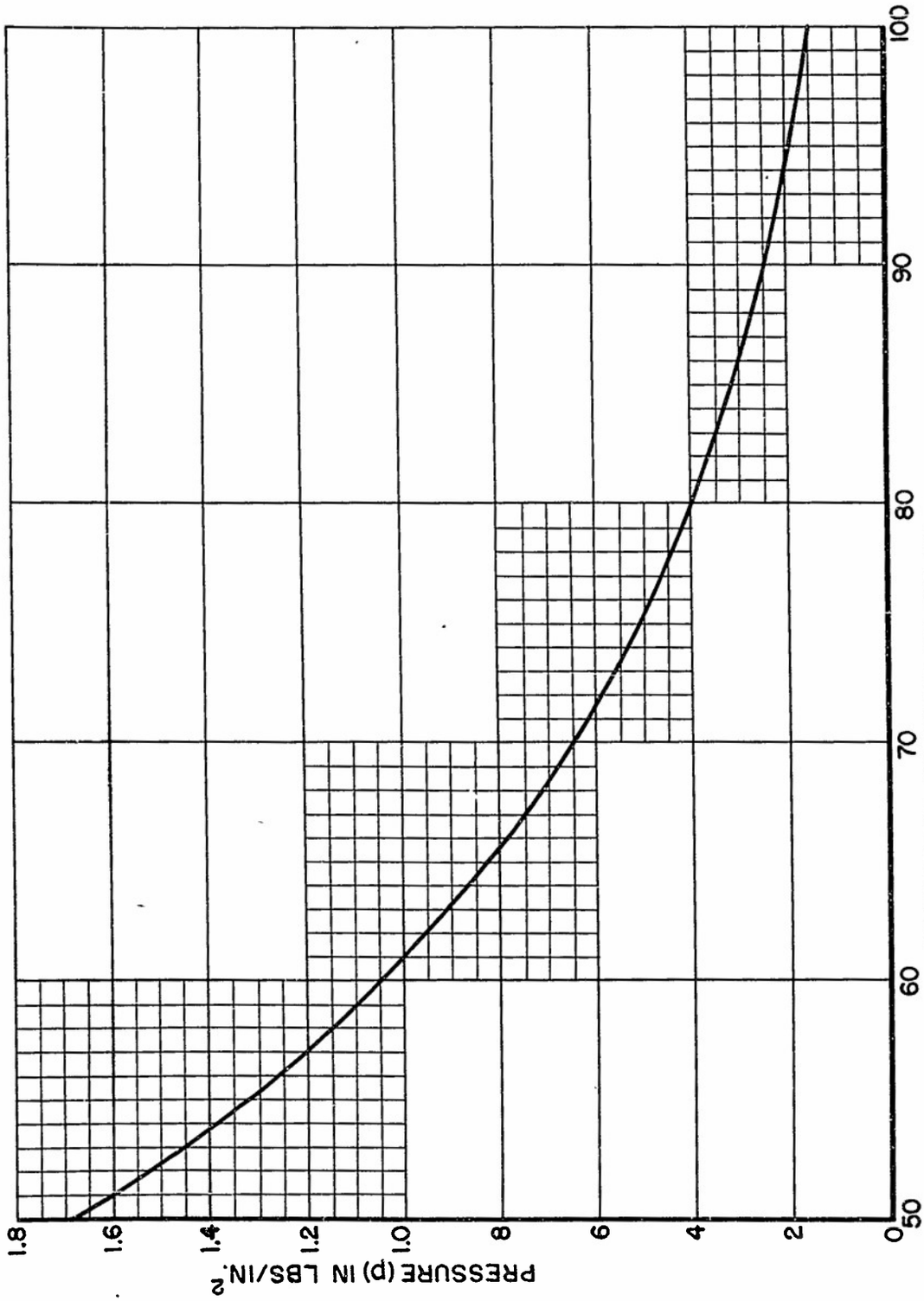


Fig. 3.3 PRESSURE OF THE ATMOSPHERE VS ALTITUDE - 50,000 TO 100,000 FT. - Data to 65,000 ft. from Diehl (Ref. 3.4). Data from 65,000 to 100,000 ft. from Aiken (Ref. 3.5).

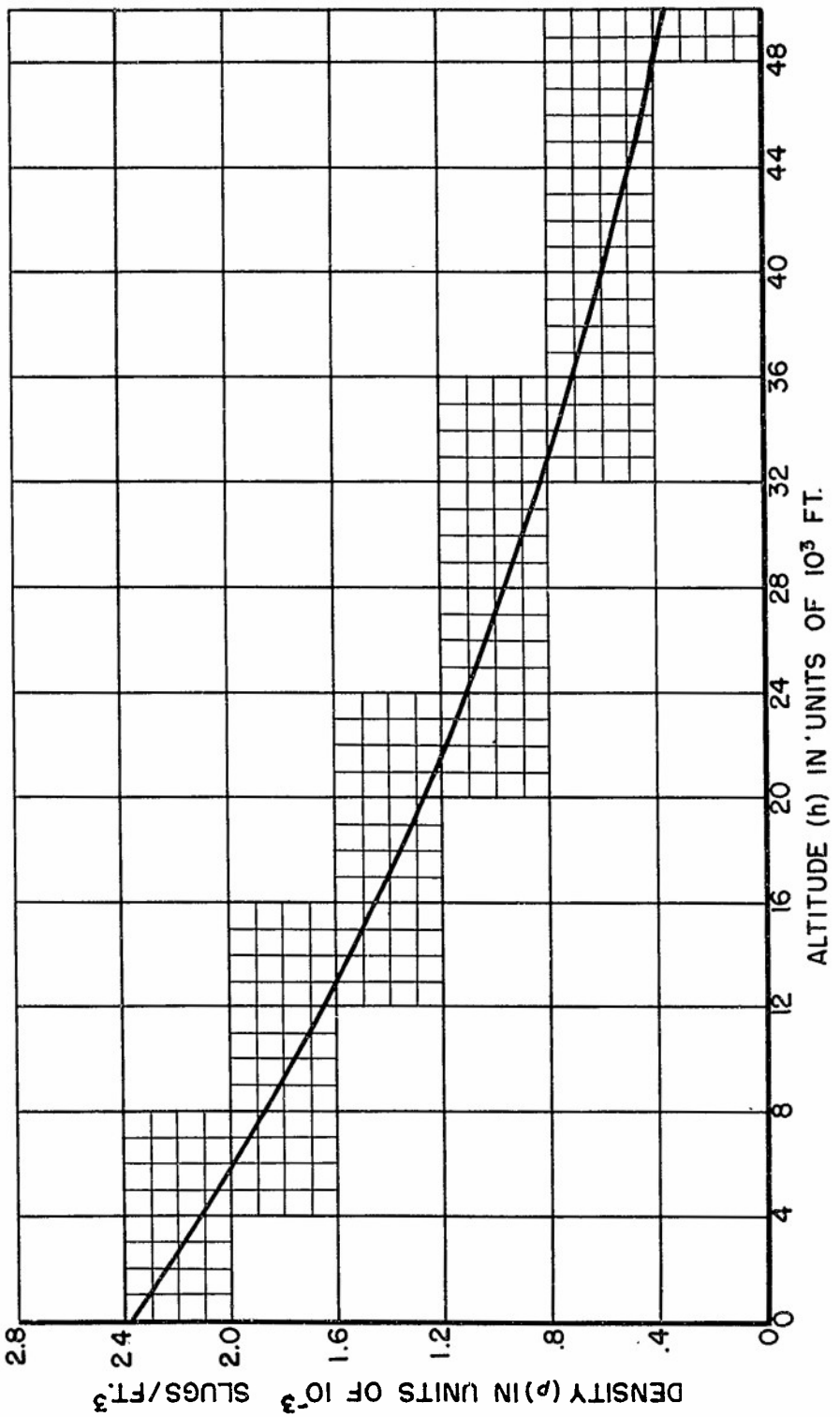


Fig. 3.4 DENSITY OF THE ATMOSPHERE (NACA STANDARD) VS ALTITUDE - 0 TO 50,000 FT. - Data from Diehl (Ref. 3.4).

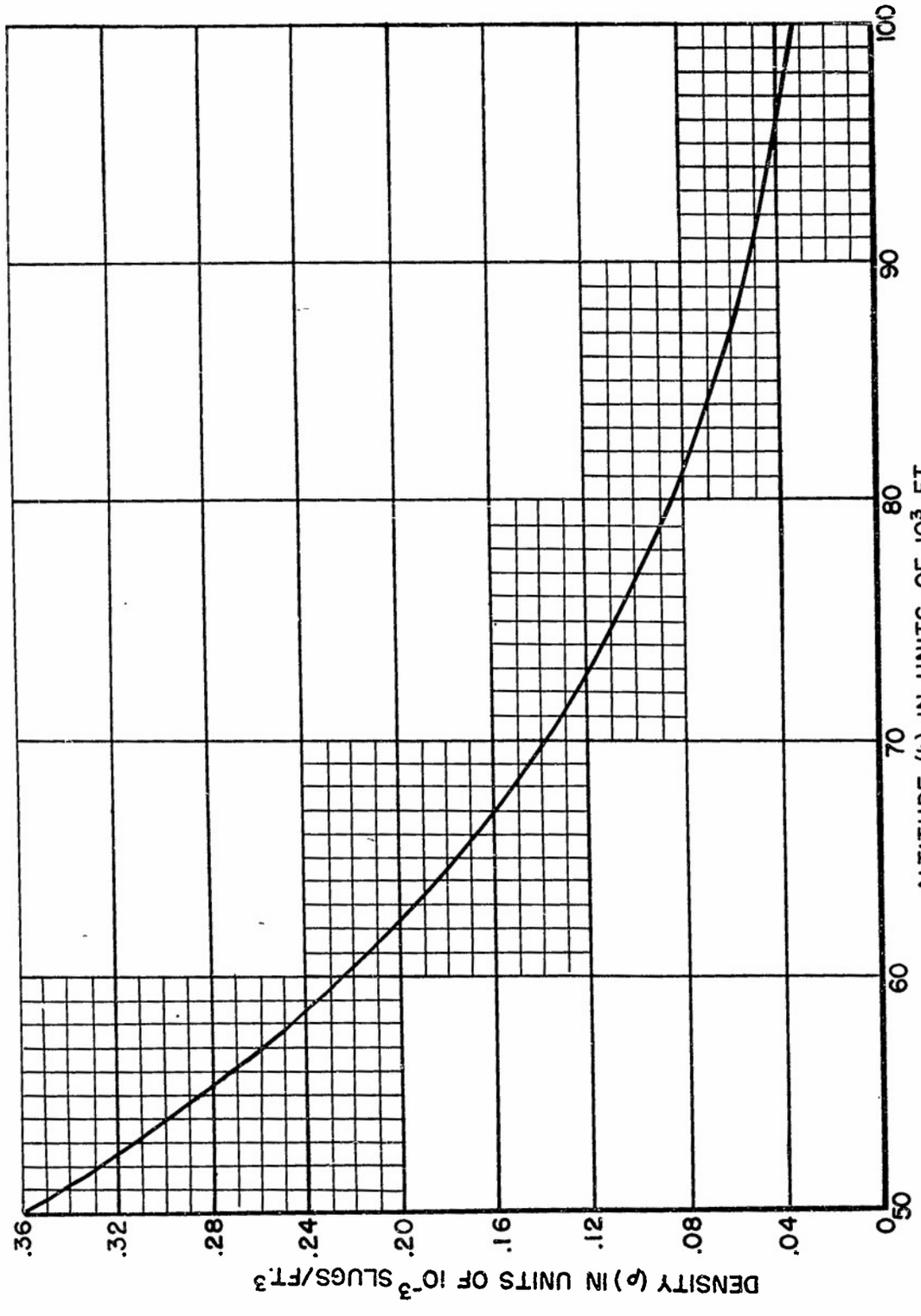


Fig. 3.5 DENSITY OF THE ATMOSPHERE VS ALTITUDE - 50,000 TO 100,000 FT.- Data to 65,000 ft. from Diehl (Ref. 3.4). Data from 65,000 to 100,000 ft. from Aiken (Ref. 3.5).

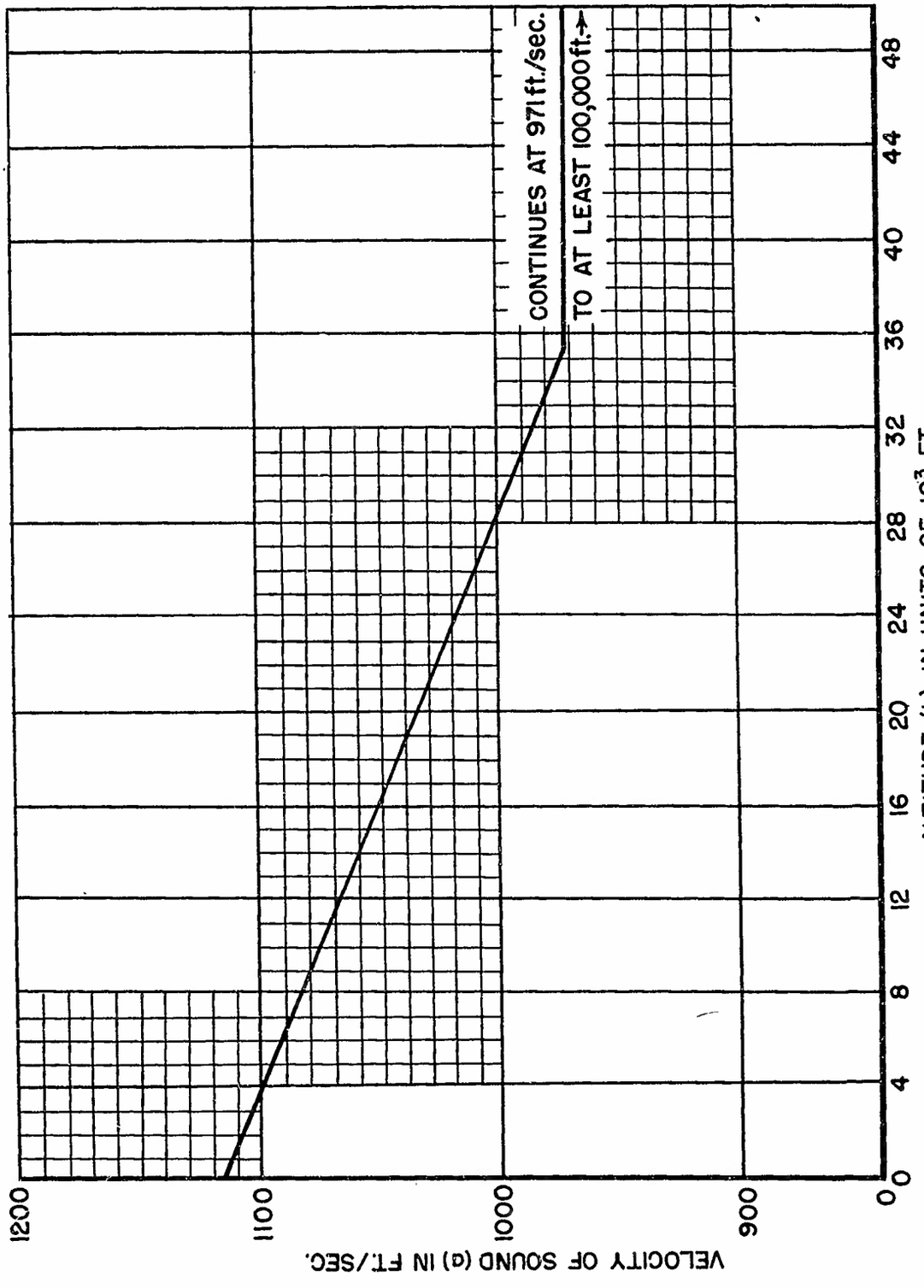


Fig. 3.6 VELOCITY OF SOUND IN THE ATMOSPHERE (NACA STANDARD) VS ALTITUDE - 0 TO 50,000 FT. - Data from Aiken (Ref. 3.5).

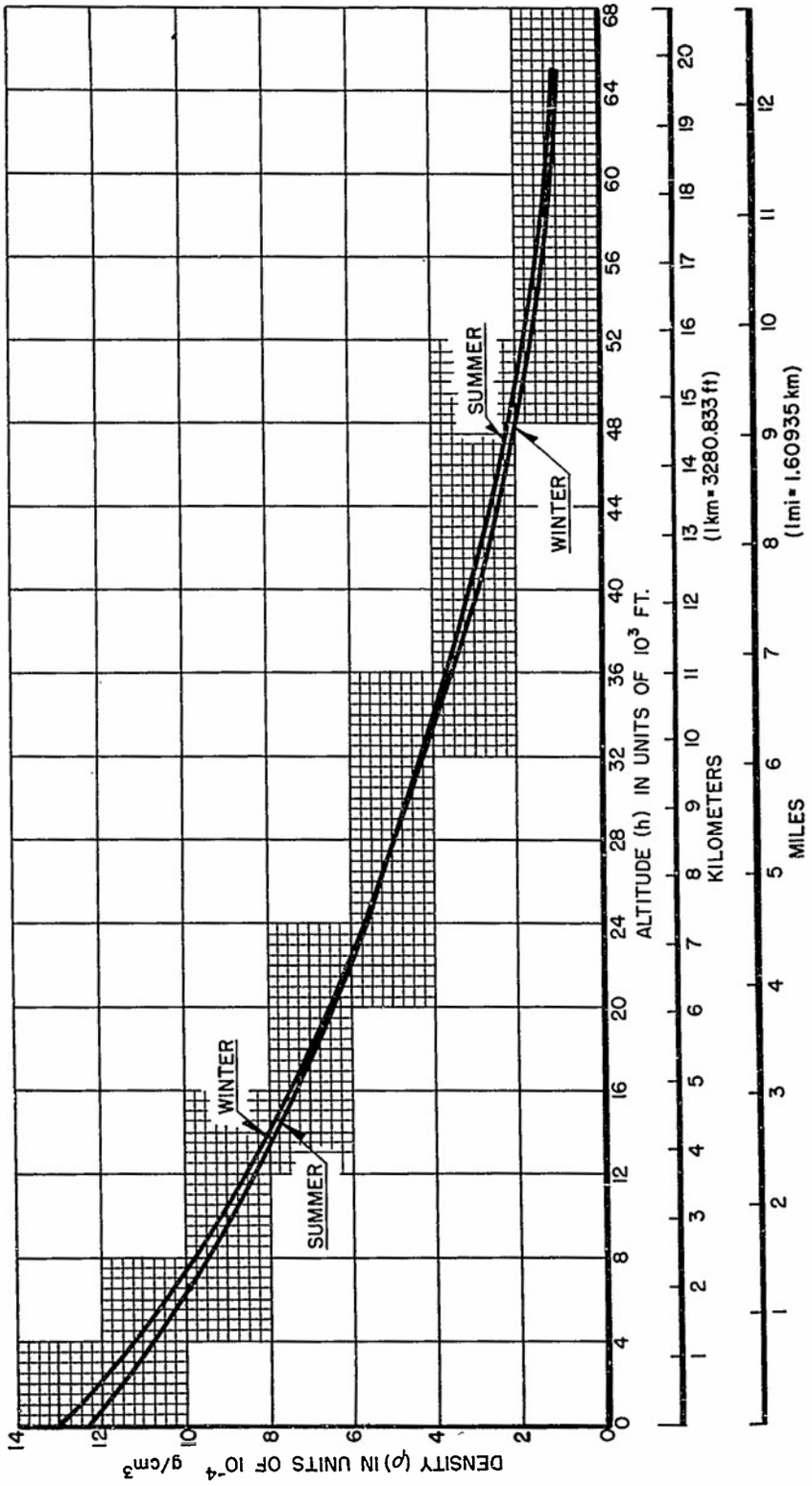


Fig. 3.7 DENSITY OF THE SUMMER AND WINTER ATMOSPHERE VS ALTITUDE - 0 TO 65,000 FT. - Data from Humphreys (Ref. 3.2, Page 78).

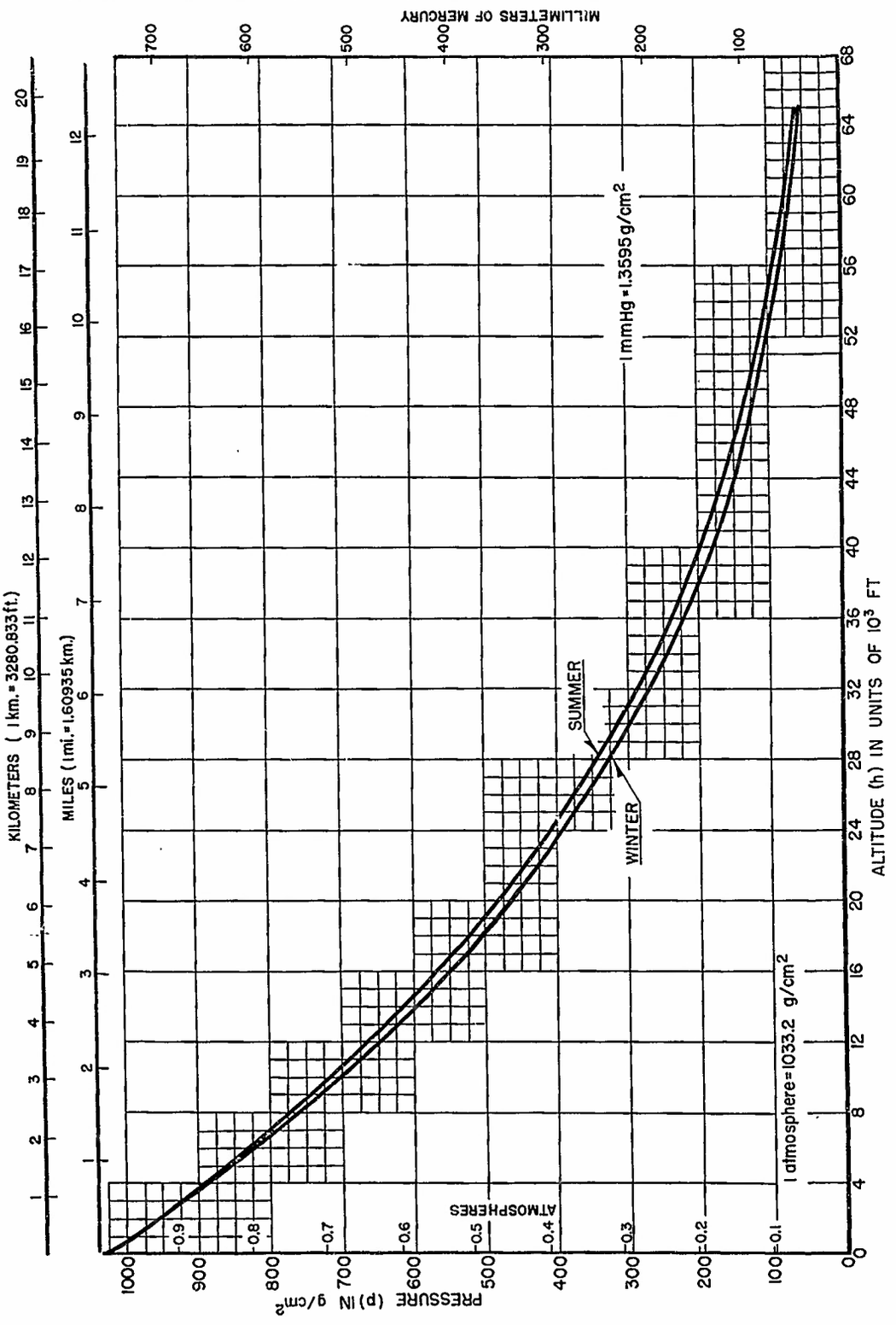


Fig. 3.8 PRESSURE OF THE SUMMER AND WINTER ATMOSPHERE VS ALTITUDE - 0 TO 65,000 FT - Data from Humphreys (Ref. 3.2, page 78).

2. Upper Atmosphere

a. Introduction

The radio-sonde balloon has provided a source of reliable information on the nature of the earth's atmosphere up to a height of approximately 130,000 feet. From data obtained by these soundings, the well known "Standard Atmosphere" has been established, to an altitude of 65,000 feet, for use in the aircraft engineering field.

Above this limit of balloon measurement, the characteristics and constituents of the atmosphere could until recently be analyzed only by indirect means. The anomalous reflection of gunfire sounds, the unusual propagation of volcanic and meteoric explosion sounds, the study of meteors and meteor trails, the study of the two free-period-oscillations of the atmosphere, the penetration and interference of radio waves, and the aurora are some of the phenomena utilized in these analyses. By combining the results of these studies, a plausible estimate of the temperature, density, pressure and composition may be obtained.

This section is primarily concerned with atmospheric conditions above the sounding balloon limit, whence the data are less accurate. Also some information on the lower atmospheric conditions is included to aid in clarity and continuity of the material presented.

b. Temperature

Pioneer study of meteors, by Lindemann and Dobson (Ref. 3.6), indicated a rise in temperature, with increasing height, above the stratosphere. This was in direct contradiction to the then accepted theory that the known low temperature of the stratosphere layer remained constant and extended to the outermost regions of the atmosphere. Furthermore, from their observations, they advanced the theory that this temperature increase was caused by the absorption of solar radiation by ozone layers. F.J.W. Whipple (Ref. 3.7) supported these claims, having found from his investigation of the abnormal propagation of sound waves indications of increasing temperatures above the stratosphere layer to a maximum temperature at a height between 164,000 and 200,000 feet. Further confirmation of such a temperature maximum was provided by Pekeris (Ref. 3.8) who, in attempting to account for the two free-period-oscillations of the atmosphere, showed that the temperature must again fall at a height immediately above the 200,000-foot level. In harmony with these conclusions was the suggestion, by Humphreys, that noctilucent clouds, found to occur only in a very small range of altitudes around 270,000 feet, were composed of ice crystals which he has shown can be formed over ice at a low temperature of 288° Rankine or lower. Another rise in temperature is required

above the 328,000-foot level to explain the energy distributions in the nitrogen bands of the auroral spectrum, observed by Vegard (Ref. 3.9), whose work on band spectra indicated a temperature of 428° Rankine in the auroral region, which occurs between 311,000 and 410,000 feet. However, Rosseland and Steensholt (Ref. 3.10) changed this value to 625° Rankine, applicable at an altitude of 361,000 feet. Martyn and Pulley (Ref. 3.11), in their study of the penetration and interaction of radio waves, as well as the periodic rise and fall of the F region, have estimated that the mean temperature at the 900,000-foot level is 1800° Rankine. They further found that the change in altitude of the F region was a function of diurnal heating and cooling, the temperature changing as much as 720° Rankine.

Several authors have adopted temperature-altitude curves which are composed from the findings of the various authors mentioned above. Martyn and Pulley (Ref. 3.11) have adopted the curve shown in Figure 3.9, while the curve shown in Figure 3.10 has been presented by F. L. Whipple (Ref. 3.12). The curve adopted by Pekeris is also plotted in Figure 3.10. The temperature given by Vegard and Tonsberg (Ref. 3.9), applicable only above 311,000 feet, also appears in this figure. The value, given by Rosseland and Steensholt, of 625° Rankine at 361,000 feet, appearing also in this figure, agrees well with Whipple's estimate. The temperature estimate attributed to Maris (Ref. 3.13, page 495) is shown in Figure 3.11.

c. Density

Less information on the density of the upper atmosphere is available. F. L. Whipple (Ref. 3.12) calculated densities to correspond to the temperature curve he adopted and substantiated his assumptions by his study of meteors. Lindemann and Dobson (Ref. 3.6), from their meteor studies, calculated a density of 1.94×10^{-8} slugs per cubic foot at 344,000 feet. However, Martyn and Pulley (Ref. 3.11) claimed this value should be 4.7×10^{-9} after certain assumptions made by Lindemann and Dobson were re-examined.

Assuming that the constitution of the atmosphere is constant below 492,000 feet, Hulburt (Ref. 3.13) has calculated the molecular density by use of the equation

$$n = n_0 e^{-h/L}$$

where $$L = \frac{kT}{mg} \quad .$$

The molecular density can readily be converted to mass density by $$\rho = n \frac{M}{C} \quad .$$

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The sum of the mass densities of each gas composing the atmosphere, namely oxygen (O_2), nitrogen (N_2), argon (A), carbon dioxide (CO_2) and helium (He), found by the above equations, gives the mass density of the atmosphere.

The density curve calculated by F. L. Whipple, on the basis of his assumed values of temperature, and the curve corrected by his meteor studies, are plotted in Figures 3.12 and 3.13. Fairly good agreement is provided by the densities given by Lindemann and Dobson and corrected by Martyn and Pulley which are shown on Figure 3.13.

d. Pressure

Still less information is available on the pressure of the atmosphere. Kurrelmeyer (Ref. 3.14) has calculated the pressure corresponding to Whipple's temperature and corrected density curve. Martyn and Pulley (Ref. 3.11) estimated, from their study of the penetration of radio waves, that the pressure at 344,500 feet is 0.001 millimeter of mercury, or 0.01316×10^{-4} atmospheres, which is in fair agreement with 0.0171×10^{-4} atmospheres given by Lindemann and Dobson (Ref. 3.6).

Kurrelmeyer's results are plotted in Figure 3.14. Also shown are points determined by Martyn and Pulley, Lindemann and Dobson, and Regener (Ref. 3.1).

e. Composition

The composition of the atmosphere at sea level, given in Table 3.1, is well known and its determination presents little difficulty, since it can be measured directly. However, measuring the composition of the upper atmosphere presents more of a problem and, as with the temperature, density and pressure, until recently had to be determined indirectly above the limit of balloon ascension.

Two fundamental laws are associated with atmospheric composition: first, the law of the exponential decrease in pressure with altitude, in other words, the barometric altitude formula; second, Dalton's law of partial pressures, which states that in a mixture of gases at a given temperature (provided the gases do not react chemically), each gas exerts the same pressure as if it alone occupied the entire volume at that temperature; and the total pressure is the sum of these partial pressures. In compliance with the terms of the first law, the gases of the atmosphere, if undisturbed, and of constant temperature, would distribute themselves in an exponential manner, i.e., the decrease of particles, with altitude, would be greater for the heavier gases. However, intermixture takes place due to motion of the air, so that this segregation cannot occur and the result is an almost constant composition up to the lower stratosphere, where, from recent experiments,

vertical motion is still evident, though reduced.

Regener (Ref. 3.1) has made balloon soundings up to 93,500 feet and, by means of apparatus carried in the balloon, determined the oxygen content of the air up to that height. The results of his observations are shown in Figure 3.15. His experiments showed that segregation is retarded below the stratosphere, proving that the composition is for all practical purposes, constant up to approximately 50,000 feet. Above this height, segregation begins to occur, although it is very far removed from a theoretical air at rest, since some mixing still takes place up to 93,500 feet. Paneth (Ref. 3.15) measured the helium increase with altitude up to 75,000 ft. His results as recorded by Regener (Ref.3.1) are shown in Figure 3.16. By comparing the relative rate of increase of helium above 50,000 ft. as shown in Figure 3.16 with the relative rate of decrease of oxygen above 50,000 ft. as shown in Figure 3.15, it can be seen the ratio of the former to the latter is, within experimental limits, 8 to 1, which is the ratio of the molecular weights of oxygen and helium. This conforms exactly to the exponential law, and indicates some segregation occurs above 50,000 ft., but the segregation remains far behind the theoretical value for atmosphere at complete rest. The slope of the curve for the oxygen deficiency may be estimated to be 1/5 of the slope of a curve in the case of an atmosphere at complete rest. The theoretical curve for oxygen reduction is shown on Figure 3.15. Hence, even at altitudes up to about 93,500 feet the atmosphere must be intermixed by vertical movements.

DATE	ALTITUDE FEET	TEMPERATURE °RANKINE	RELATIVE HUMIDITY IN RESPECT TO ICE
5-1-38	23,000	452.4	16.7%
7-8-38	23,000	456.4	36.0%
	34,500	416.8	58.0%
	52,500	413.4	18.0%
12-13-38	24,600	429.0	44.0%
2-25-39	23,000	431.7	42.0%
	34,500	394.0	39.0%
7-19-39	25,300	448.0	19.0%
	34,800	404.0	59.0%
	73,000	407.5	7.0%

Table 3.4 COMPOSITION OF THE ATMOSPHERE, VARIATION OF RELATIVE HUMIDITY WITH ALTITUDE. Data from Regener (Ref. 3.1).

Water vapor, the amount of which undergoes a great fluctuation, has also been measured by Regener, the results of his observations are given in Table 3.4. Quite low humidities were observed in the stratosphere. However, exceptions were noted, indicating that supersaturation could occur in the stratosphere, thereby supporting the theory that nacreous clouds, which occur at heights between 75,500 feet and 85,500 feet, are composed of ice crystals.

Although water vapor is formed at the earth's surface by absorption of the complete solar radiation, ozone is formed principally at high altitudes by the absorption of the ultraviolet radiation. The ozone concentration at sea level is low, and quite variable. At high altitudes there is about 5 to 7 times the ozone concentration at sea level, the maximum ozone concentration occurring between 72,100 feet and 82,000 feet. Slight variations with latitude and air sources are noted. Regener measured the ozone content by balloon-carried spectrographs and observed that normally 70 percent of the entire ozone stratum of the atmosphere was concentrated below the 98,000 foot level. However, even a low percentage of ozone has very peculiar and important consequences which result from a very high absorption of solar radiation and cause a heating of the ozone layer, the overall height of which is from 72,000 feet to 147,500 feet. Regener observes (Ref. 3.1) that this heating means that vertical motion of the air must be retarded more below the upper part of the ozone strata (115,000 feet) than in the underlying troposphere layer, where the temperature remains almost constant. Regener concludes that conditions for segregation must be favorable up into the ozone layer, probably up to its upper limit (147,500 feet), the temperature there being approximately 580° Rankine and the oxygen content probably decreases rapidly with altitude in this region.

Above this level, until recently, little was knwon of the composition. Regener remarks that the spectra of the aurora-borealis, observed by Stormer and Vegard, show no hydrogen or helium lines, but only oxygen and nitrogen. This indicates that the composition above 280,000 feet may be made up principally of these two elements. Regener's estimate of the composition (with respect to Argon, Nitrogen and Oxygen) of the upper atmosphere is shown on Figure 3.17.

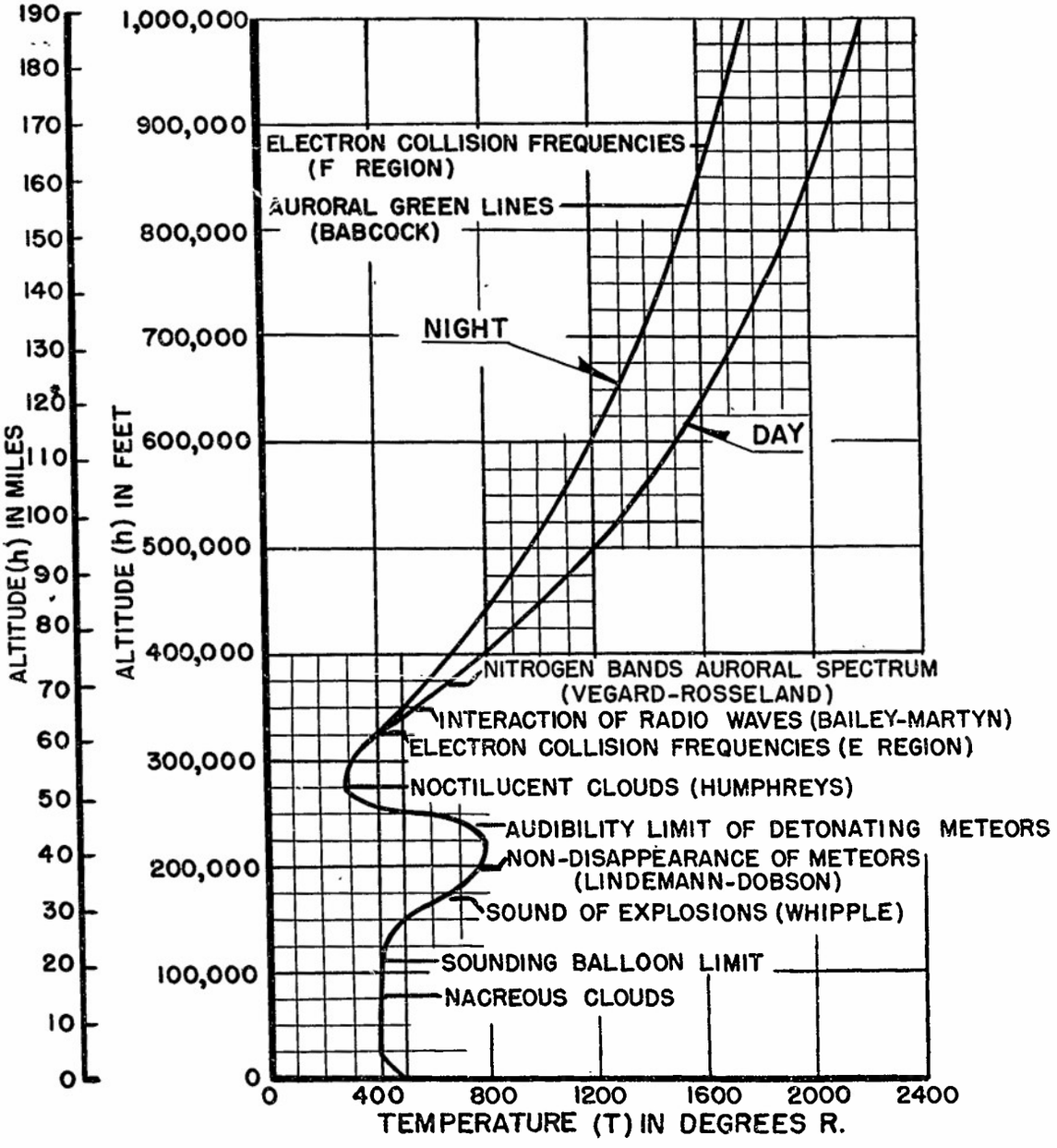


Fig. 3.9 ALTITUDE VS TEMPERATURE OF THE ATMOSPHERE - Data from Martyn and Pulley (Ref. 3.11).

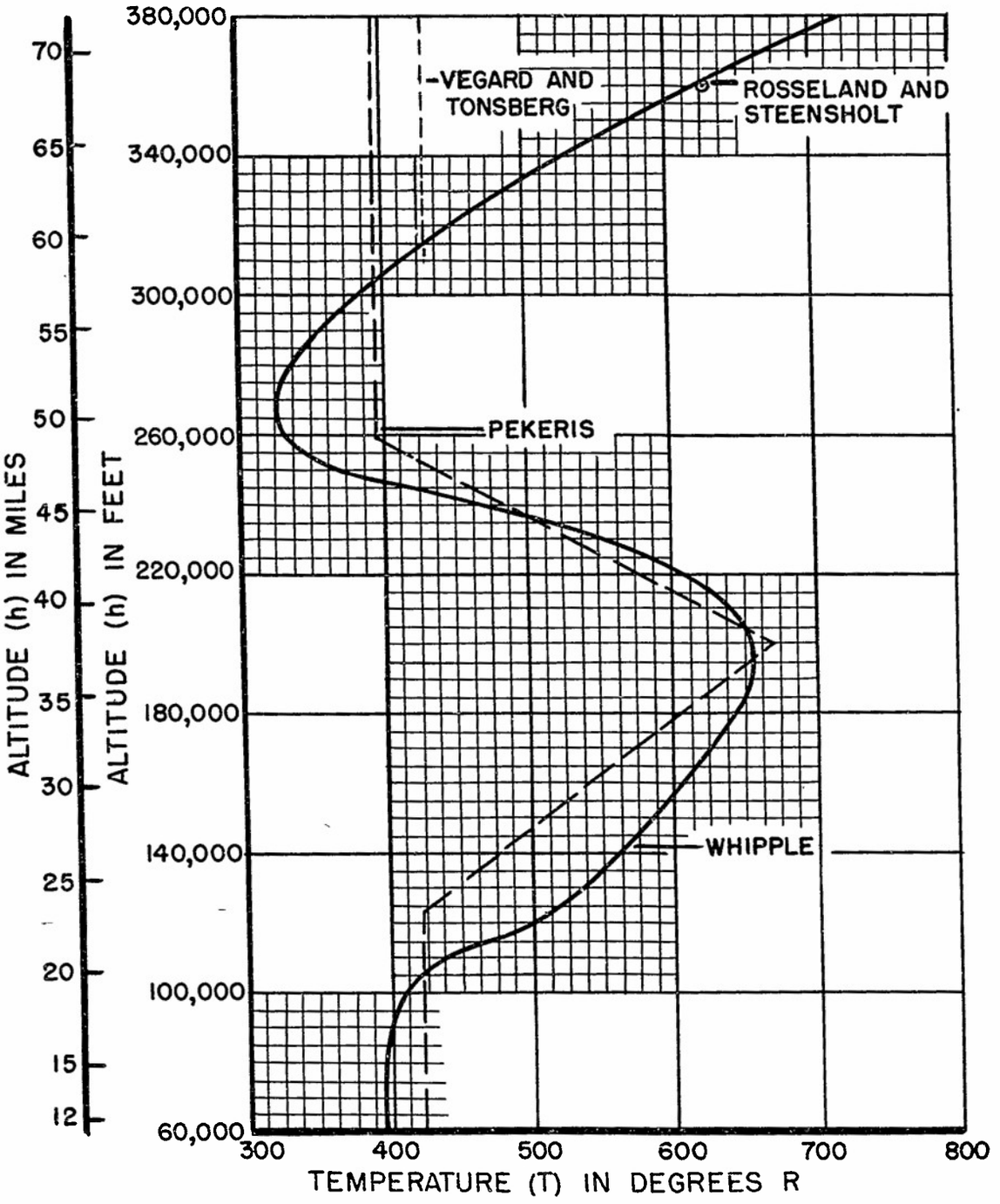


Fig. 3.10 ALTITUDE VS TEMPERATURE OF THE ATMOSPHERE - Data from Whipple, Fred L. (Ref. 3.12).

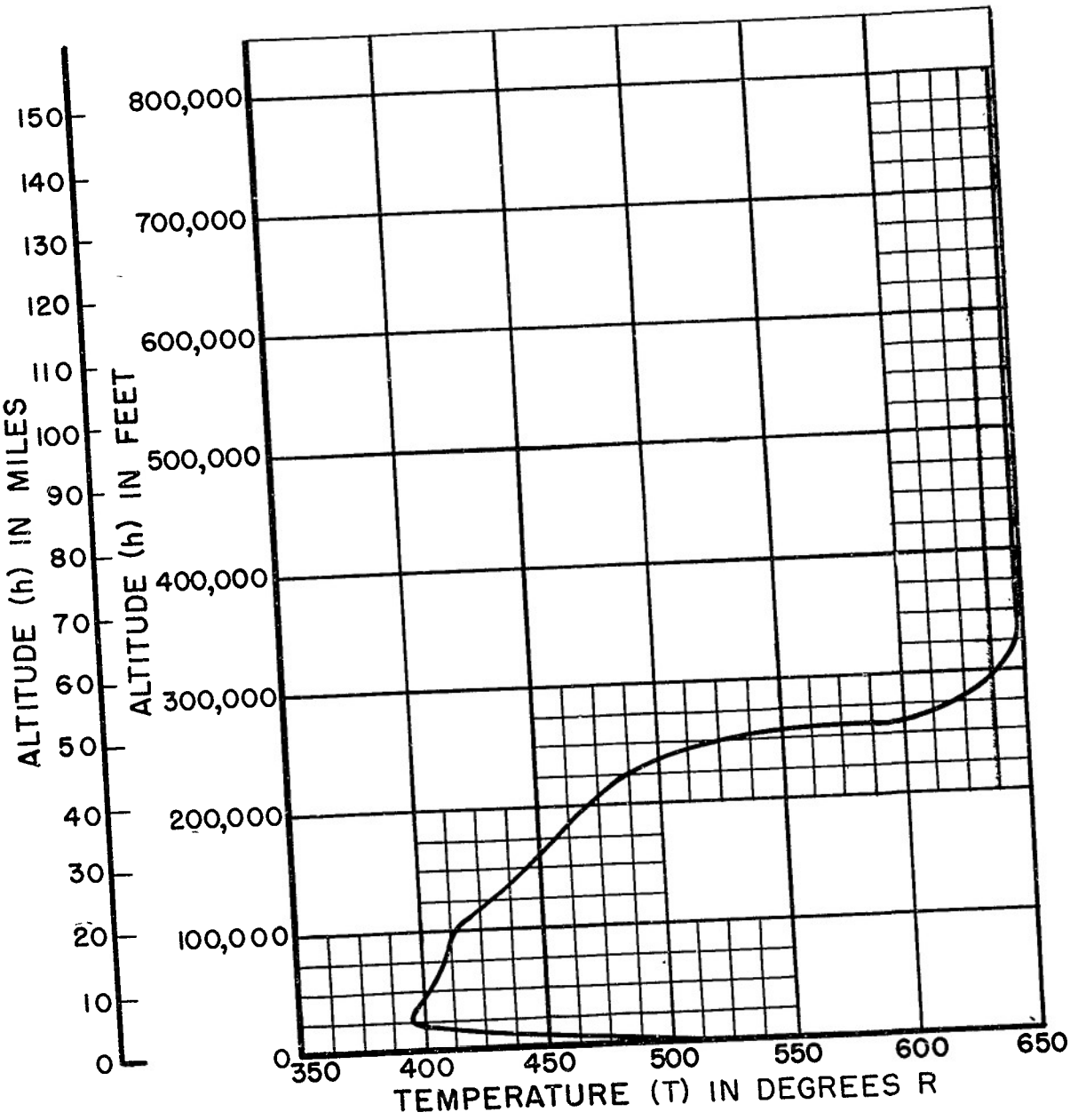


Fig. 3.11 ALTITUDE VS TEMPERATURE OF THE ATMOSPHERE - Converted from data attributed to Maris (Ref 3.13, page 495).

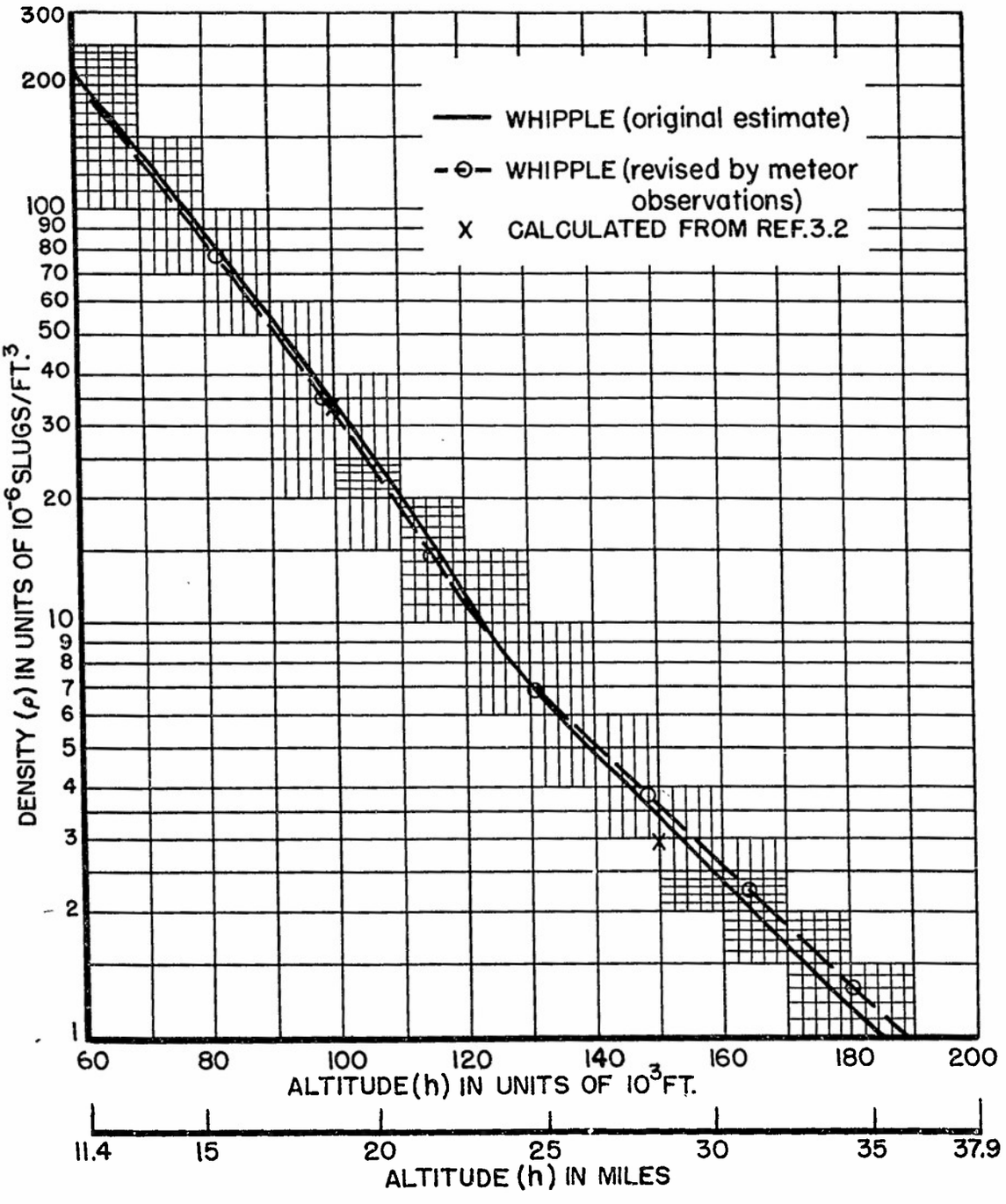


Fig. 3.12 DENSITY OF THE ATMOSPHERE VS ALTITUDE - 60,000 TO 189,000 FT. - Data from various authorities as shown.

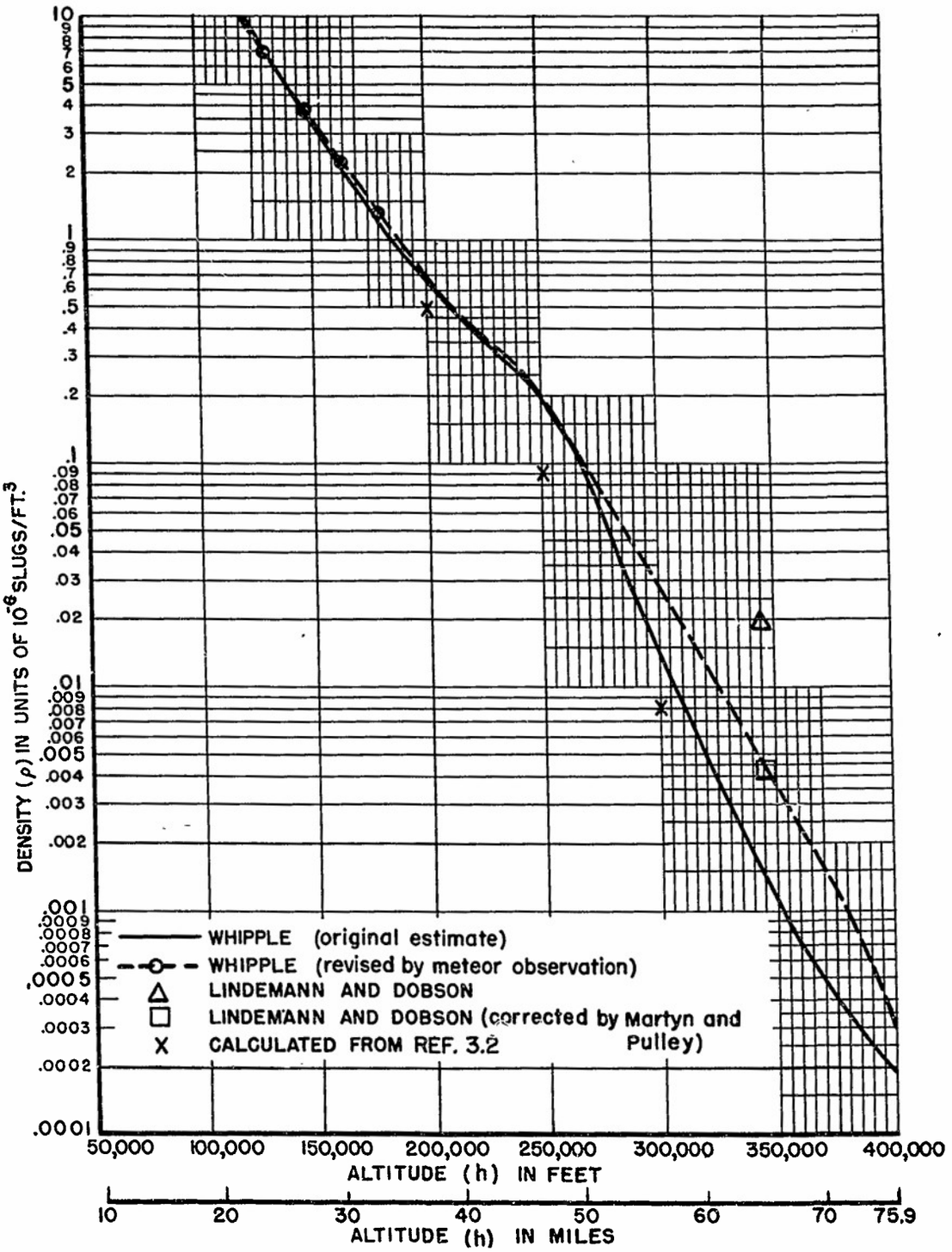


Fig. 3.13 DENSITY OF THE ATMOSPHERE VS ALTITUDE - 120,000 TO 400,000 FT. - Data from various authorities as shown.

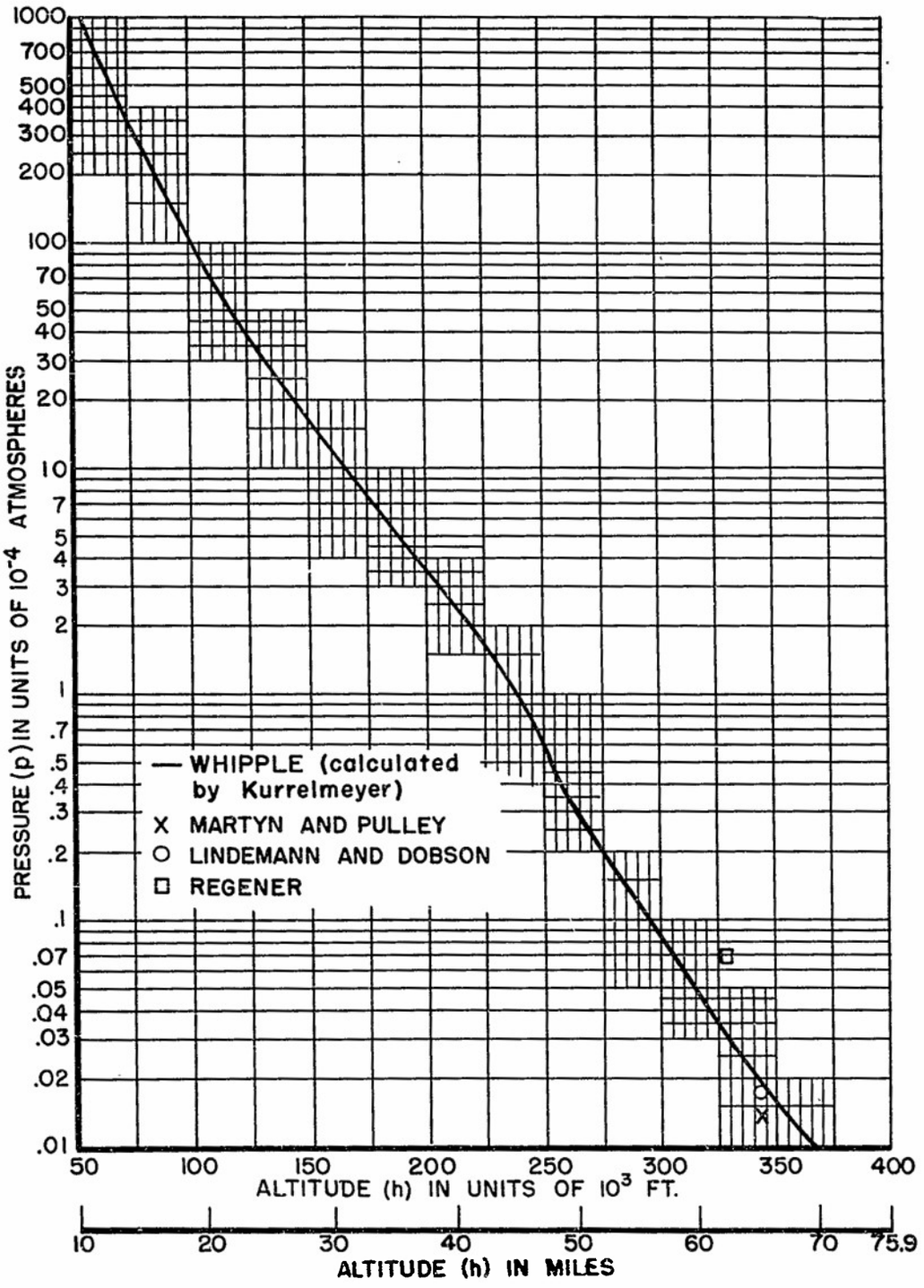
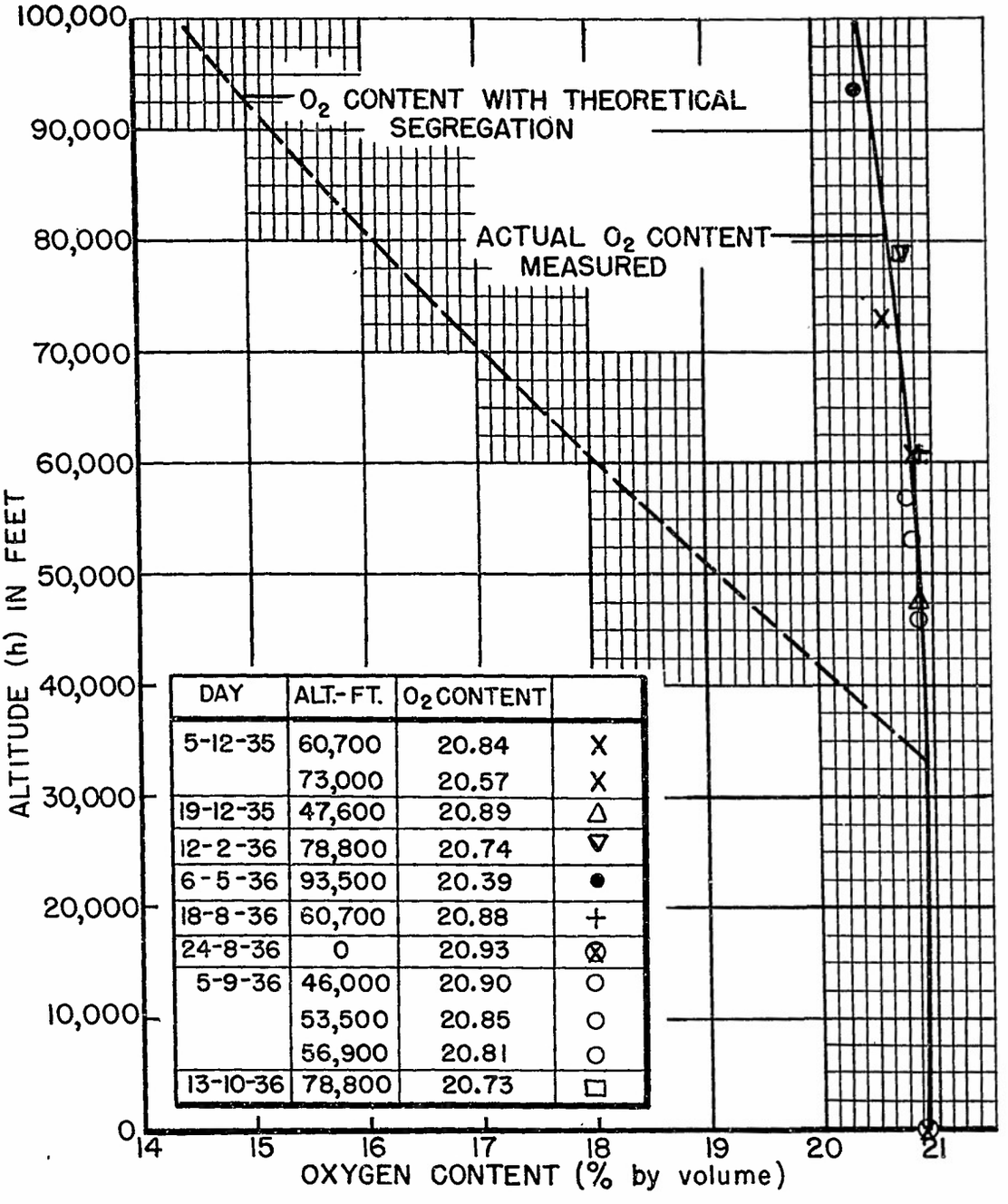


Fig. 3.14 PRESSURE OF THE ATMOSPHERE VS ALTITUDE - Data from various authorities as shown.



DAY	ALT.-FT.	O_2 CONTENT	
5-12-35	60,700	20.84	X
	73,000	20.57	X
19-12-35	47,600	20.89	△
12-2-36	78,800	20.74	▽
6-5-36	93,500	20.39	●
18-8-36	60,700	20.88	+
24-8-36	0	20.93	⊗
5-9-36	46,000	20.90	○
	53,500	20.85	○
	56,900	20.81	○
13-10-36	78,800	20.73	□

Fig. 3.15 COMPOSITION OF THE ATMOSPHERE, REDUCTION OF OXYGEN CONTENT WITH ALTITUDE. - Data from Regener (Ref. 3.1).

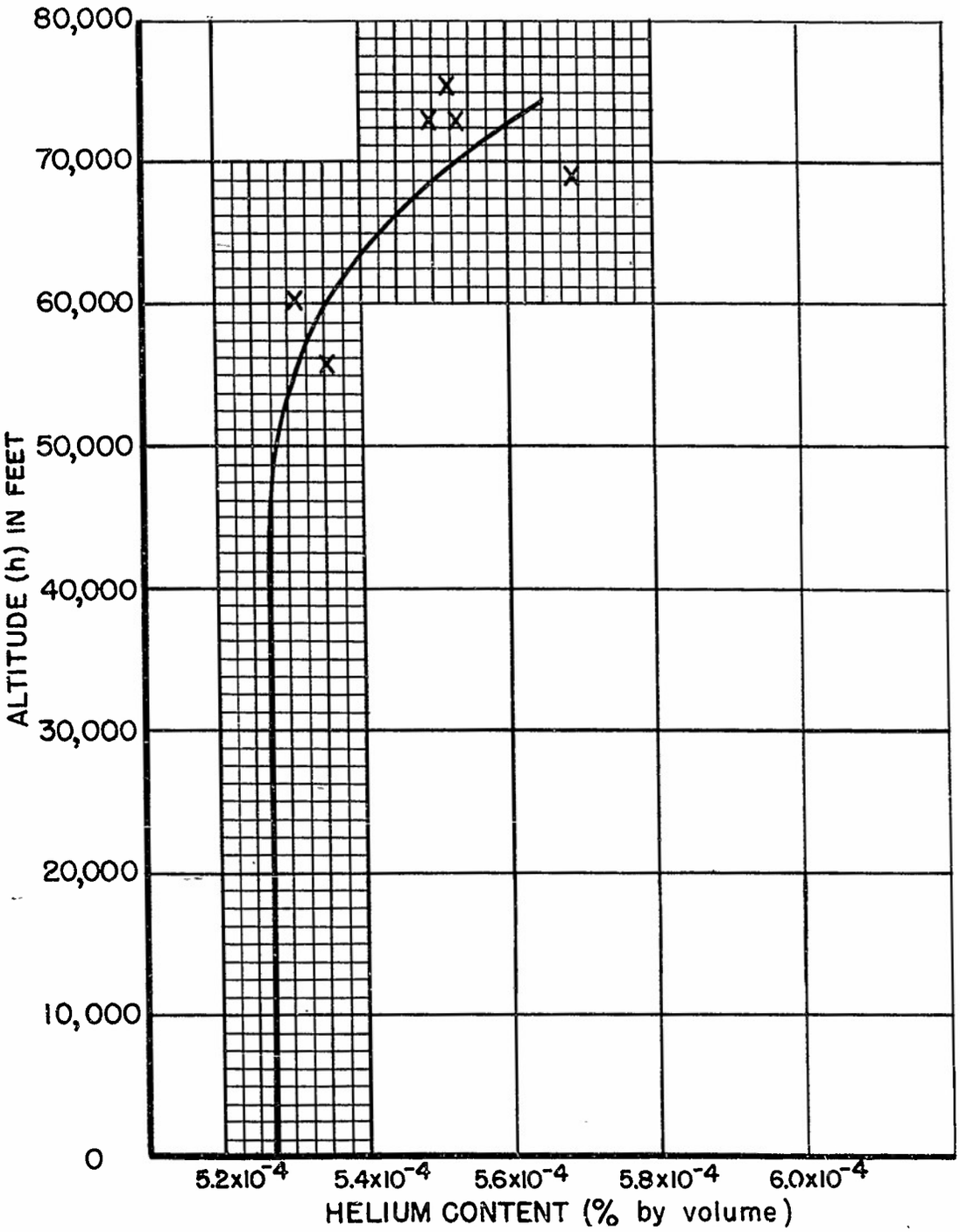


Fig. 3.16 COMPOSITION OF THE ATMOSPHERE, INCREASE OF HELIUM CONTENT WITH ALTITUDE - Data attributed to Paneth from Regener (Ref. 3.1).

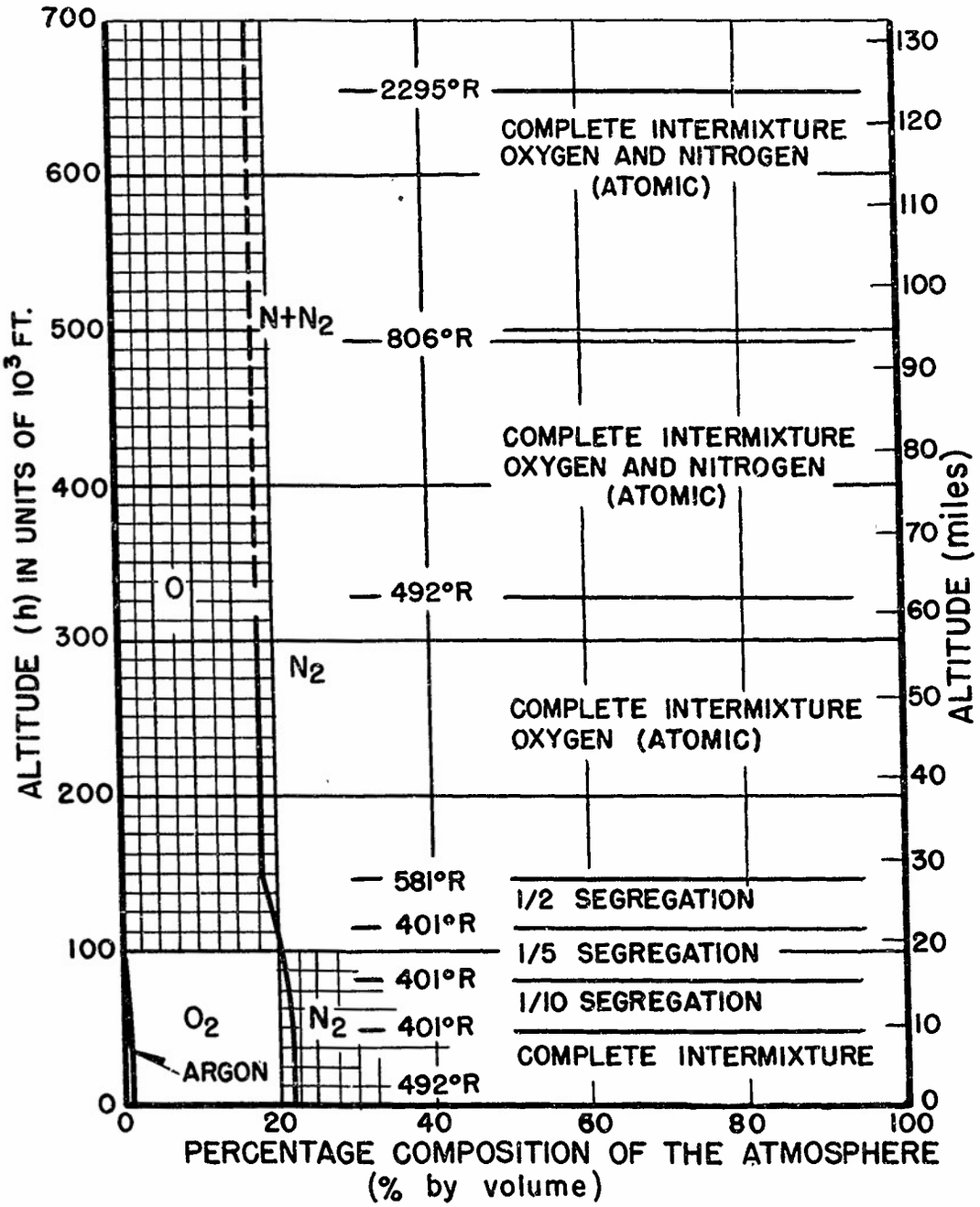


Fig. 3.17 ALTITUDE VS PERCENTAGE COMPOSITION OF THE ATMOSPHERE, WITH RESPECT TO ARGON, OXYGEN AND NITROGEN ONLY - Data from Regener (Ref. 3.1).

3. NACA Tentative Data for the Properties of the Upper Atmosphere

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 (Ref. 3.4). 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 (Tables 3.5 and 3.6) 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 (Ref. 3.4). 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 (Tables 3.7 and 3.8) 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 difference in height at which dissociated oxygen exists by day and by night.

If still greater accuracy than is inherent in Tables 3.7 and 3.8 is required at latitudes displaced from latitude 45°, an estimate of the latitude effect upon pressure may be obtained by use of Table 3.9 in which are tabulated values of the latitude correction factor, defined by $L.C.F. = p_\phi/p$ where p_ϕ is the pressure at latitude ϕ, corresponding to the pressure p at latitude 45°.

The three temperature-height relationships (Fig. 3.18) represent tentative standard temperatures and probable minimum and probable maximum temperatures throughout the world. The tables based upon the tentative standard temperatures should be useful

in evaluating performance characteristics and for design purposes, and such tables (Tables 3.5-3.8) are given in this sub-section. The probable minimum and probable maximum temperature should be useful for estimating limiting performance of aircraft, missiles, and prime movers.

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. Furthermore, it is 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:

a. 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.

b. 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.

c. At altitudes below the regions of oxygen dissociation, the composition is the same as that at sea level.

d. At altitudes above the regions in which both molecular and atomic oxygen exist, as stipulated in (a) and (b), 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 atmosphere is graphically portrayed in Figure 3.19(a).

The sea level values for the several properties of the atmosphere, upon which the computed values for the upper atmosphere are based, are given in Table 3.2.

The graphs of Figure 3.20 are based on the inverse square variation of gravity and therefore correspond to Tables 3.6 and 3.7. The variation of the ratio of specific heat (γ) shown in Figure 3.20(a) is based on the dissociation of oxygen above 80 kilometers by day, and above 105 kilometers by night. The effect of pressure and temperature upon γ is estimated to be less than 0.6% and is ignored.

Figure 3.21 shows the temperature as a function of the altitude. The graph from 0 to 65,000 feet is based on data from Diehl (Ref. 3.4) and from 65,000 to 393,700 feet on data from Warfield (Ref. 3.3) .

The graphs of Figures 3.22 and 3.23 are based on an arbitrary constant value of gravitational force and therefore correspond to Tables 3.4 and 3.5.

The velocity of sound in the NACA standard atmosphere (Ref. 3.4) and in the NACA tentative standard atmosphere (Ref. 3.3) is shown in Figure 3.24.

Altitude, h (m)	Absolute temperature, T (°K)	Pressure, p (kg/m^2)	Pressure ratio, p/p_0	Density, ρ ($\frac{kg\text{-}sec^2}{m^4}$)	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	Specific weight, $w = g\rho$ (kg/m^3)	Coefficient of viscosity, μ ($\frac{kg\text{-}sec}{m^2}$)	Kinematic viscosity, $\upsilon = \frac{\mu}{\rho}$ (m^2/sec)	Speed of sound, a (m/sec)	Mean free path of molecules, λ (m)
(a) For both day and night										
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	530.5	5038	8318	6656	8157	1.446	0.01738	296.0	0.00111
21,000	218.0	491.3	4668	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	4866	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	0.00163
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	1.457	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	406.8	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	1.286	359.0	0.0596
46,500	324.3	13.50	130.6	144.9	116.0	142.1	1.996	1.387	361.0	0.0636
47,000	328.0	12.81	123.9	136.0	108.8	133.4	2.013	1.492	363.1	0.0677
47,500	332.7	12.16	117.7	127.7	102.2	125.2	2.030	1.599	365.1	0.0721
48,000	335.3	11.56	111.8	120.0	96.01	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	1.820	369.1	0.0815
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	8.586	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	69.10	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	5.959	375.1	0.259
60,500	346.9	3.396	32.87	34.10	27.28	33.44	2.101	6.163	373.8	0.270
61,000	343.7	3.232	31.28	32.74	26.20	32.11	2.087	6.375	372.5	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	22.32	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	19.52	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	16.96	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	13.41	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	0.5713	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	0.3751	3.631	5.448	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

Table 3.5 PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE - Metric Engineering System. Table II of Ref. 3.3.

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Altitude, h (m)	Absolute temperature, T (°K)	Pressure, p (kg/m^2)	Pressure ratio, p/p_0	Density, ρ ($\frac{kg\text{-}sec^2}{m^4}$)	Density ratio, $\sigma = \rho/\rho_0$	Specific weight, $w = g\rho$ (kg/m^3)	Coefficient of viscosity, μ ($\frac{kg\text{-}sec}{m^2}$) (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	0.2137	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	920.9	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
93,000	283.8	0.05079	491.6	538.8	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	325.5	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	268.3	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	79.53	97.48	2.079	20.92	416.7	76.8
112,000	345.8	0.01088	105.3	90.69	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
115,000	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	46.28	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	0.2124	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	153.8	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

[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 3.5 PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE - Metric Engineering System. Table II of Ref. 3.3. (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, $\gamma = g\rho$ (lb/ft^3)	Coefficient of viscosity, μ ($lb\ sec/ft^2$)	Kinematic viscosity, $\nu = \frac{\mu}{\rho}$ (ft^2/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}	7434×10^{-5}	5672×10^{-6}	2.961×10^{-7}	0.001680	971.1	0.00326×10^{-3}
66,000	392.4	113.9	5380	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	6431	4914	2.961	0.001938	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	77.28	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	3293	2518	2.961	0.003784	971.1	0.00735
83,000	392.4	50.26	2375	746.2	3138	2401	2.961	0.003971	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	35.96	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	0.006711	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	0.007741	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	0.0165
100,000	392.4	22.31	1054	331.0	1392	1065	2.961	0.008946	971.1	0.0174
102,000	392.4	20.24	956.6	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
106,000	392.4	16.80	793.2	248.8	1046	799.6	2.961	0.01190	971.1	0.0231
108,000	394.5	15.36	721.2	226.8	954.2	729.1	2.959	0.01308	972.2	0.0254
110,000	412.6	13.92	658.0	196.6	826.8	632.6	2.950	0.01437	979.8	0.0293
112,000	430.6	12.71	601.4	176.2	741.2	567.1	2.941	0.01581	1005	0.0326
114,000	448.7	11.65	550.6	158.3	665.9	509.5	2.931	0.02016	1015	0.0363
116,000	466.7	10.69	505.0	142.6	599.5	458.7	2.921	0.02273	1025	0.0403
118,000	484.8	9.817	463.9	128.6	540.9	413.8	2.912	0.02568	1034	0.0447
120,000	502.8	9.026	426.5	116.1	488.3	373.6	2.902	0.02876	1043	0.0495
122,000	520.9	8.315	392.9	105.1	442.0	338.2	2.893	0.03224	1052	0.0547
124,000	538.9	7.671	362.5	95.31	400.8	306.6	2.883	0.03605	1062	0.0604
126,000	556.9	7.089	335.0	86.58	364.1	278.6	2.874	0.04024	1071	0.0664
128,000	575.0	6.558	309.8	78.73	331.1	253.3	2.864	0.04485	1080	0.0731
130,000	593.0	6.071	286.9	71.74	301.7	230.8	2.855	0.04989	1089	0.0802
132,000	611.1	5.631	266.1	65.46	275.2	210.6	2.845	0.05538	1097	0.0879
134,000	629.1	5.229	247.1	59.83	251.6	192.5	2.836	0.06137	1106	0.0961
136,000	647.2	4.859	229.6	54.73	230.1	176.0	2.826	0.06795	1115	0.105
138,000	665.2	4.522	213.7	50.15	210.9	161.4	2.817	0.07505	1124	0.115
140,000	683.3	4.213	199.1	46.01	193.5	148.0	2.809	0.08279	1132	0.125
142,000	701.3	3.930	185.7	42.20	177.8	136.0	2.801	0.09115	1141	0.136
144,000	719.4	3.670	173.4	38.70	163.6	125.2	2.792	0.1002	1149	0.148
146,000	737.4	3.428	162.0	35.83	150.7	115.3	2.944	0.1101	1157	0.161
148,000	755.5	3.208	151.6	33.05	139.0	106.3	2.968	0.1207	1166	0.174
150,000	773.5	3.003	141.9	30.51	128.3	98.12	3.032	0.1322	1174	0.189
152,000	791.6	2.815	133.0	28.20	118.6	90.74	3.076	0.1445	1182	0.204
154,000	809.6	2.638	124.7	26.06	109.6	83.85	3.119	0.1581	1190	0.221
156,000	827.6	2.470	117.1	24.16	101.6	77.73	3.163	0.1723	1199	0.238
158,000	845.7	2.328	110.0	22.39	94.35	72.03	3.205	0.1878	1207	0.257
160,000	863.7	2.190	103.5	20.79	87.42	66.88	3.247	0.2043	1215	0.277
162,000	881.8	2.061	97.37	19.30	81.18	62.13	3.289	0.2222	1223	0.298
164,000	899.8	1.941	91.72	17.95	75.49	57.72	3.331	0.2413	1232	0.320
166,042	920.0	1.838	86.90	16.69	70.18	53.68	3.379	0.2619	1241	0.343
168,000	938.0	1.739	82.42	15.61	65.64	50.22	3.419	0.2817	1249	0.367
170,000	956.0	1.644	78.03	14.51	61.04	46.69	3.459	0.3029	1257	0.393
172,000	974.0	1.554	73.79	13.48	56.68	43.36	3.499	0.3254	1265	0.420
174,000	992.0	1.469	69.75	12.52	52.63	40.26	3.539	0.3495	1273	0.448
176,000	1010.0	1.388	65.92	11.62	48.84	37.37	3.579	0.3752	1281	0.478
178,000	1028.0	1.312	62.30	10.78	45.32	34.68	3.619	0.4027	1289	0.509
180,000	1046.0	1.240	58.87	10.00	42.04	32.17	3.659	0.4320	1297	0.543
182,000	1064.0	1.172	55.64	9.280	39.01	29.85	3.699	0.4632	1305	0.578
184,000	1082.0	1.107	52.58	8.611	36.20	27.70	3.739	0.4965	1313	0.616
186,000	1100.0	1.046	49.68	7.990	33.59	25.71	3.779	0.5320	1321	0.656
188,000	1118.0	0.9882	46.93	7.412	31.16	23.85	3.819	0.5698	1329	0.699
190,000	1136.0	0.9336	44.33	6.875	28.90	22.12	3.859	0.6100	1337	0.745
192,000	1154.0	0.8818	41.87	6.377	26.81	20.52	3.899	0.6528	1345	0.794
194,000	1172.0	0.8329	39.54	5.914	24.86	19.03	3.939	0.6983	1353	0.846
196,000	1190.0	0.7866	37.34	5.485	23.06	17.65	3.979	0.7466	1361	0.902
198,000	1208.0	0.7430	35.27	5.088	21.39	16.37	4.019	0.7979	1369	0.962
200,000	1226.0	0.7019	33.32	4.719	19.84	15.19	4.059	0.8523	1377	1.026
202,000	1244.0	0.6631	31.48	4.378	18.41	14.09	4.099	0.9100	1385	1.094
204,000	1262.0	0.6265	29.74	4.062	17.08	13.08	4.139	0.9713	1393	1.167
206,000	1280.0	0.5920	28.11	3.769	15.85	12.13	4.179	1.036	1401	1.244
208,000	1298.0	0.5594	26.56	3.496	14.70	11.26	4.219	1.105	1409	1.326
210,000	1316.0	0.5286	25.10	3.243	13.64	10.45	4.259	1.176	1417	1.414
212,000	1334.0	0.4995	23.72	3.009	12.66	9.696	4.299	1.252	1425	1.507
214,000	1352.0	0.4721	22.42	2.793	11.75	9.000	4.339	1.332	1433	1.606
216,000	1370.0	0.4462	21.19	2.592	10.90	8.351	4.379	1.417	1441	1.711
218,000	1388.0	0.4218	20.03	2.406	10.12	7.753	4.419	1.507	1449	1.822
220,000	1406.0	0.3988	18.94	2.234	9.396	7.199	4.459	1.603	1457	1.940
222,000	1424.0	0.3771	17.91	2.074	8.725	6.686	4.499	1.704	1465	2.065
224,000	1442.0	0.3566	16.94	1.926	8.104	6.210	4.539	1.812	1473	2.197
226,000	1460.0	0.3372	16.02	1.788	7.524	5.766	4.579	1.926	1481	2.337
228,000	1478.0	0.3188	15.14	1.660	6.985	5.353	4.619	2.047	1489	2.485
230,000	1496.0	0.3014	14.32	1.541	6.485	4.970	4.659	2.176	1497	2.642
232,000	1514.0	0.2850	13.54	1.431	6.022	4.615	4.699	2.313	1505	2.808
234,000	1532.0	0.2695	12.80	1.329	5.593	4.287	4.739	2.458	1513	2.984
236,000	1550.0	0.2548	12.10	1.233	5.192	3.980	4.779	2.612	1521	3.170
238,000	1568.0	0.2409	11.44	1.145	4.821	3.695	4.819	2.776	1529	3.367
240,000	1586.0	0.2278	10.82	1.062	4.474	3.430	4.859	2.950	1537	3.576
242,000	1604.0	0.2154	10.23	0.9858	4.152	3.183	4.899	3.134	1545	3.797
244,000	1622.0	0.2037	9.672	0.9147	3.853	2.954	4.939	3.329	1553	4.032
246,000	1640.0	0.1926	9.145	0.8488	3.575	2.741	4.979	3.534	1561	4.281
248,000	1658.0	0.1821	8.646	0.7877	3.318	2.544	5.019	3.751	1569	4.545
250,000	1676.0	0.1721	8.173	0.7311	3.079	2.361	5.059	3.981	1577	4.825
252,000	1694.0	0.1627	7.726	0.6784	2.857	2.191	5.099	4.224	1585	5.120
254,000	1712.0	0.1538	7.303	0.6296	2.651	2.033	5.139	4.482	1593	5.432
256,000	1730.0	0.1454	6.904	0.5843	2.460	1.887	5.179	4.756	1601	5.762
258,000	1748.0	0.1374	6.526	0.5423	2.284	1.751	5.219	5.047	1609	6.111
260,000	1766.0	0.1299	6.169	0.5033	2.119	1.625	5.259	5.355	1617	6.480
262,000	1784.0	0.1227	5.829	0.4670	1.967	1.508	5.299	5.681	1625	6.870
262,467	1788.0	0.1211	5.751	0.4589	1.933	1.482	5.309	5.757	1627	6.966
264,000	1802.0	0.1157	5.494	0.4335	1.826	1.400	5.339	6.028	1633	7.292
266,000	1820.0	0.1091	5.181	0.4026	1.696	1.300	5.379	6.393	1641	7.737
268,000	1838.0	0.1029	4.886	0.3737	1.574	1.207	5.419	6.780	1649	8.206
270,000	1856.0	0.09705	4.608	0.3469	1.461	1.120	5.459	7.189	1657	8.701
272,000	1874.0	0.09153	4.346	0.3220	1.356	1.040	5.499	7.622	1665	9.224
274,000	1892.0	0.08633	4.099	0.2988	1.259	0.9650	5.539	8.080	1673	9.778
276,000	1910.0	0.08143	3.866	0.2773	1.168	0.8955	5.579	8.565	1681	10.36
278,000	1928.0	0.07681	3.647	0.2573	1.084	0.8309	5.619	9.078	1689	10.98
280,000	1946.0	0.07246	3.441	0.2387	1.006	0.7709	5.659	9.621	1697	11.64
282,000	1964.0	0.06836	3.246	0.2215	0.9331	0.7151	5.699	10.19	1705	12.33
284,000	1982.0	0.06450	3.063	0.2055	0.8658	0.6635	5.739	10.80	1713	13.07
286,000	2000.0	0.06086	2.890	0.1907	0.8034	0.6157	5.779	11.45	1721	13.86
288,000	2018.0	0.05743	2.727	0.1769	0.7453	0.5712	5.819	12.13	1729	14.69
290,000	2036.0	0.05420	2.574	0.1642	0.6918	0.5301	5.859	12.84	1737	15.57
292,000	2054.0	0.05115	2.429	0.1523	0.6417	0.4917	5.899	13.60	1745	16.50
294,000	2072.0	0.04827	2.293	0.1414	0.5956	0.4564	5.939	14.40	1753	17.49
296,000	2090.0	0.04556	2.164	0.1312	0.5528	0.4236	5.979	15.24	1761	18.53
298,000	2108.0	0.04300	2.043	0.1218	0.5131	0.3932	6.019	16.13	1769	19.63
300,000	2126.0	0.04059	1.928	0.1130	0.4761	0.3649	6.059	17.07	1777	20.79
302,000	2144.0	0.03832	1.820	0.1048	0.4416	0.3384	6.099	18.06	1785	22.01
304,000	2162.0	0.03618	1.719	0.09720	0.4095	0.3138	6.139	19.11	1793	23.30
306,000	2180.0	0.03416	1.623	0.09016	0.3798	0.2911	6.179	20.22	1801	24.66
308,000	2198.0	0.03225	1.532	0.08362	0.3523	0.2700	6.219	21.39	1809	26.09
310,000	2216.0	0.03045	1.447	0.07756	0.3268	0.2504	6.259	22.63	1817	27.60
312,000	2234.0	0.02875	1.366	0.07194	0.3031	0.2323	6.299	23.94	1825	29.19
314,000	2252.0	0.02715	1.290	0.06674	0.2812	0.2155	6.339	25.32	1833	30.87
316,000	2270.0	0.02564	1.218	0.06192	0.2609	0.1999	6.379	26.78	1841	32.64
318,000	2288.0	0.02421	1.150	0.05745	0.2421	0.1855	6.419	28.32	1849	34.51
320,000	2306.0	0.02286	1.086	0.05331	0.2246	0.1721	6.459	29.95	1857	36.48
322,000	2324.0	0.02158	1.025	0.04947	0.2084	0.1597	6.499	31.67	1865	38.56
324,000	2342.0	0.02037	0.9677	0.04590	0.1934	0.1482	6.539	33.49	1873	40.75
326,000	2360.0	0.01923	0.9135	0.04259	0.1794	0.1375	6.579	35.42	1881	43.06
328,000	2378.0	0.01815	0.8622	0.03952	0.1665	0.1276	6.619	37.46	1889	45.50
330,000	2396.0	0.01713	0.8137	0.03667	0.1545	0.1184	6.659	39.62	1897	48.07
332,000	2414.0	0.01617	0.7679	0.03402	0.1433	0.1098	6.699	41.91	1905	50.78
334,000	2432.0	0.01526	0.7248	0.03157	0.1330	0.1019	6.739	44.33	1913	53.64
336,000	2450.0	0.01440	0.6841	0.02929	0.1234	0.09457	6.779	46.88	1921	56.65
338,000	2468.0	0.01359	0.6457	0.02718	0.1145	0.08774	6.819	49.58	1929	59.82
340,000	2486.0	0.01282	0.6094	0.02522	0.1062	0.08142	6.859	52.43	1937	63.16
342,000	2504.0	0.01210	0.5751	0.02341	0.09860	0.07556	6.899	55.44	1945	66.68
344,000	2522.0	0.01142	0.5427	0.02172	0.09150	0.07013	6.939	58.62	1953	70.38
346,000	2540.0	0.01078	0.5122	0.02016	0.08493	0.06510	6.979	61.98	1961	74.28
348,000	2558.0	0.01017	0.4834	0.01870	0.07878	0.06038	7.019	65.53	1969	78.39
350,000	2576.0	0.009600	0.4562	0.01735	0.07309	0.05602	7.059	69.28	1977	82.72
352,000	2594.0	0.009060	0.4306	0.01610	0.06782	0.05198	7.099	73.24	1985	87.29
354,000	2612.0	0.008550	0.4064	0.01494	0.06293	0.04823	7.139	77.43	1993	92.09
356,000	2630.0	0.008070	0.3836	0.01386	0.05839	0.04475	7.179	81.84	2001	97.14
358,000	2648.0	0.007617	0.3621	0.01287	0.05420	0.04154	7.219	86.49	2009	102.5
360,000	2666.0	0.007189	0.3418	0.01194	0.05030	0.03855	7.259	91.39	2017	108.1
362,000	2684.0	0.006785	0.3226	0.01108	0.04668	0.03578	7.299	96.54	2025	114.1
364,000	2702.0	0.006404	0.3045	0.01028	0.04331	0.03320	7.339	102.0	2033	120.4
366,000	2720.0	0.006045	0.2874	0.009539	0.04018	0.03080	7.379	107.8	2041	127.0
368,000	2738.0	0.005706	0.2713	0.008850	0.03728	0.02858	7.419	113.9	2049	134.0
370,000	2756.0	0.005387	0.2561	0.008210	0.03458	0.02651	7.459	120.4	2057	141.4
372,000	2774.0	0.005086	0.2418	0.007617	0.03208	0.02459	7.499	127.2	2065	149.2
374,000	2792.0	0.004802	0.2283	0.007067	0.02976	0.02281	7.539	134.4	2073	157.4
376,000	2810.0	0.004534	0.2155	0.006556	0.02761	0.02116	7.579	142.0	2081	166.1
378,000	2828.0	0.004281	0.2035	0.006083	0.02562	0.01964	7.619	150.0	2089	175.2
380,000	2846.0	0.004042	0.1922	0.005644	0.02377	0.01822	7.659	158.4	2097	184.8
382,000	2864.0	0.003816	0.1814	0.005236	0.02205	0.01690	7.699	167.3	2105	194.9
384,000	2882.0	0.003602	0.1713	0.004858	0.02046	0.01568	7.739	176.7	2113	205.5
386,000	2900.0	0.003400	0.1617	0.004508	0.01898	0.01454	7.779	186.6	2121	216.6
388,000	2918.0	0.003209	0.1526	0.004183	0.01762	0.01350	7.819	197.0	2129	228.3
390,000	2936.0	0.003029	0.1440	0.003882	0.01635	0.01252	7.859	208.0	2137	240.6
392,000	2954.0	0.002859	0.1359	0.003602	0.01517	0.01162	7.899	219.6	2145	253.5
394,000	2972.0	0.002699	0.1283	0.003343	0.01408	0.01078	7.939	231.8	2153	267.0
396,000	2990.0	0.002548	0.1211	0.003103	0.01307	0.01001	7.979	244.7	2161	281.2
398,000	3008.0	0.002406	0.1144	0.002880	0.01213	0.009291	8.019	258.3	2169	296.1
400,000	3026.0	0.002272	0.1080	0.002674	0.01126	0.008624	8.059	272.6	2177	311.7
402,000	3044.0	0.002145	0.1020	0.002482	0.01045	0.008006	8.099	287.6	2185	328.0
404,000	3062.0	0.002025	0.09628	0.002304	0.009702	0.007432	8.139	303.4	2193	345.1
406,000	3080.0	0.001912	0.09090	0.002139	0.009006	0.006899	8.179	320.0	2201	363.0
408,000	3098.0	0.001805	0.08581	0.001985	0.008358	0.006403	8.219	337.4	2209	381.7
410,000	3116.0	0.001704	0.08101	0.001843	0.007758	0.005943	8.259	355.7	2217	401.3
412,000	3134.0	0.001608	0.07647	0.001710	0.007198	0.005514	8.299	374.8	2225	421.8
414,000	3152.0	0.001518	0.07219	0.001587	0.006679	0.005117	8.339	394.8	2233	443.2
416,000	3170.0	0.001432	0.06814	0.001473	0.006199	0.004749	8.379	415.8	2241	465.5
418,000	3188.0	0.001352	0.06431	0.001367	0.005753	0.004407	8.419	437.8	2249	488.8
420,000	3206.0	0.001276	0.06069	0.001269	0.005340	0.004091	8.459	460.8	2257	513.1
422,000	3224.0	0.001204	0.05727	0.001177	0.004956	0.003797	8.499	484.9	2265	538.4
424,000	3242.0	0.001136	0.05403	0.001092	0.004598	0.003523	8.539	510.0	2273	564.8
426,000	3260.0	0.001072	0.05098	0.001013	0.004266	0.003268	8.579	536.2	2281	592.3
428,000	3278.0	0.001011	0.04809	0.0009400	0.003958	0.003032	8.619	563.5	2289	620.9
430,000	3296.0	0.0009540	0.04536	0.0008720	0.003671	0.002812	8.659	591.9	2297	650.7
432,000	3314.0	0.0009000	0.04279	0.0008090	0.003406	0.002608	8.699	621.4	2305	681.7
434,000	3332.0	0.0008490	0.04036	0.0007505	0.003160	0.002419	8.739	652.1	2313	713.9
436,000	3350.0	0.0008010	0.03807	0.0006962	0.002931	0.002244	8.779	684.0	2321	747.4
438,000	3368.0	0.0007555	0.03591	0.0006459	0.002719	0.002081	8.819	717.1	2329	782.2
440,000	3386.0	0.0007128	0.03388	0.0005992	0.002523	0.001931	8.859	751.4	2337	818.3
442,000	3404.0	0.0006725	0.03196	0.0005559	0.002341	0.001792	8.899	786.9	2345	855.7
444,000	3422.0	0.0006345	0.03016	0.0005158	0.002172	0.001662	8.939	823.6	2353	894.4
446,000	3440.0	0.0005986	0.02845	0.0004786	0.002015	0.001542	8.979	861.6	2361	934.5
448,000	3458.0	0.0005648	0.02685	0.0004441	0.001870	0.001431	9.019	901.0	2369	976.0
450,000	3476.0	0.0005329	0.02533	0.0004121	0.001735	0.001328	9.059	941.8	2377	1018
452,000	3494.0	0.0005028	0.02390	0.0003824	0.001610	0.001232	9.099	983.9	2385	1062
454,000	3512.0	0.0004744	0.02255	0.0003548	0.001494	0.001143	9.139	1027	2393	1107
456,000	3530.0	0.0004476	0.02127	0.0003292	0.001386	0.001061	9.179	1071	2401	1153
458,000	3548.0	0.0004224	0.02007	0.0003054	0.001286	0.0009844	9.219	1116	2409	1200
460,000	3566.0	0.0003986	0.01894	0.0002834	0.001193	0.0009132	9.259	1163	2417	1249
462,000	3584.0	0.0003761	0.01787	0.0002630	0.001107	0.0008474	9.299	1211	2425	1299
464,000	3602.0	0.0003550	0.01687	0.0002440	0.001027	0.0007862	9.339	1261	2433	1351
466,000	3620.0	0.0003350	0.01592	0.0002264	0.0009529	0.0007294	9.379	1312	2441	1404
468,000	3638.0	0.0003162	0.01502	0.0002100	0.0008840	0.0006766	9.419	1365	2449	1459
470,

Altitude, h (ft)	Absolute temperature, T (°F abs.)	Pressure, p (lb/ft²)	Pressure ratio, p/p₀	Density, ρ (sluge/ft³)	Density ratio, σ = ρ/ρ₀	Specific weight, w = gρ (lb/ft³)	Coefficient of viscosity, μ (lb sec/ft²) (1)	Kinematic viscosity, ν = μ/ρ (ft²/sec) (1)	Speed of sound, a (ft/sec)	Mean free path of molecules, λ (ft)
(b) Per day 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	0.06241	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 3.6 PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE - British Engineering System. Table III of Ref. 3.3.(Continued)

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 = gρ (lb/ft³)	Coefficient of viscosity μ (lb-sec/ft²) (1)	Kinematic viscosity, ν = μ/ρ (ft²/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	21.78	0.9142	0.6994	3.475	15.98	1069	26.5
296,000	479.4	0.01640	0.7748	19.99	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

[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 3.6 PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE - British Engineering System. Table III of Ref. 3.3. (Concluded)

Altitude, h (m)	Absolute temperature, T (°K)	Pressure, p (kg/m^2)	Pressure ratio, p/p_0	Density, ρ ($\frac{kg\text{-}sec^2}{m^4}$)	Density ratio, $\sigma = \rho/\rho_0$	Specific weight, $w = g\rho$ (kg/m^3)	Coefficient of viscosity, μ ($\frac{kg\text{-}sec}{m^2}$)	Kinematic viscosity, $U = \frac{\mu}{\rho}$ (m^2/sec)	Speed of sound, A (m/sec)	Mean free path of molecules, λ (m)
(a) For both day and night										
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	0.03101×10^{-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	994.2	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	678.8	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	715.1	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	470.7	569.9	1.647	0.2802	319.9	0.0155
37,500	258.3	40.24	389.4	542.5	435.1	525.8	1.666	0.3072	322.2	0.0168
38,000	262.0	37.71	365.0	501.1	401.1	485.0	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	21.84	211.5	258.0	206.1	249.8	1.853	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	144.2	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	10.96	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	9.970	96.46	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	2.277	375.1	0.0959
51,000	350.0	9.052	87.61	90.12	72.11	87.00	2.115	2.446	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	64.17	2.115	3.132	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	6.349	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	6.798	365.1	0.302
63,500	328.6	2.704	26.17	28.64	22.92	27.56	2.016	7.038	363.4	0.315
64,000	325.6	2.569	24.86	27.49	21.99	26.43	2.002	7.288	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	29.45	310.6	1.68

Table 3.7 PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE - Metric Engineering System. Table IV of Ref. 3.3.

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Altitude, h (m)	Absolute temperature, T (^{o}K)	Pressure, p (kg/m^2)	Pressure ratio, p/p_0	Density, ρ ($\frac{kg\text{-}sec^2}{m^4}$)	Density ratio, $\sigma = \rho/\rho_0$	Specific weight, $w = g\rho$ (kg/m^3)	Coefficient of viscosity, μ ($\frac{kg\text{-}sec}{m^2}$) (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	0.3675	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.

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Table 3.7 PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE - Metric Engineering System. Table IV of Ref. 3.3.(Concluded)

Altitude, h (ft)	Absolute tempera-ture, T (°r 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	119.9	5664×10⁻⁵	1779×10⁻⁷	748.3×10⁻⁵	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	4703	2.961	0.002013	971.1	0.00388
70,000	392.4	94.53	4467	1403	5901	4485	2.961	0.002110	971.1	0.00407
71,000	392.4	90.17	4261	1338	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	3696	1161	4881	3708	2.961	0.002550	971.1	0.00492
75,000	392.4	74.54	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	4235	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	0.003565	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	689.3	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	0.005710	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	1246	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	0.01181	976.2	0.0226
108,000	404.5	15.66	740.0	226.5	948.3	718.1	3.039	0.01348	986.0	0.0262
110,000	412.6	14.30	675.8	203.9	849.1	642.8	3.090	0.01530	995.8	0.0282
112,000	420.6	13.08	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	0.02483	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	86.69	4.119	0.1508	1190	0.207
156,000	597.6	2.598	122.8	25.32	106.5	80.28	4.162	0.1644	1199	0.224
158,000	605.7	2.448	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	2.043	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	7.234	30.42	22.84	4.332	0.5968	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	15.66	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	3.953	0.9330	1159	1.33
220,000	552.4	0.3807	17.99	4.014	16.88	12.65	3.916	0.9753	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	2.541	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
256,905	432.0	0.09936	4.693	1.340	5.634	4.207	3.212	2.397	1019	4.19
258,000	432.0	0.09095	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
262,487	432.0	0.07527	3.557	1.015	4.268	3.185	3.212	3.165	1019	5.53

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Table 3.8 PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE - British Engineering System. Table V of Ref. 3.3.

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, γ = gρ (lb/ft³)	Coefficient of viscosity, μ (lb-sec/ft²) (1)	Kinematic viscosity, ν = μ/ρ (ft²/sec) (1)	Speed of sound, a (ft/sec)	Mean free path of molecules, λ (ft)
(b) For day only										
262,467	432.0	0.07527	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	0.6889	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

[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 3.8 PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE - British Engineering System. Table V of Ref. 3.3.(Continued)

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 = gρ (lb/ft³)	Coefficient of viscosity μ (lb-sec/ft²) (1)	Kinematic viscosity, ν = μ/ρ (ft²/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	61.63	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	4.088	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	1297	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	671.5	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 3.8 PROPERTIES OF THE UPPER ATMOSPHERE FOR TENTATIVE STANDARD TEMPERATURES BASED ON AN INVERSE SQUARE VARIATION OF GRAVITATIONAL FORCE - British Engineering System. Table V of Ref. 3.3.(Concluded)

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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Table 3.9 LATITUDE CORRECTION FACTORS FOR VALUES OF PRESSURE IN TABLE 3.7 AND 3.8. Table VI of Ref. 3.3.

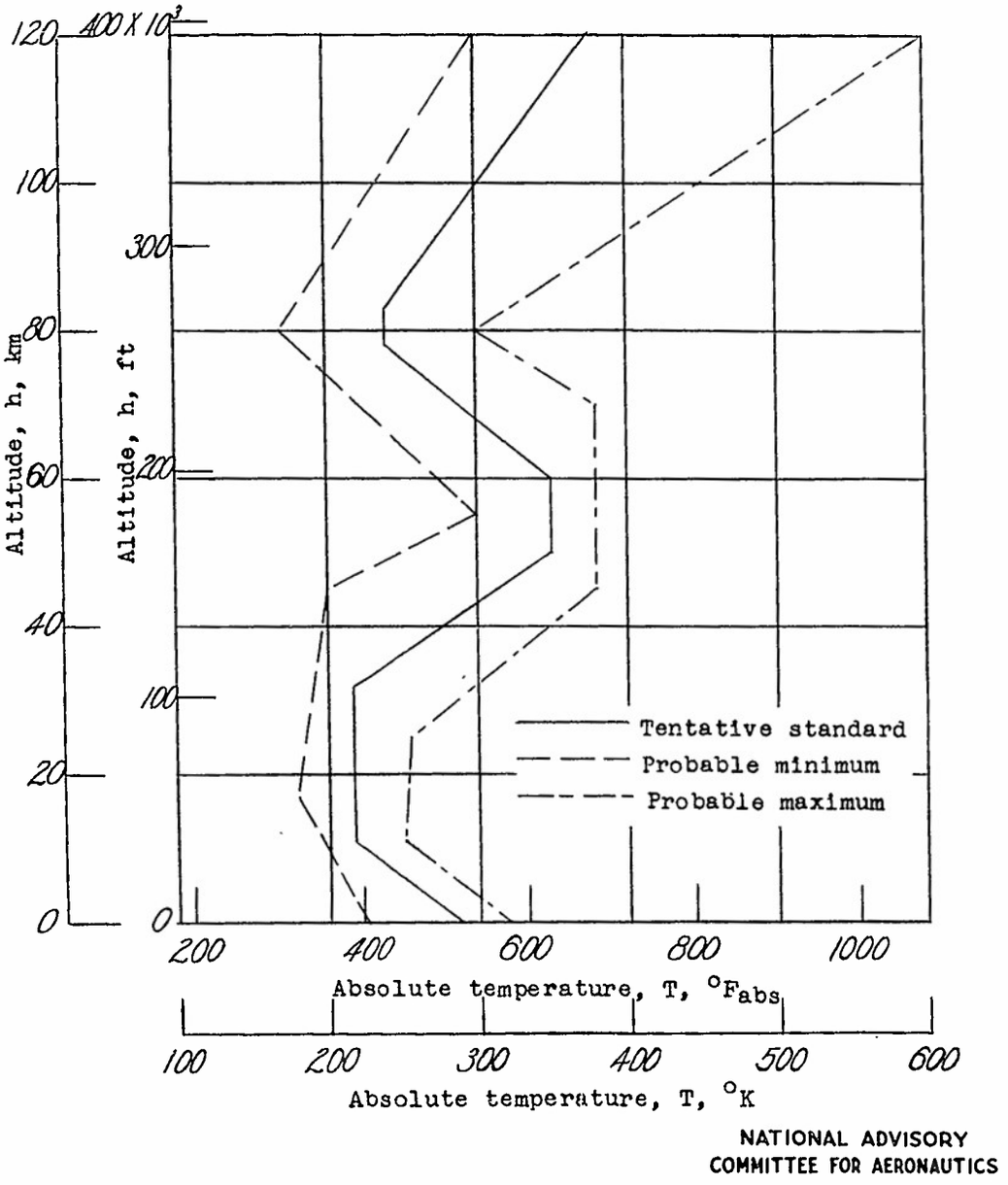
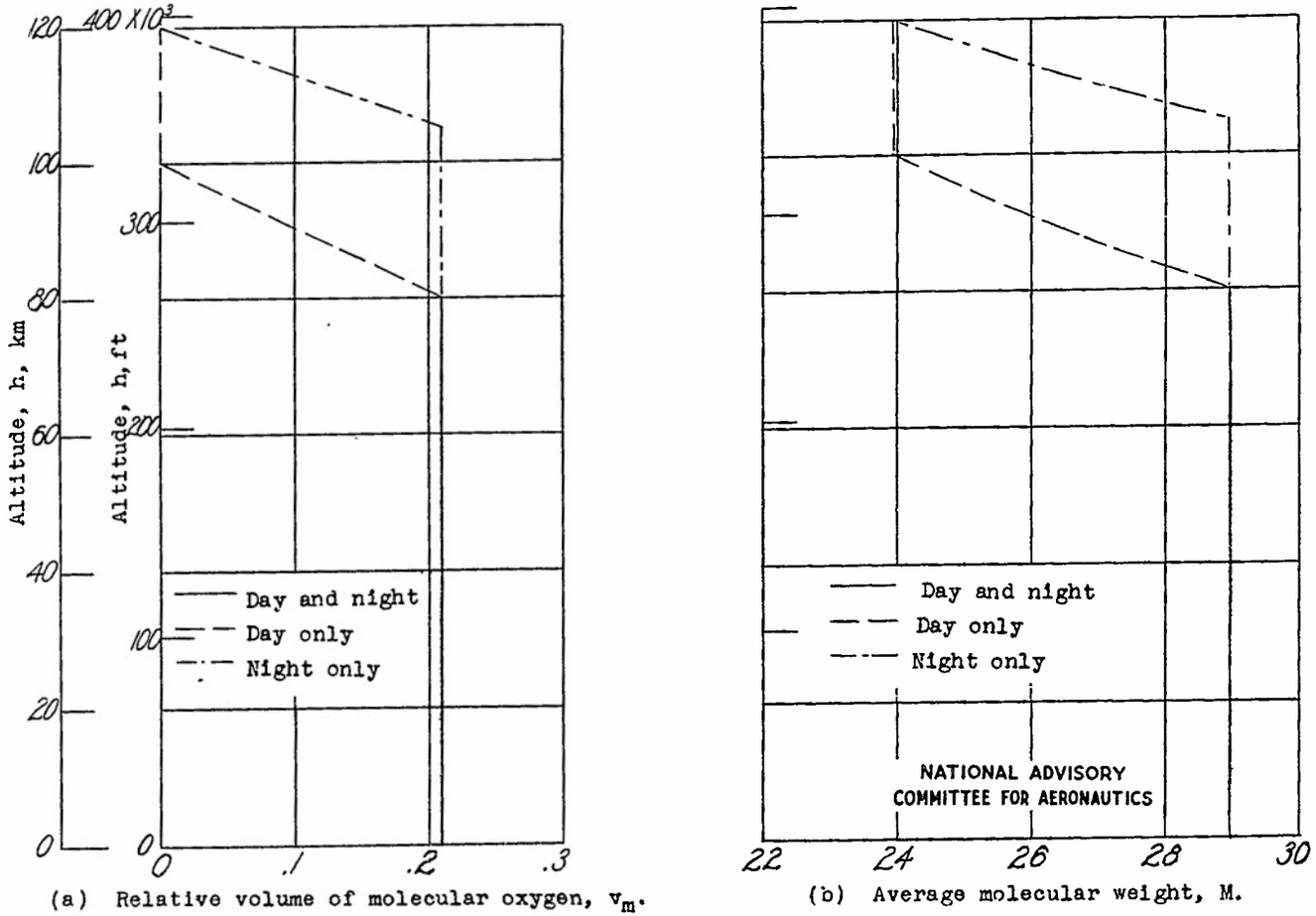


Fig. 3.18 VARIATION OF AMBIENT TEMPERATURE WITH ALTITUDE
Fig. 1 of Ref. 3.3.

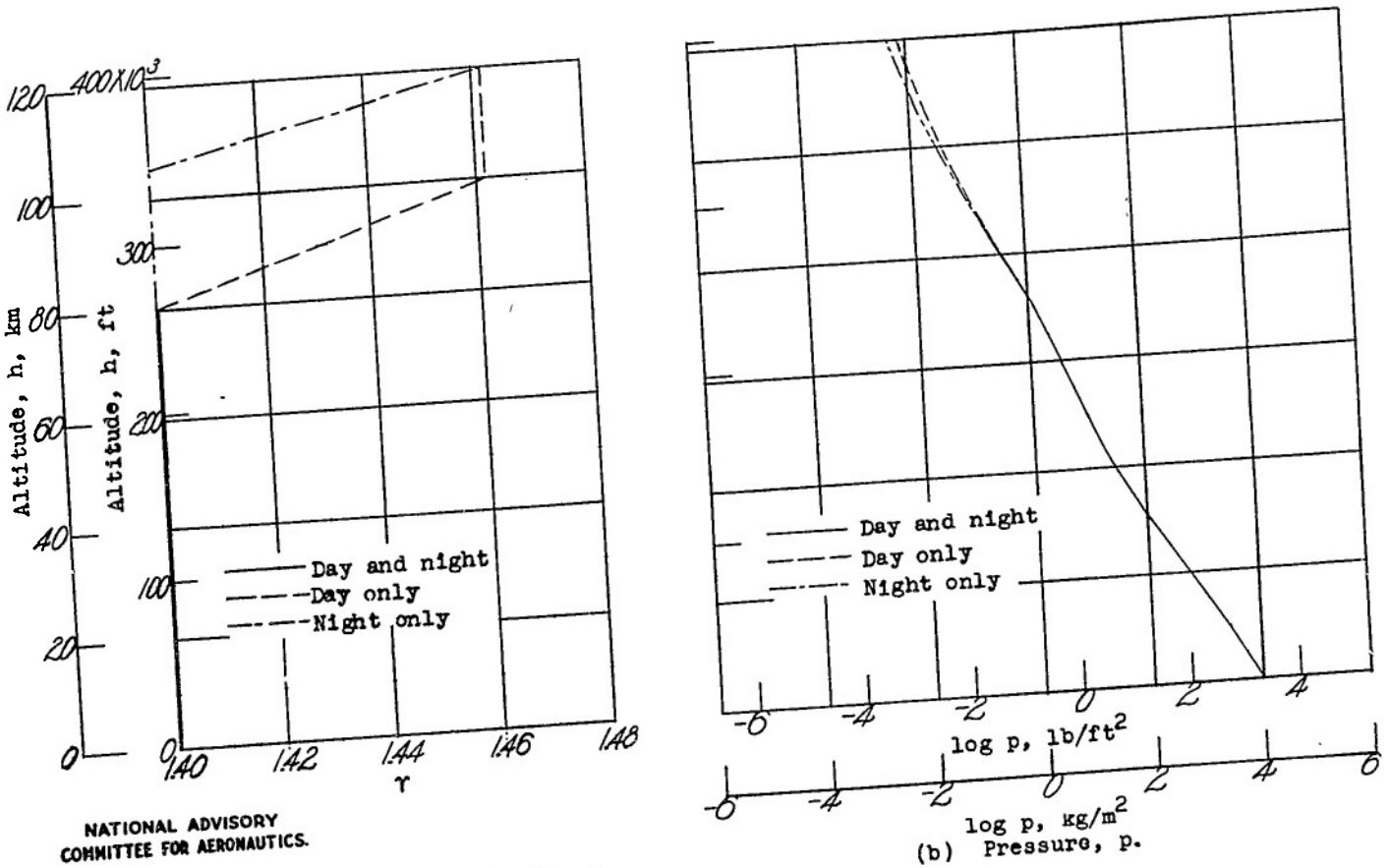


(a) Relative volume of molecular oxygen, v_m.

(b) Average molecular weight, M.

Fig. 3.19 VARIATION OF COMPOSITION OF THE TENTATIVE STANDARD ATMOSPHERE WITH ALTITUDE. Fig. 2 of Ref. 3.3.

The dissociation of oxygen is the only change in composition occurring in the tentative standard atmosphere.

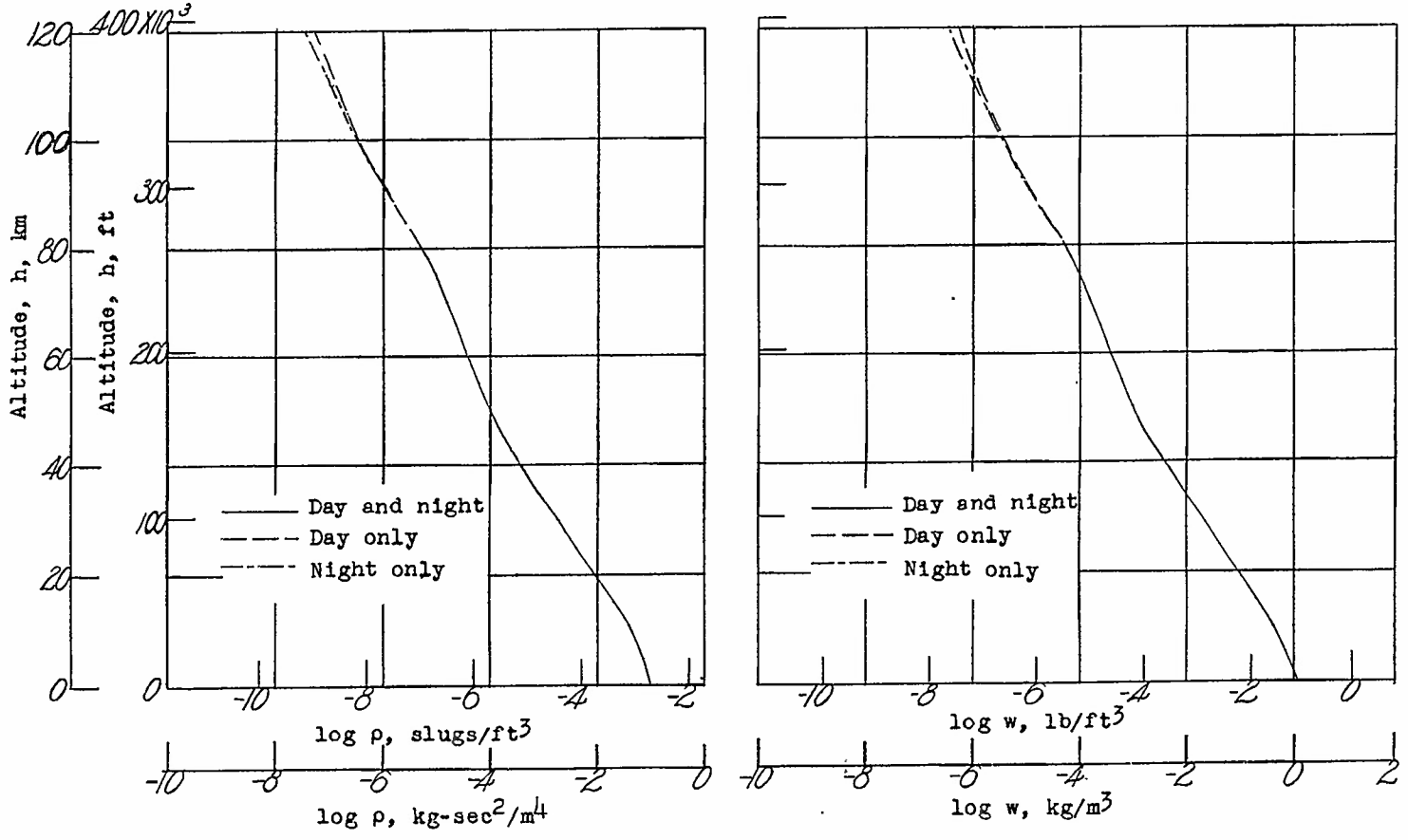


(a) Ratio of specific heats, γ.

(b) Pressure, p.

Fig. 3.20 VARIATION WITH ALTITUDE OF THE PHYSICAL PROPERTIES OF THE TENTATIVE STANDARD ATMOSPHERE. Fig. 3 of Ref. 3.3.

The variation of the ratio of specific heats, γ, is based on the dissociation of oxygen above 80 km. by day, and above 105 km by night. The effect of pressure and temperature upon γ is estimated to be less than 0.6% and is ignored.

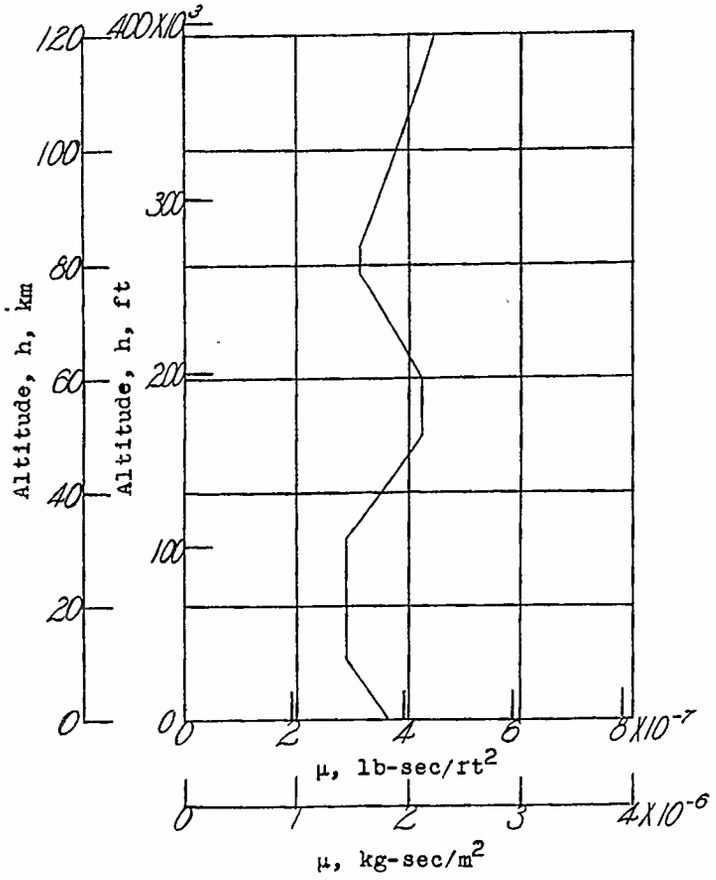


(c). Density, ρ.

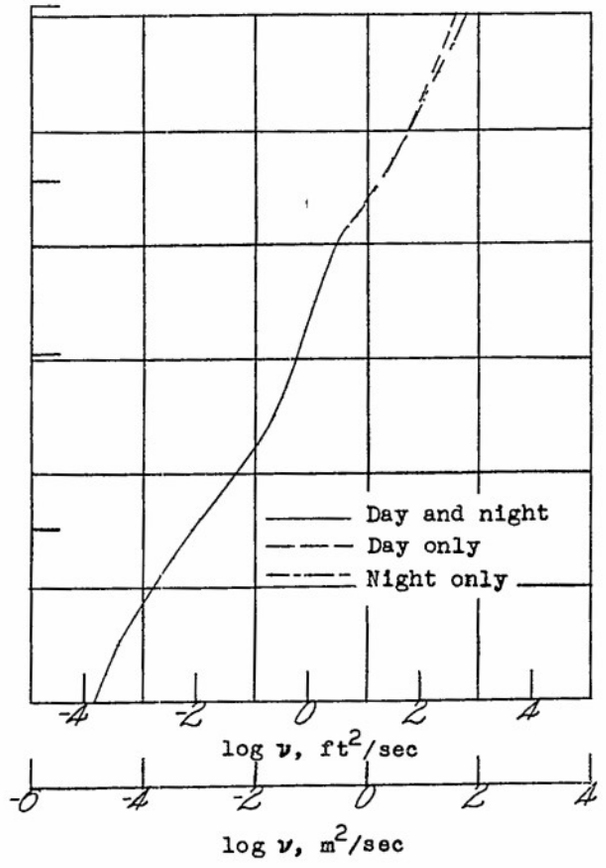
(d) Specific weight, w.

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Fig. 3.20 VARIATION WITH ALTITUDE OF THE PHYSICAL PROPERTIES OF THE TENTATIVE STANDARD ATMOSPHERE. Fig. 3 of Ref. 3.3.(Continued)



(e) Coefficient of viscosity, μ.

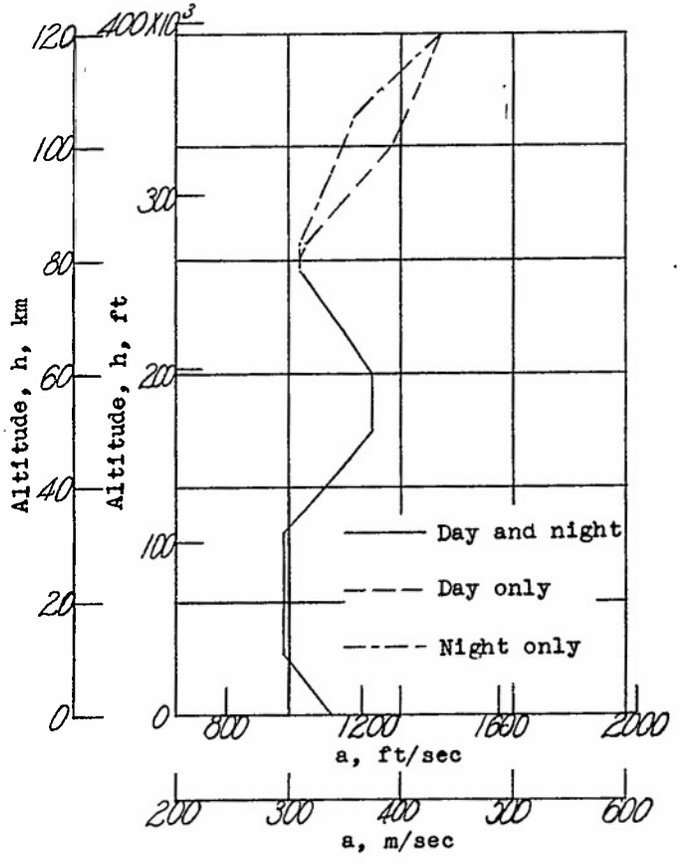


(f) Kinematic viscosity, ν.

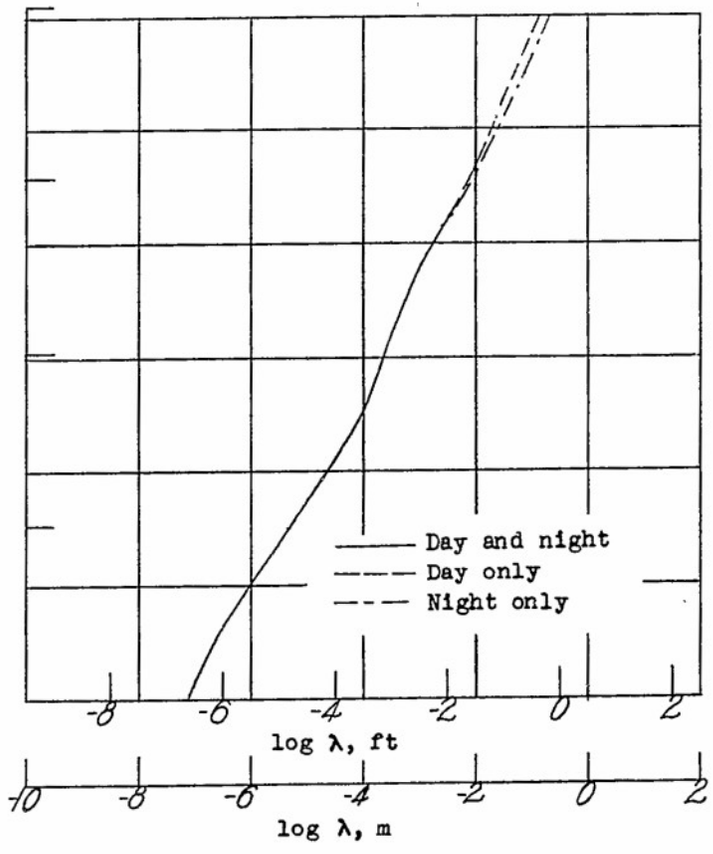
Fig. 3.20 VARIATION WITH ALTITUDE OF THE PHYSICAL PROPERTIES OF THE TENTATIVE STANDARD ATMOSPHERE. Fig. 3 of Ref. 3.3. (Continued)

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(g) Speed of sound, a.



(h) Mean free path of molecules, λ.

Fig. 3.20 VARIATION WITH ALTITUDE OF THE PHYSICAL PROPERTIES OF THE TENTATIVE STANDARD ATMOSPHERE. Fig. 3 of Ref. 3.3. (Concluded)

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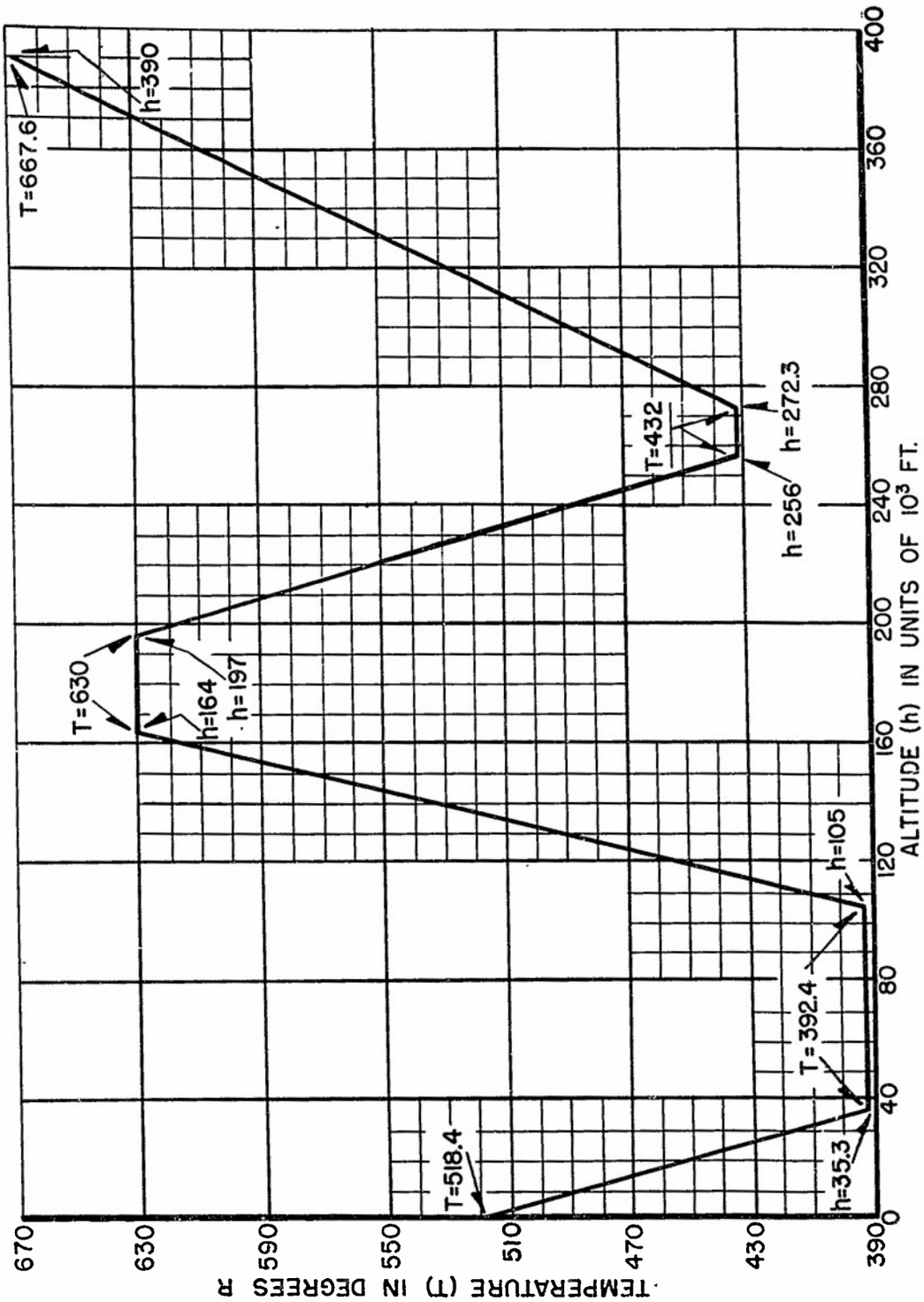


Fig. 3.21 TEMPERATURE OF THE ATMOSPHERE VS ALTITUDE - 0 TO 390,000 FT. - Data to 65,000 ft. from Diehl (Ref. 3.4). Data from 65,000 to 390,000 ft. from Warfield (Ref. 3.3).

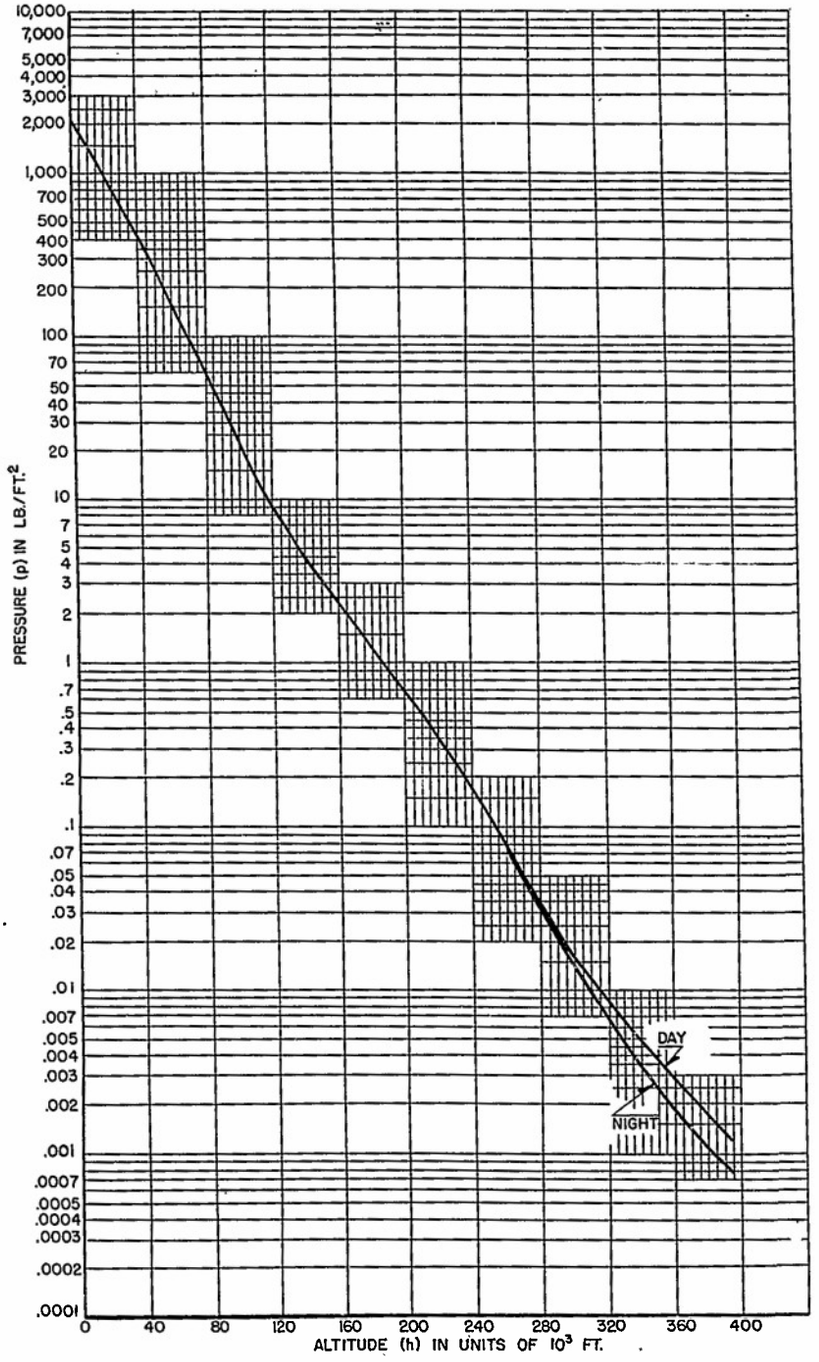


Fig. 3.22 PRESSURE OF THE ATMOSPHERE BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE VS ALTITUDE - 0 TO 390,000 FT. - Data to 65,000 ft. from Diehl (Ref. 3.4). Data from 65,000 to 390,000 ft. from Warfield (Ref. 3.3).

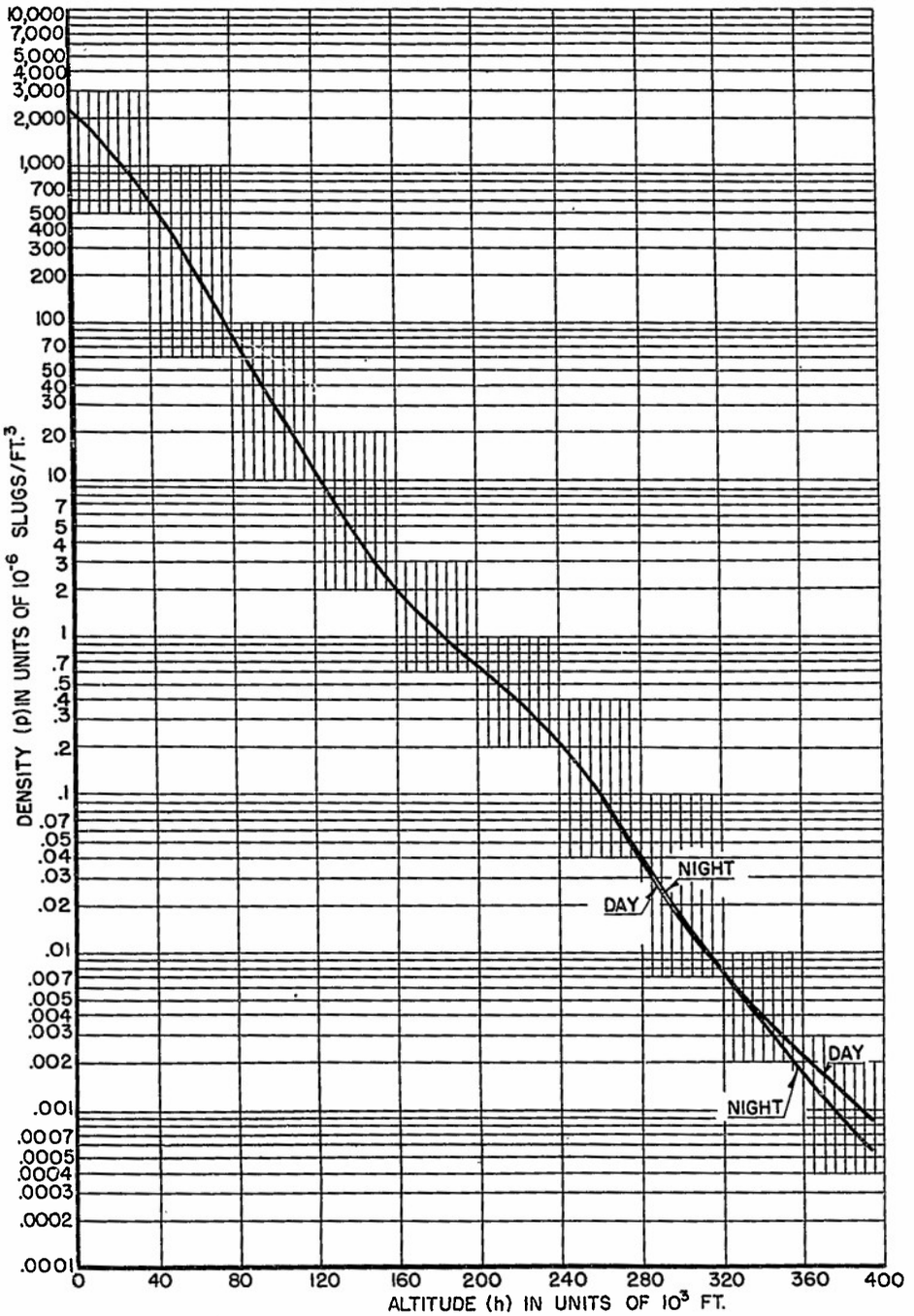


Fig. 3.23 DENSITY OF THE ATMOSPHERE BASED ON AN ARBITRARY CONSTANT VALUE OF GRAVITATIONAL FORCE VS ALTITUDE - Data to 65,000 ft. from Diehl (Ref. 3.4). Data from 65,000 to 390,000 ft. from Warfield (Ref. 3.3)

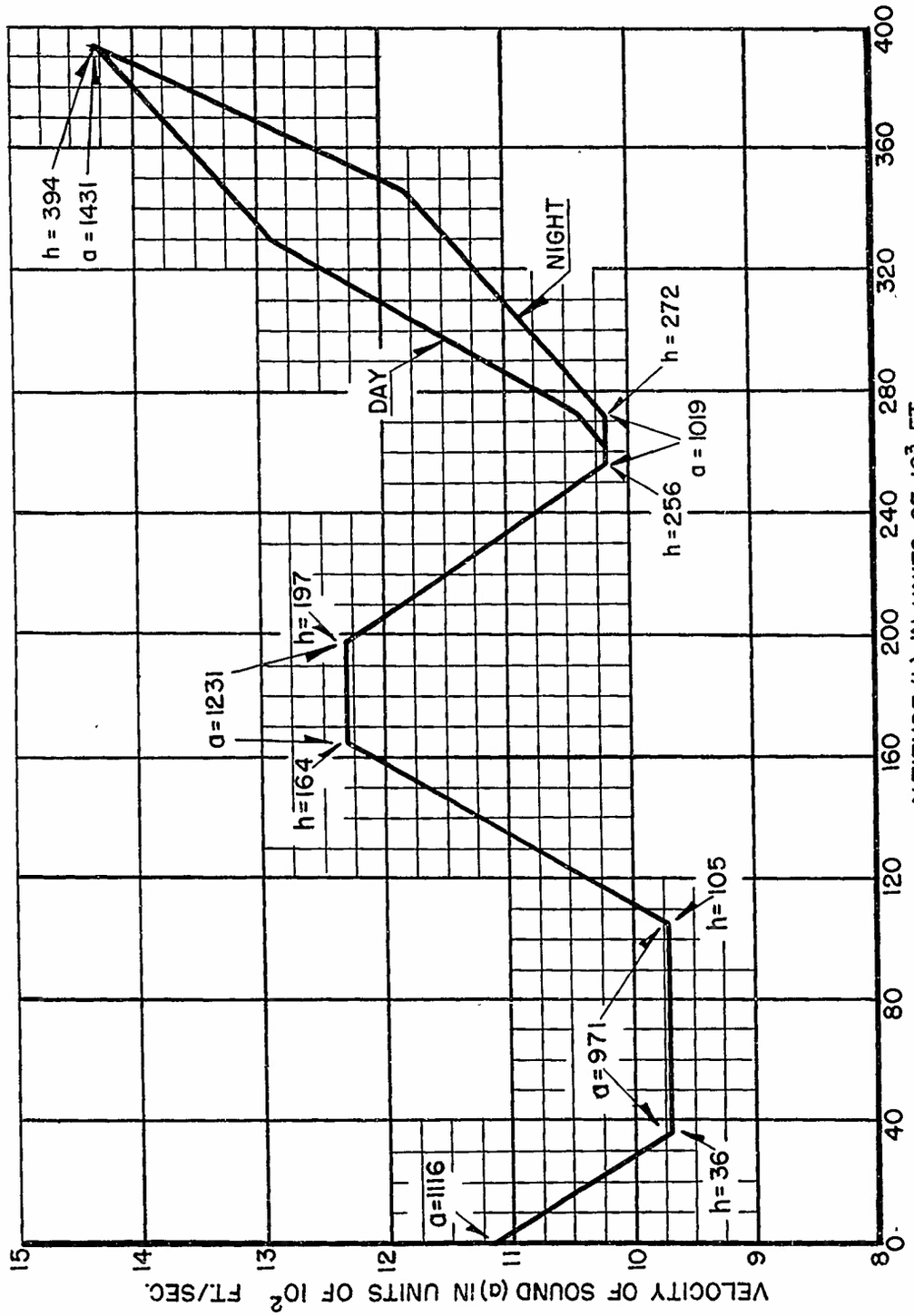


Fig. 3.24 VELOCITY OF SOUND IN THE ATMOSPHERE VS ALTITUDE - 0 to 390,000 FT. - Data to 65,000 ft. from Aiken (Ref. 3.5). Data from 65,000 to 390,000 ft. from Warfield (Ref. 3.3).

4. The Atmosphere Extending to Extreme Altitudes

a. Introduction

Owing to the recent development of high speed, high altitude rockets and jet propelled missiles, more and more demand has arisen for information concerning the temperature, pressure, and density of the atmosphere up to extreme altitudes of 300 miles (480 km) or more. The pressure and density at such heights are extremely small, corresponding to conditions of a highly rarefied gas. Nevertheless, there may still be sufficient atmosphere to affect the motion of a long-range vehicle traveling at high supersonic speeds. This is especially true for motion like that of a rocket-propelled satellite where it is desired to keep a body on a specified orbit for long periods of time in which the rarefied gas effects, although small in themselves, operate over a sufficiently long time interval to give an integrated effect which may be quite appreciable.

For the purpose of discussion, the atmosphere is usually divided into three main regions. That portion from sea level to 10-15 km is referred to as the troposphere, and that above this up to about 30 km is called the stratosphere (isothermal region). The region above the stratosphere extending outward to interplanetary space may be called the upper atmosphere.

The atmosphere above 80 km is strongly ionized and hence this region of the upper atmosphere, from 80 km outwards, is known as the ionosphere. The ionosphere is of fundamental importance in radio-wave propagation since it is owing to the reflection of radio waves by the ionosphere that long distance radio communication is possible. It seems to be established that the ionization of the ionosphere, and therefore its electrical conductivity, is caused primarily by the ultra-violet solar radiation.

The ionosphere itself is divided into three main regions or layers which are stratified on the basis of electron or ion density (Refs. 3.13 and 3.16). The lowest of these regions, known as the E-layer, is moderately ionized and is situated in the vicinity of the 100-km level. The next higher layer, the F_1-layer, is more strongly ionized and is situated in the vicinity of 200 km. Still higher and still more strongly ionized is the F_2-layer at about 300 km. There is recent evidence (Ref. 3.17) which strongly suggests the presence of an additional ionized layer, called the G-layer, situated above the F_2-layer somewhere in the region from 400 to 700 km. The upper region of ionization comprising the F_1 and F_2-layers is referred to in its entirety as the F-region. The regular E-layer and the F_1-layer are present only during the day and are most intensely ionized during the hours of local noon. A sporadic E-layer may be present at any time.

Although many gaps and uncertainties still exist in the knowledge of the upper atmosphere, it is believed that the results presented here, at least up to the F_2-layer, represent about the best that can be done considering the data which are available at the present time, and that the calculated values of temperature, pressure, and density up to the F_2-layer may be accepted with considerable confidence. It must be emphasized that the calculations for the atmosphere beyond the F_2-layer, where there are no data available and where the atmospheric models considered here are based on rather speculative reasoning, must be regarded as representing little more than possible values. However, there seem to be no other calculations of this nature available, and the values given here should at least give some indication of the limits within which the actual values would lie.

b. The atmosphere up to the F_2-layer.

The exact calculation of the variation of atmospheric pressure and density with altitude requires a knowledge of the following quantities expressed as a function of altitude above the earth's surface:

(1) Temperature

(2) Composition. This includes not only the kind of constituent gases, but also the degree of ionization as well as the degree of dissociation, since these effects can be important in determining the value of the molecular weight which is used in the equation of state. Finally a knowledge of the composition presupposes a knowledge of the degree of diffusion equilibrium which is present; that is, the degree to which the constituent gases are distributed in the vertical according to their molecular weights, with the lighter gases situated above those which are heavier.

(3) The angular velocity of rotation of the atmosphere about the axis of the earth. The angular velocity will affect the value of apparent gravity, thereby producing an effect on the pressure distribution.

The Temperature Distribution. Practically all the deductions of temperature from ionosphere measurements indicate a considerable increase in temperature above 100 km (the E-layer)and the evidence in favor of high temperature in the F_2-layer is very considerable. Although the determination of the value for the temperature in the F_2-layer is not one of great accuracy, it is generally recognized that a high temperature must prevail in this region, of the order of 1000°K.

As far as ionosphere temperatures at the equator are concerned, the only values available are those given by Fuchs (Ref. 3.18), which are based on observations of the ionosphere at Huancayo, Peru, latitude 12° south, by Berkner and Wells (Ref.3.19). The temperatures derived by Fuchs are shown in Table 3.10.

Altitude, km	190	220	350	420
Temperature, °K	400	1000	1400	1900

Table 3.10 TEMPERATURE IN THE F-REGION AT THE EQUATOR ACCORDING TO FUCHS (Ref. 3.18)

These values are plotted in Figure 3.25 together with the values for altitudes of 120 km and less from Figure 3.18. Except for the point T = 400°K at 190 km which has been discounted, the values are represented with sufficient accuracy by the straight line shown in the figure and this is the linear relationship which will be used for the temperature distribution in the F-region at the equator. Thus it will be assumed that the temperature in this region is defined by the straight line connecting the points T = 375°K at 120 km and T = 1900°K at 420 km. The corresponding curve in engineering units is plotted in Figure 3.26.

In the middle latitudes considerable choice exists in the temperatures to be used in the F-region. It has been decided here to adopt a value of 1100°K at 300 km which, from data given by Martyn and Pulley (Ref. 3.11) (see Figure 5 of Reference 3.11), represents a probable mean diurnal value. The distribution of temperature is assumed to be linear between this value and the value 375°K at 120 km, since there is no information available to specify the exact nature of the temperature curve in this region. It is well known that there is a distinct diurnal variation in the properties of the F-region. During the day this contains the F_1 as well as the F_2-layer, with the F_2-layer situated at about 300 km and at a temperature of the order of 1200°K. During the night only the F_2-layer remains, and in middle latitudes this is usually at a lower height and temperature than during the day. From the data of Martyn and Pulley it is considered that the mean diurnal condition of the F_2-layer is represented by the value 1100°K at 300 km. No attempt is made here to take into account any seasonal variations which occur, mainly because there seems to be very little data in usable form (height and temperature) available in this respect. The vertical distribution of temperature adopted to represent conditions in the F-region in middle latitudes is presented in Figures 3.27 and 3.28.

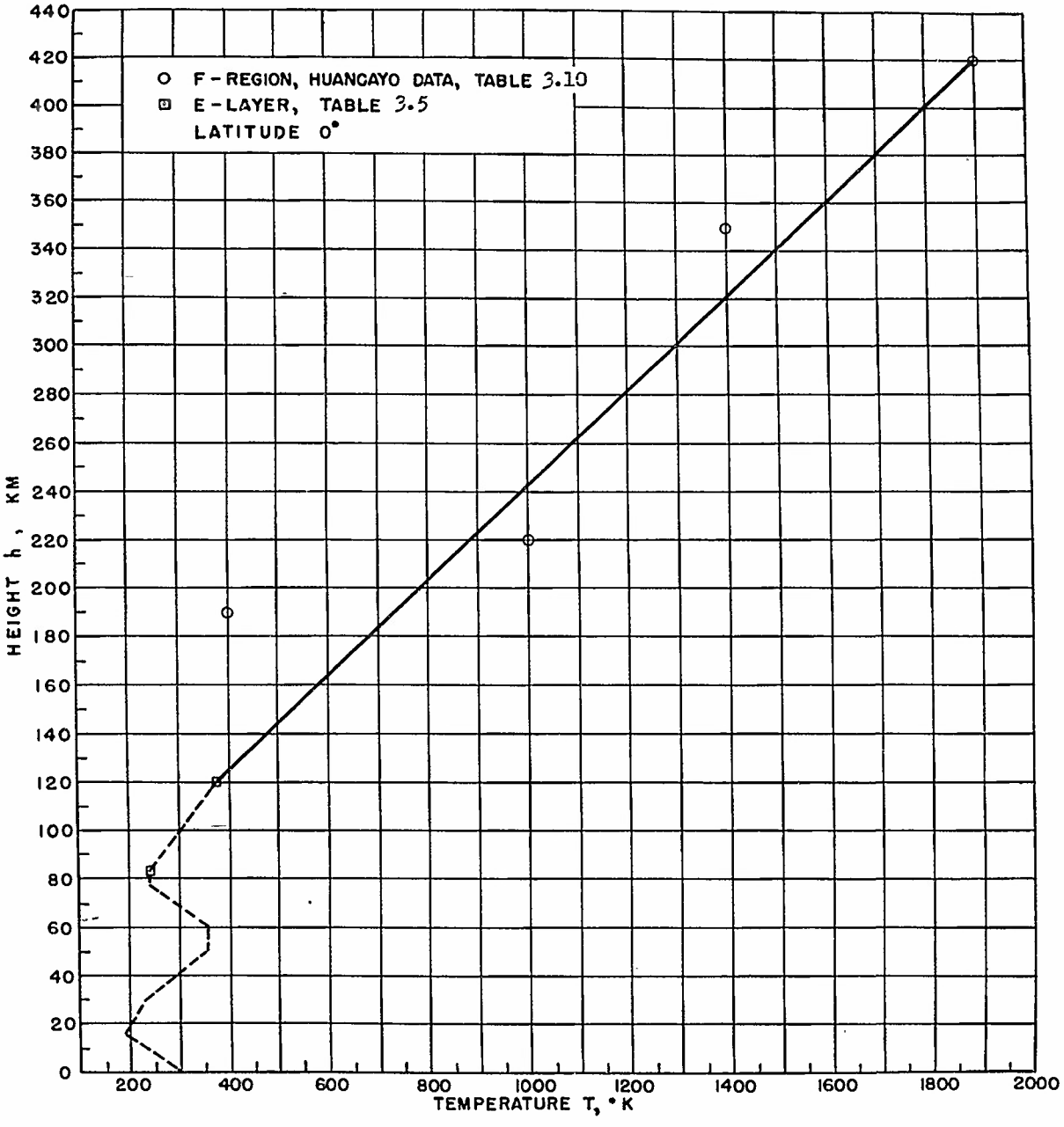


Fig. 3.25 VERTICAL DISTRIBUTION OF TEMPERATURE IN THE F-REGION Latitude 0°. Metric Units. Based on Huancayo Data (Refs. 3.18 and 3.19). Fig. 5 of Ref. 3.20.

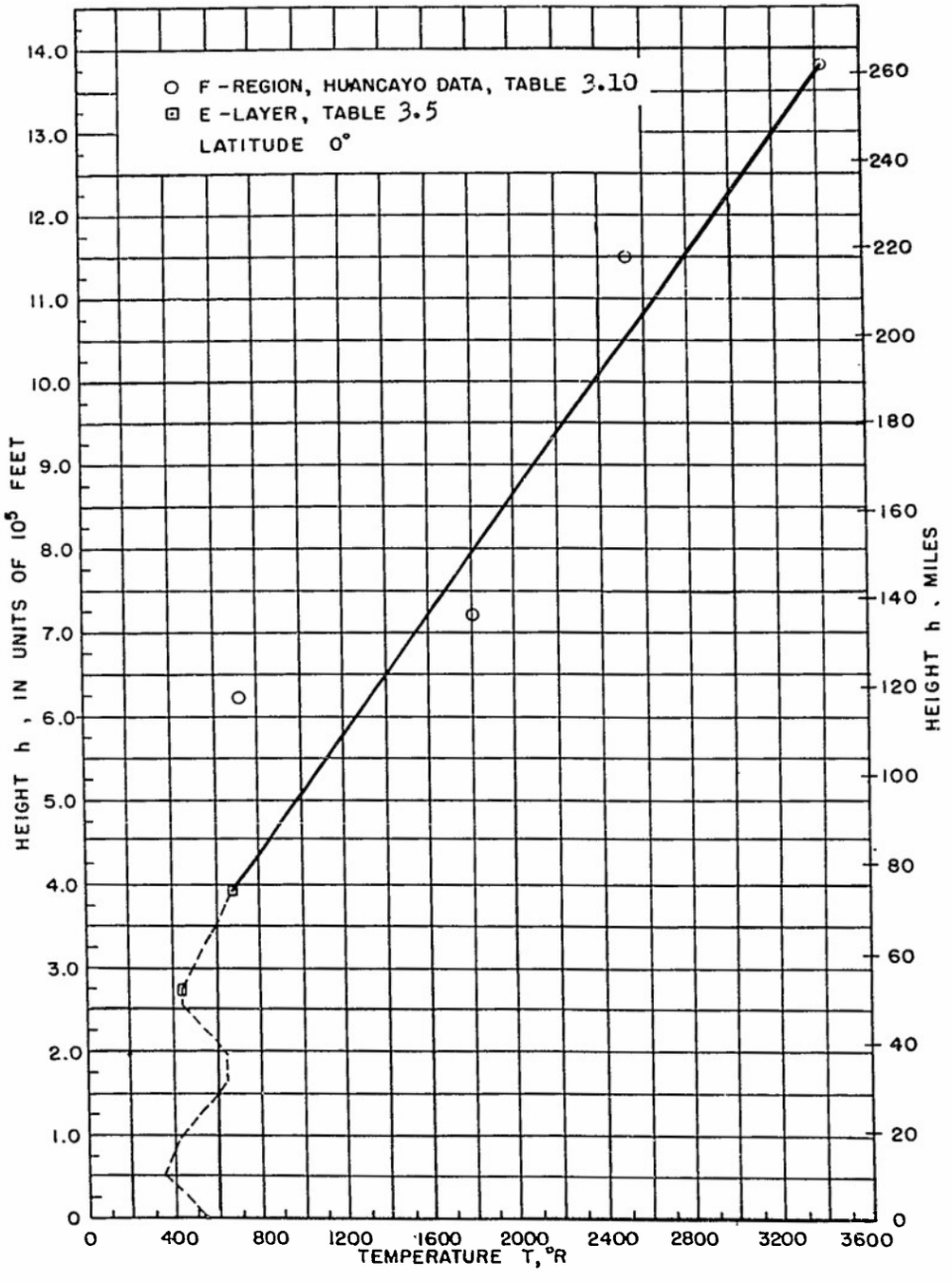


Fig. 3.26 VERTICAL DISTRIBUTION OF TEMPERATURE IN THE F-REGION Latitude 0°. Engineering Units. Based on Huancayo Data (Refs. 3.18 and 3.19). Fig. 6 of Ref. 3.20.

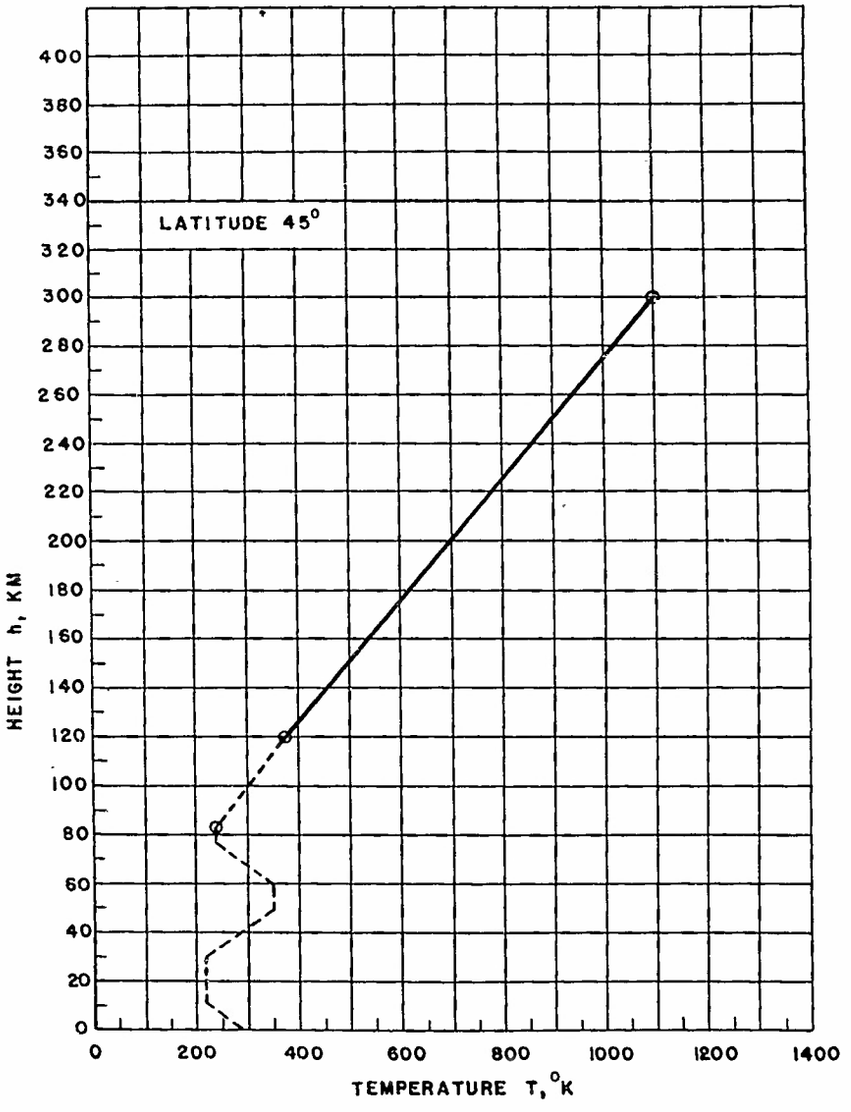


Fig. 3.27 VERTICAL DISTRIBUTION OF TEMPERATURE IN THE F-REGION Latitude 45°. Metric Units. Fig. 7 of Ref. 3.20.

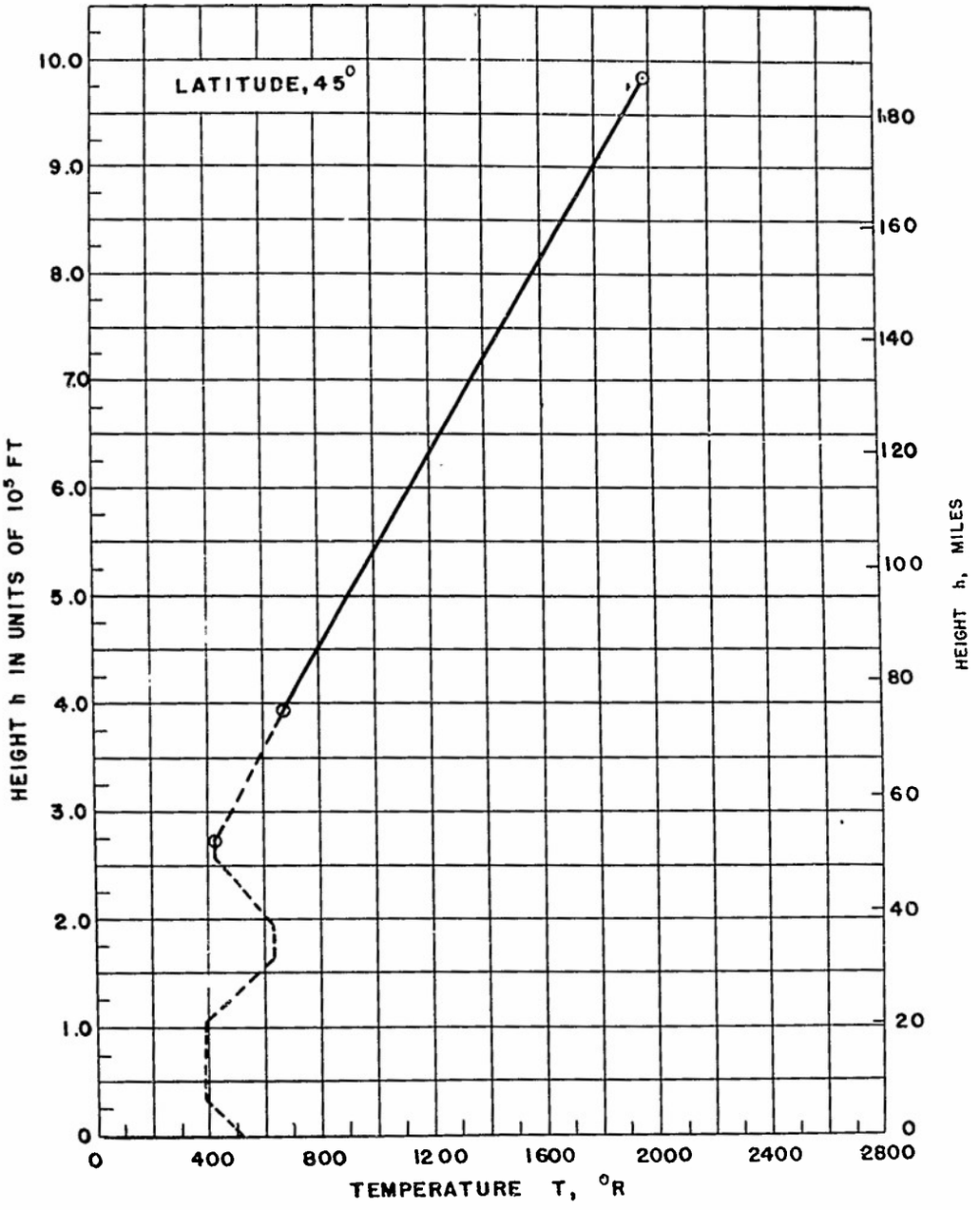


Fig. 3.28 VERTICAL DISTRIBUTION OF TEMPERATURE IN THE F-REGION
Latitude 45°. Engineering Units, Fig. 8 of Ref. 3.20.

The Composition. The composition used to represent conditions in the equatorial atmosphere up to the F_2-layer is given in Table 3.11. It will be noted that the composition is assumed to remain unchanged from 120 km up to and including the F_2-layer; that is, the constituent gases in this region are assumed to be completely mixed, giving an atmosphere of uniform composition. This agrees more or less with the results of Mitra and Rakshit (Ref. 3.21) who found that, for an N_2 - O atmosphere with temperature increasing with height, diffusive equilibrium would exist only above 350 km. The values 33% O and 67%N_2 are based on a gas which corresponds to 20% O_2 and 80% N_2 when there is no dissociation of oxygen. Essentially it is assumed that the dissociation occurs at constant pressure, but that the volume may change.

Altitude km	Composition, % Volume	Molecular Weight of Mixture, M	Ratio of Specific Heats, γ
0	21% O_2, 78% N_2, 0.93% Ar	28.9	1.405
83	20% O_2, 80% N_2	28.8	1.405
120	33% O , 67% N_2	24.0	1.46
400 (F_2 layer)	33% O , 67% N_2	24.0	1.46

Table 3.11 COMPOSITION OF THE ATMOSPHERE UP TO THE F_2-LAYER
Latitude 0°. Table 7 of Ref. 3.20.

In middle latitude it appears likely (Penndorf, Ref. 3.22; and Regener, Ref. 3.1) that there is a slight change in composition at about 50 km to the values 18% O_2 and 82% N_2. Using these figures the values in Table 3.12 are obtained as representative of the composition of the atmosphere up to the F_2-layer in middle latitudes.

Altitude km	Composition, % Volume	Molecular Weight of Mixture, M	Ratio of Specific Heats, γ
0	21% O_2, 78% N_2, 0.93% Ar	28.9	1.405
50	18% O_2, 82% N_2	28.66	1.405
83	18% O_2, 82% N	28.66	1.405
120	30.5% O, 69.5% N_2	24.35	1.46
300 (F_2 layer)	30.5% O, 69.5% N_2	24.35	1.46

Table 3.12 COMPOSITION OF THE ATMOSPHERE UP TO THE F_2-LAYER Latitude 45°. Table 8 of Ref. 3.20.

Tables of Properties of the Atmosphere and Graphs of Density Ratio and Sonic Velocity up to the F_2 - Layer

Editor's Note: A discussion of the effect of composition on the determination of the temperature in an ionized layer, and details of the calculations of the properties of the atmosphere are to be found in the RAND Report (Ref. 3.20). Lack of space prevents the inclusion of the full discussion here. The results are given in the tables and graphs which follow.

Height h ft	Height h mi	Apparent Gravity g' ft/sec^2	Mean Mol Wt M	Temp T °R	Scale Height H ft	Pressure p lb/ft^2	Pressure Ratio p/p_0	Density ρ slug/ft^3	Density Ratio σ ρ/ρ_0	Number Density n particles/ft^3	Mean Particle Speed v ft/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ ft	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ ft	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	Speed of Sound a ft/sec
0	0	32.088	28.90	538.2	2.883×10^4	2115	1.0000	2.286×10^{-3}	1.0000	7.000×10^{22}	1.535×10^3	3.321×10^{-7}	4.622×10^8	7.472×10^{-7}	2.054×10^8	1.141×10^3
5,000	.947	32.072	28.90	522.8	2.802×10^4	1774	.8389	1.974×10^{-3}	.8636	6.045×10^{22}	1.513×10^3	3.845×10^{-7}	3.934×10^8	8.652×10^{-7}	1.748×10^8	1.124×10^3
10,000	1.894	32.057	28.90	507.5	2.721×10^4	1481	.7002	1.698×10^{-3}	.7426	5.198×10^{22}	1.490×10^3	4.472×10^{-7}	3.333×10^8	1.006×10^{-6}	1.481×10^8	1.071×10^3
15,000	2.841	32.041	28.90	492.1	2.640×10^4	1229	.5813	1.453×10^{-3}	.6357	4.450×10^{22}	1.468×10^3	5.224×10^{-7}	2.810×10^8	1.175×10^{-6}	1.249×10^8	1.090×10^3
16,404	3.107	32.037	28.90	487.8	2.617×10^4	1166	.5511	1.390×10^{-3}	.6081	4.257×10^{22}	1.461×10^3	5.461×10^{-7}	2.676×10^8	1.229×10^{-6}	1.189×10^8	1.085×10^3
20,000	3.788	32.026	28.90	473.8	2.543×10^4	1014	.4795	1.245×10^{-3}	.5447	3.813×10^{22}	1.440×10^3	6.096×10^{-7}	2.362×10^8	1.372×10^{-6}	1.050×10^8	1.070×10^3
25,000	4.735	32.011	28.90	454.3	2.440×10^4	830.1	.3925	1.063×10^{-3}	.4649	3.254×10^{22}	1.410×10^3	7.143×10^{-7}	1.974×10^8	1.607×10^{-6}	8.775×10^7	1.047×10^3
30,000	5.682	31.996	28.90	434.8	2.336×10^4	673.6	.3185	9.012×10^{-4}	.3942	2.759×10^{22}	1.380×10^3	8.425×10^{-7}	1.638×10^8	1.896×10^{-6}	7.278×10^7	1.025×10^3
32,808	6.214	31.987	28.90	423.9	2.278×10^4	596.6	.2821	8.187×10^{-4}	.3581	2.507×10^{22}	1.362×10^3	9.273×10^{-7}	1.469×10^8	2.086×10^{-6}	6.529×10^7	1.012×10^3
35,000	6.629	31.980	28.90	415.0	2.230×10^4	541.4	.2560	7.589×10^{-4}	.3320	2.324×10^{22}	1.348×10^3	1.000×10^{-6}	1.347×10^8	2.251×10^{-6}	5.988×10^7	1.001×10^3
40,000	7.576	31.965	28.90	394.6	2.122×10^4	430.6	.2036	6.348×10^{-4}	.2777	1.944×10^{22}	1.314×10^3	1.196×10^{-6}	1.099×10^8	2.691×10^{-6}	4.884×10^7	9.762×10^2
45,000	8.523	31.950	28.90	374.3	2.014×10^4	338.2	.1599	5.256×10^{-4}	.2299	1.609×10^{22}	1.280×10^3	1.444×10^{-6}	8.861×10^7	3.250×10^{-6}	3.938×10^7	9.508×10^2
50,000	9.470	31.934	28.90	353.9	1.905×10^4	262.2	.1240	4.309×10^{-4}	.1885	1.319×10^{22}	1.245×10^3	1.762×10^{-6}	7.065×10^7	3.964×10^{-6}	3.140×10^7	9.246×10^2
52,493	9.942	31.926	28.90	343.8	1.851×10^4	229.7	.1086	3.887×10^{-4}	.1700	1.190×10^{22}	1.227×10^3	1.953×10^{-6}	6.280×10^7	4.395×10^{-6}	2.791×10^7	9.112×10^2
55,000	10.417	31.919	28.90	347.7	1.873×10^4	200.8	9.494×10^{-2}	3.359×10^{-4}	.1469	1.029×10^{22}	1.234×10^3	2.260×10^{-6}	5.459×10^7	5.085×10^{-6}	2.426×10^7	9.164×10^2
60,000	11.364	31.904	28.90	355.6	1.916×10^4	154.3	7.296×10^{-2}	2.525×10^{-4}	.1104	7.730×10^{22}	1.248×10^3	3.007×10^{-6}	4.149×10^7	6.766×10^{-6}	1.844×10^7	9.267×10^2
65,000	12.311	31.888	28.90	363.4	1.959×10^4	119.3	5.640×10^{-2}	1.910×10^{-4}	8.352×10^{-2}	5.847×10^{22}	1.261×10^3	3.976×10^{-6}	3.172×10^7	8.946×10^{-6}	1.410×10^7	9.368×10^2
70,000	13.258	31.873	28.90	371.2	2.002×10^4	92.74	4.385×10^{-2}	1.453×10^{-4}	6.356×10^{-2}	4.450×10^{22}	1.275×10^3	5.224×10^{-6}	2.440×10^7	1.176×10^{-5}	1.084×10^7	9.469×10^2
75,000	14.205	31.858	28.90	379.1	2.045×10^4	72.50	3.428×10^{-2}	1.113×10^{-4}	4.867×10^{-2}	3.407×10^{22}	1.288×10^3	6.824×10^{-6}	1.888×10^7	1.535×10^{-5}	8.390×10^6	9.568×10^2
80,000	15.152	31.842	28.90	386.9	2.089×10^4	56.97	2.694×10^{-2}	8.567×10^{-5}	3.747×10^{-2}	2.623×10^{22}	1.301×10^3	8.862×10^{-6}	1.468×10^7	1.994×10^{-5}	6.527×10^6	9.667×10^2
85,000	16.098	31.827	28.90	394.8	2.133×10^4	45.03	2.129×10^{-2}	6.636×10^{-5}	2.903×10^{-2}	2.032×10^{22}	1.314×10^3	1.144×10^{-5}	1.149×10^7	2.574×10^{-5}	5.106×10^6	9.764×10^2
90,000	17.045	31.812	28.90	402.6	2.175×10^4	35.72	1.689×10^{-2}	5.162×10^{-5}	2.258×10^{-2}	1.580×10^{22}	1.328×10^3	1.471×10^{-5}	9.025×10^6	3.310×10^{-5}	4.011×10^6	9.860×10^2
95,000	17.992	31.797	28.90	410.4	2.219×10^4	28.48	1.347×10^{-2}	4.037×10^{-5}	1.766×10^{-2}	1.236×10^{22}	1.340×10^3	1.880×10^{-5}	7.128×10^6	4.231×10^{-5}	3.168×10^6	9.956×10^2
98,424	18.641	31.786	28.90	415.8	2.249×10^4	24.46	1.156×10^{-2}	3.422×10^{-5}	1.497×10^{-2}	1.048×10^{22}	1.349×10^3	2.218×10^{-5}	6.081×10^6	4.992×10^{-5}	2.703×10^6	1.002×10^3
100,000	18.939	31.782	28.90	421.2	2.278×10^4	22.82	1.079×10^{-2}	3.152×10^{-5}	1.378×10^{-2}	9.650×10^{21}	1.358×10^3	2.409×10^{-5}	5.636×10^6	5.420×10^{-5}	2.505×10^6	1.009×10^3
105,000	19.886	31.766	28.90	438.2	2.371×10^4	18.41	8.703×10^{-3}	2.449×10^{-5}	1.071×10^{-2}	7.500×10^{21}	1.385×10^3	3.100×10^{-5}	4.468×10^6	6.974×10^{-5}	1.986×10^6	1.029×10^3
110,000	20.833	31.751	28.90	455.2	2.464×10^4	14.97	7.080×10^{-3}	1.914×10^{-5}	8.371×10^{-3}	5.860×10^{21}	1.412×10^3	3.967×10^{-5}	3.558×10^6	8.926×10^{-5}	1.581×10^6	1.048×10^3
115,000	21.780	31.736	28.90	472.2	2.557×10^4	12.28	5.804×10^{-3}	1.512×10^{-5}	6.616×10^{-3}	4.631×10^{21}	1.438×10^3	5.020×10^{-5}	2.864×10^6	1.129×10^{-4}	1.273×10^6	1.068×10^3
120,000	22.727	31.721	28.90	489.2	2.651×10^4	10.14	4.793×10^{-3}	1.206×10^{-5}	5.273×10^{-3}	3.691×10^{21}	1.463×10^3	6.297×10^{-5}	2.324×10^6	1.417×10^{-4}	1.033×10^6	1.087×10^3
125,000	23.674	31.706	28.90	506.2	2.744×10^4	8.428	3.985×10^{-3}	9.686×10^{-6}	4.237×10^{-3}	2.966×10^{21}	1.488×10^3	7.838×10^{-5}	1.899×10^6	1.764×10^{-4}	8.441×10^5	1.106×10^3
130,000	24.621	31.691	28.90	523.2	2.838×10^4	7.051	3.334×10^{-3}	7.840×10^{-6}	3.429×10^{-3}	2.401×10^{21}	1.513×10^3	9.683×10^{-5}	1.563×10^6	2.179×10^{-4}	6.946×10^5	1.124×10^3
135,000	25.568	31.671	28.90	540.2	2.932×10^4	5.934	2.806×10^{-3}	6.390×10^{-6}	2.795×10^{-3}	1.957×10^{21}	1.538×10^3	1.188×10^{-4}	1.294×10^6	2.673×10^{-4}	5.752×10^5	1.142×10^3
140,000	26.515	31.660	28.90	557.2	3.025×10^4	5.021	2.374×10^{-3}	5.243×10^{-6}	2.293×10^{-3}	1.605×10^{21}	1.562×10^3	1.448×10^{-4}	1.078×10^6	3.258×10^{-4}	4.793×10^5	1.160×10^3
145,000	27.462	31.645	28.90	574.2	3.118×10^4	4.271	2.020×10^{-3}	4.327×10^{-6}	1.893×10^{-3}	1.325×10^{21}	1.585×10^3	1.754×10^{-4}	9.037×10^5	3.947×10^{-4}	4.016×10^5	1.178×10^3
150,000	28.409	31.630	28.90	591.2	3.213×10^4	3.651	1.726×10^{-3}	3.592×10^{-6}	1.571×10^{-3}	1.100×10^{21}	1.609×10^3	2.113×10^{-4}	7.612×10^5	4.755×10^{-4}	3.383×10^5	1.195×10^3
155,000	29.356	31.615	28.90	608.2	3.307×10^4	3.135	1.482×10^{-3}	2.999×10^{-6}	1.312×10^{-3}	9.182×10^{20}	1.632×10^3	2.532×10^{-4}	6.445×10^5	5.696×10^{-4}	2.864×10^5	1.212×10^3
160,000	30.303	31.600	28.90	625.3	3.401×10^4	2.704	1.279×10^{-3}	2.516×10^{-6}	1.101×10^{-3}	7.705×10^{20}	1.654×10^3	3.017×10^{-4}	5.484×10^5	6.788×10^{-4}	2.437×10^5	1.229×10^3
164,040	31.068	31.588	28.90	639.0	3.477×10^4	2.407	1.138×10^{-3}	2.191×10^{-6}	9.584×10^{-4}	6.709×10^{20}	1.672×10^3	3.465×10^{-4}	4.827×10^5	7.796×10^{-4}	2.145×10^5	1.242×10^3
165,000	31.250	31.585	28.90	639.0	3.478×10^4	2.341	1.107×10^{-3}	2.132×10^{-6}	9.324×10^{-4}	6.527×10^{20}	1.672×10^3	3.562×10^{-4}	4.696×10^5	8.013×10^{-4}	2.087×10^5	1.242×10^3
170,000	32.197	31.570	28.90	639.0	3.479×10^4	2.028	9.590×10^{-4}	1.846×10^{-6}	8.077×10^{-4}	5.654×10^{20}	1.672×10^3	4.112×10^{-4}	4.068×10^5	9.251×10^{-4}	1.808×10^5	1.242×10^3
175,000	33.144	31.555	28.90	639.0	3.481×10^4	1.757	8.295×10^{-4}	1.600×10^{-6}	6.998×10^{-4}	4.899×10^{20}	1.672×10^3	4.745×10^{-4}	3.524×10^5	1.068×10^{-3}	1.566×10^5	1.242×10^3
180,000	34.091	31.540	28.90	639.0	3.483×10^4	1.523	7.200×10^{-4}	1.386×10^{-6}	6.064×10^{-4}	4.245×10^{20}	1.672×10^3	5.476×10^{-4}	3.054×10^5	1.232×10^{-3}	1.357×10^5	1.242×10^3
185,000	35.038	31.525	28.90	639.0	3.484×10^4	1.320	6.239×10^{-4}	1.201×10^{-6}	5.255×10^{-4}	3.679×10^{20}	1.672×10^3	6.319×10^{-4}	2.646×10^5	1.422×10^{-3}	1.176×10^5	1.242×10^3
190,000	35.985	31.510	28.90	639.0	3.486×10^4	1.144	5.408×10^{-4}	1.041×10^{-6}	4.555×10^{-4}	3.188×10^{20}	1.672×10^3	7.291×10^{-4}	2.294×10^5	1.640×10^{-3}	1.020×10^5	1.242×10^3
195,000	36.932	31.495	28.90	639.0	3.488×10^4	.9914	4.688×10^{-4}	9.026×10^{-7}	3.948×10^{-4}	2.764×10^{20}	1.672×10^3	8.411×10^{-4}	1.988×10^5	1.892×10^{-3}	8.837×10^4	1.242×10^3

Table 3.13 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER Latitude 0°. Engineering Units. $p_0 = 2115$ lb/ft^2, $\rho_0 = 2.286 \times 10^{-3}$ slug/ft^3. Table 11 of Ref. 3.20.

Height h ft	Height h mi	Apparent Gravity g' ft/sec²	Mean Mol Wt M	Temp T °R	Scale Height H ft	Pressure p lb/ft²	Pressure Ratio p/p_0	Density ρ slug/ft³	Density Ratio σ ρ/ρ_0	Number Density n particles/ft³	Mean Particle Speed v ft/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ ft	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ ft	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	Speed of Sound a ft/sec
196,848	37.282	31.489	28.90	639.0	3.488×10^4	.9405	4.447×10^{-4}	8.562×10^{-7}	3.745×10^{-4}	2.622×10^{20}	1.672×10^3	8.867×10^{-4}	1.886×10^6	1.995×10^{-3}	8.383×10^5	1.242×10^3
200,000	37.879	31.480	28.90	628.0	3.429×10^4	.8566	4.060×10^{-4}	7.955×10^{-7}	3.480×10^{-4}	2.436×10^{20}	1.658×10^3	9.544×10^{-4}	1.737×10^6	2.147×10^{-3}	7.720×10^5	1.232×10^3
205,000	38.826	31.465	28.90	610.4	3.335×10^4	.7408	3.502×10^{-4}	7.060×10^{-7}	3.088×10^{-4}	2.162×10^{20}	1.635×10^3	1.075×10^{-3}	1.520×10^6	2.419×10^{-3}	6.756×10^5	1.214×10^3
210,000	39.773	31.450	28.90	592.9	3.241×10^4	.6365	3.009×10^{-4}	6.245×10^{-7}	2.732×10^{-4}	1.912×10^{20}	1.611×10^3	1.216×10^{-3}	1.325×10^6	2.735×10^{-3}	5.890×10^5	1.197×10^3
215,000	40.720	31.435	28.90	575.4	3.146×10^4	.5444	2.574×10^{-4}	5.505×10^{-7}	2.408×10^{-4}	1.686×10^{20}	1.587×10^3	1.379×10^{-3}	1.151×10^6	3.103×10^{-3}	5.114×10^5	1.179×10^3
220,000	41.667	31.420	28.90	557.9	3.052×10^4	.4635	2.192×10^{-4}	4.834×10^{-7}	2.114×10^{-4}	1.480×10^{20}	1.563×10^3	1.571×10^{-3}	9.948×10^5	3.534×10^{-3}	4.422×10^5	1.161×10^3
225,000	42.614	31.405	28.90	540.3	2.957×10^4	.3927	1.857×10^{-4}	4.228×10^{-7}	1.849×10^{-4}	1.294×10^{20}	1.538×10^3	1.796×10^{-3}	8.564×10^5	4.040×10^{-3}	3.806×10^5	1.142×10^3
230,000	43.561	31.390	28.90	522.8	2.863×10^4	.3309	1.564×10^{-4}	3.682×10^{-7}	1.611×10^{-4}	1.127×10^{20}	1.513×10^3	2.062×10^{-3}	7.336×10^5	4.639×10^{-3}	3.261×10^5	1.124×10^3
235,000	44.508	31.375	28.90	505.3	2.768×10^4	.2772	1.311×10^{-4}	3.192×10^{-7}	1.396×10^{-4}	9.774×10^{19}	1.487×10^3	2.378×10^{-3}	6.253×10^5	5.351×10^{-3}	2.779×10^5	1.105×10^3
240,000	45.455	31.360	28.90	487.7	2.673×10^4	.2309	1.092×10^{-4}	2.754×10^{-7}	1.205×10^{-4}	8.433×10^{19}	1.461×10^3	2.757×10^{-3}	5.301×10^5	6.202×10^{-3}	2.356×10^5	1.085×10^3
245,000	46.402	31.346	28.90	470.2	2.579×10^4	.1910	9.033×10^{-5}	2.364×10^{-7}	1.034×10^{-4}	7.237×10^{19}	1.435×10^3	3.212×10^{-3}	4.466×10^5	7.227×10^{-3}	1.985×10^5	1.066×10^3
250,000	47.348	31.331	28.90	452.7	2.484×10^4	.1570	7.421×10^{-5}	2.017×10^{-7}	8.823×10^{-5}	6.176×10^{19}	1.408×10^3	3.764×10^{-3}	3.740×10^5	8.469×10^{-3}	1.662×10^5	1.046×10^3
255,000	48.295	31.316	28.90	435.2	2.389×10^4	.1280	6.051×10^{-5}	1.711×10^{-7}	7.484×10^{-5}	5.239×10^{19}	1.380×10^3	4.437×10^{-3}	3.110×10^5	9.984×10^{-3}	1.382×10^5	1.025×10^3
255,902	48.466	31.313	28.90	432.0	2.371×10^4	.1233	5.828×10^{-5}	1.669×10^{-7}	7.260×10^{-5}	5.082×10^{19}	1.375×10^3	4.574×10^{-3}	3.006×10^5	1.029×10^{-2}	1.336×10^5	1.021×10^3
260,000	49.242	31.301	28.90	432.0	2.372×10^4	.1037	4.902×10^{-5}	1.397×10^{-7}	6.110×10^{-5}	4.277×10^{19}	1.375×10^3	5.435×10^{-3}	2.530×10^5	1.223×10^{-2}	1.124×10^5	1.021×10^3
265,000	50.189	31.286	28.90	432.0	2.373×10^4	8.405×10^{-2}	3.972×10^{-5}	1.132×10^{-7}	4.951×10^{-5}	3.466×10^{19}	1.375×10^3	6.707×10^{-3}	2.050×10^5	1.509×10^{-2}	9.112×10^4	1.021×10^3
270,000	51.136	31.271	28.90	432.0	2.374×10^4	6.813×10^{-2}	3.220×10^{-5}	9.174×10^{-8}	4.013×10^{-5}	2.809×10^{19}	1.375×10^3	8.276×10^{-3}	1.662×10^5	1.862×10^{-2}	7.385×10^4	1.021×10^3
272,306	51.573	31.264	28.90	432.0	2.375×10^4	6.184×10^{-2}	2.922×10^{-5}	8.327×10^{-8}	3.642×10^{-5}	2.550×10^{19}	1.375×10^3	9.117×10^{-3}	1.508×10^5	2.051×10^{-2}	6.704×10^4	1.021×10^3
275,000	52.083	31.256	28.79	437.3	2.414×10^4	5.528×10^{-2}	2.612×10^{-5}	7.326×10^{-8}	3.205×10^{-5}	2.252×10^{19}	1.386×10^3	1.032×10^{-2}	1.343×10^5	2.323×10^{-2}	5.968×10^4	1.030×10^3
280,000	53.030	31.242	28.59	447.2	2.487×10^4	4.511×10^{-2}	2.132×10^{-5}	5.807×10^{-8}	2.540×10^{-5}	1.798×10^{19}	1.407×10^3	1.293×10^{-2}	1.088×10^5	2.910×10^{-2}	4.834×10^4	1.046×10^3
285,000	53.977	31.227	28.39	457.0	2.561×10^4	3.703×10^{-2}	1.750×10^{-5}	4.630×10^{-8}	2.025×10^{-5}	1.443×10^{19}	1.427×10^3	1.611×10^{-2}	8.861×10^4	3.624×10^{-2}	3.938×10^4	1.062×10^3
290,000	54.924	31.212	28.19	466.9	2.636×10^4	3.057×10^{-2}	1.445×10^{-5}	3.715×10^{-8}	1.625×10^{-5}	1.166×10^{19}	1.448×10^3	1.993×10^{-2}	7.263×10^4	4.484×10^{-2}	3.228×10^4	1.078×10^3
295,000	55.871	31.197	27.98	476.8	2.713×10^4	2.538×10^{-2}	1.199×10^{-5}	2.998×10^{-8}	1.312×10^{-5}	9.482×10^{18}	1.468×10^3	2.452×10^{-2}	5.988×10^4	5.516×10^{-2}	2.661×10^4	1.094×10^3
300,000	56.818	31.182	27.78	486.6	2.790×10^4	2.117×10^{-2}	1.001×10^{-5}	2.434×10^{-8}	1.064×10^{-5}	7.751×10^{18}	1.488×10^3	2.999×10^{-2}	4.963×10^4	6.748×10^{-2}	2.206×10^4	1.111×10^3
305,000	57.765	31.168	27.58	496.5	2.869×10^4	1.776×10^{-2}	8.391×10^{-6}	1.986×10^{-8}	8.685×10^{-6}	6.371×10^{18}	1.509×10^3	3.649×10^{-2}	4.136×10^4	8.210×10^{-2}	1.838×10^4	1.127×10^3
310,000	58.712	31.153	27.38	506.3	2.949×10^4	1.496×10^{-2}	7.071×10^{-6}	1.629×10^{-8}	7.124×10^{-6}	5.264×10^{18}	1.530×10^3	4.416×10^{-2}	3.464×10^4	9.936×10^{-2}	1.539×10^4	1.143×10^3
315,000	59.659	31.138	27.18	516.2	3.030×10^4	1.267×10^{-2}	5.986×10^{-6}	1.342×10^{-8}	5.872×10^{-6}	4.371×10^{18}	1.550×10^3	5.318×10^{-2}	2.915×10^4	1.196×10^{-1}	1.296×10^4	1.159×10^3
320,000	60.606	31.123	26.97	526.1	3.113×10^4	1.077×10^{-2}	5.089×10^{-6}	1.112×10^{-8}	4.862×10^{-6}	3.646×10^{18}	1.571×10^3	6.375×10^{-2}	2.464×10^4	1.434×10^{-1}	1.095×10^4	1.176×10^3
325,000	61.553	31.109	26.77	535.9	3.197×10^4	9.196×10^{-3}	4.346×10^{-6}	9.248×10^{-9}	4.045×10^{-6}	3.057×10^{18}	1.591×10^3	7.605×10^{-2}	2.092×10^4	1.711×10^{-1}	9.300×10^3	1.192×10^3
330,000	62.500	31.094	26.57	545.8	3.282×10^4	7.886×10^{-3}	3.727×10^{-6}	7.728×10^{-9}	3.380×10^{-6}	2.574×10^{18}	1.612×10^3	9.032×10^{-2}	1.785×10^4	2.032×10^{-1}	7.932×10^3	1.208×10^3
335,000	63.447	31.079	26.37	555.6	3.368×10^4	6.789×10^{-3}	3.208×10^{-6}	6.485×10^{-9}	2.837×10^{-6}	2.176×10^{18}	1.633×10^3	1.068×10^{-1}	1.528×10^4	2.403×10^{-1}	6.794×10^3	1.225×10^3
340,000	64.394	31.065	26.17	565.5	3.456×10^4	5.867×10^{-3}	2.773×10^{-6}	5.465×10^{-9}	2.390×10^{-6}	1.848×10^{18}	1.654×10^3	1.258×10^{-1}	1.314×10^4	2.830×10^{-1}	5.842×10^3	1.242×10^3
345,000	65.341	31.050	25.97	575.4	3.545×10^4	5.089×10^{-3}	2.405×10^{-6}	4.623×10^{-9}	2.022×10^{-6}	1.575×10^{18}	1.674×10^3	1.476×10^{-1}	1.135×10^4	3.320×10^{-1}	5.043×10^3	1.258×10^3
350,000	66.288	31.035	25.76	585.2	3.636×10^4	4.430×10^{-3}	2.093×10^{-6}	3.926×10^{-9}	1.717×10^{-6}	1.348×10^{18}	1.695×10^3	1.724×10^{-1}	9.832×10^3	3.879×10^{-1}	4.370×10^3	1.275×10^3
355,000	67.235	31.020	25.56	595.1	3.728×10^4	3.870×10^{-3}	1.829×10^{-6}	3.346×10^{-9}	1.464×10^{-6}	1.158×10^{18}	1.716×10^3	2.007×10^{-1}	8.550×10^3	4.516×10^{-1}	3.800×10^3	1.292×10^3
360,000	68.182	31.006	25.36	604.9	3.822×10^4	3.391×10^{-3}	1.603×10^{-6}	2.862×10^{-9}	1.252×10^{-6}	9.986×10^{17}	1.737×10^3	2.328×10^{-1}	7.460×10^3	5.238×10^{-1}	3.316×10^3	1.308×10^3
365,000	69.129	30.991	25.16	614.8	3.917×10^4	2.982×10^{-3}	1.409×10^{-6}	2.456×10^{-9}	1.074×10^{-6}	8.640×10^{17}	1.758×10^3	2.691×10^{-1}	6.535×10^3	6.054×10^{-1}	2.904×10^3	1.325×10^3
370,000	70.076	30.977	24.96	624.7	4.014×10^4	2.630×10^{-3}	1.243×10^{-6}	2.115×10^{-9}	9.252×10^{-7}	7.500×10^{17}	1.779×10^3	3.099×10^{-1}	5.741×10^3	6.974×10^{-1}	2.552×10^3	1.342×10^3
375,000	71.023	30.962	24.75	634.5	4.113×10^4	2.327×10^{-3}	1.100×10^{-6}	1.828×10^{-9}	7.994×10^{-7}	6.533×10^{17}	1.801×10^3	2.558×10^{-1}	5.060×10^3	8.006×10^{-1}	2.249×10^3	1.360×10^3
380,000	71.970	30.947	24.55	644.4	4.213×10^4	2.065×10^{-3}	9.758×10^{-7}	1.584×10^{-9}	6.927×10^{-7}	5.708×10^{17}	1.822×10^3	4.073×10^{-1}	4.474×10^3	9.164×10^{-1}	1.988×10^3	1.377×10^3
385,000	72.917	30.933	24.35	654.2	4.315×10^4	1.837×10^{-3}	8.687×10^{-7}	1.377×10^{-9}	6.021×10^{-7}	5.002×10^{17}	1.844×10^3	4.647×10^{-1}	3.967×10^3	1.046	1.763×10^3	1.394×10^3
390,000	73.864	30.918	24.15	664.1	4.418×10^4	1.639×10^{-3}	7.751×10^{-7}	1.200×10^{-9}	5.249×10^{-7}	4.397×10^{17}	1.865×10^3	5.287×10^{-1}	3.528×10^3	1.190	1.568×10^3	1.412×10^3
393,696	74.564	30.907	24.00	671.4	4.496×10^4	1.469×10^{-3}	6.944×10^{-7}	1.057×10^{-9}	4.622×10^{-7}	3.896×10^{17}	1.881×10^3	5.966×10^{-1}	3.153×10^3	1.342	1.401×10^3	1.424×10^3
395,000	74.811	30.904	24.00	675.0	4.521×10^4	1.427×10^{-3}	6.746×10^{-7}	1.021×10^{-9}	4.466×10^{-7}	3.688×10^{17}	1.886×10^3	6.174×10^{-1}	3.055×10^3	1.389	1.358×10^3	1.428×10^3
400,000	75.758	30.889	24.00	689.0	4.617×10^4	1.279×10^{-3}	6.047×10^{-7}	8.968×10^{-10}	3.923×10^{-7}	3.372×10^{17}	1.906×10^3	7.030×10^{-1}	2.711×10^3	1.582	1.205×10^3	1.443×10^3

Table 3.13 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER Latitude 0°. Engineering Units. $p_0 = 2115$ lb/ft², $\rho_0 = 2.286 \times 10^{-3}$ slug/ft³. Table 11 of Ref. 3.20. (Continued)

Height h ft	Height h mi	Apparent Gravity g' ft/sec²	Mean Mol Wt M	Temp T °R	Scale Height H ft	Pressure p lb/ft²	Pressure Ratio p/p_0	Density ρ slug/ft³	Density Ratio σ ρ/ρ_0	Number Density n particles/ft³	Mean Particle Speed $\bar{v}$ ft/sec	$d = 3 \times 10^{-8}$cm Mean Free Path λ ft	$d = 3 \times 10^{-8}$cm Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$cm Mean Free Path λ ft	$d = 2 \times 10^{-8}$cm Mean Collision Freq f 1/sec	Speed of Sound a ft/sec
4.500×10^5	85.23	30.744	24.00	828.8	5.580×10^4	4.80×10^{-4}	2.27×10^{-7}	2.80×10^{-10}	1.22×10^{-7}	1.03×10^{17}	2.090×10^3	2.25	9.28×10^3	5.07	4.13×10^2	1.583×10^3
5.000×10^5	94.70	30.600	24.00	968.6	6.552×10^4	2.12×10^{-4}	1.00×10^{-7}	1.06×10^{-10}	4.64×10^{-8}	3.91×10^{16}	2.260×10^3	5.95	3.80×10^3	1.34×10	1.69×10^2	1.711×10^3
5.280×10^5	100.0	30.520	24.00	1047	7.100×10^4	1.40×10^{-4}	6.62×10^{-8}	6.45×10^{-11}	2.82×10^{-8}	2.38×10^{16}	2.349×10^3	9.77	2.40×10^2	2.20×10	1.07×10^2	1.779×10^3
5.500×10^5	104.2	30.457	24.00	1108	7.533×10^4	1.04×10^{-4}	4.92×10^{-8}	4.53×10^{-11}	1.98×10^{-8}	1.67×10^{16}	2.417×10^3	1.39×10	1.74×10^2	3.13×10	7.72×10	
6.000×10^5	113.6	30.315	24.00	1248	8.523×10^4	5.57×10^{-5}	2.63×10^{-8}	2.15×10^{-11}	9.41×10^{-9}	7.93×10^{15}	2.565×10^3	2.93×10	8.75×10	6.60×10	3.89×10	
6.500×10^5	123.1	30.174	24.00	1388	9.522×10^4	3.20×10^{-5}	1.51×10^{-8}	1.11×10^{-11}	4.86×10^{-9}	4.09×10^{15}	2.705×10^3	5.68×10	4.76×10	1.28×10^2	2.12×10	
7.000×10^5	132.6	30.033	24.00	1528	1.053×10^5	1.94×10^{-5}	9.17×10^{-9}	6.13×10^{-12}	2.68×10^{-9}	2.26×10^{15}	2.838×10^3	1.03×10^2	2.76×10	2.31×10^2	1.23×10	
7.500×10^5	142.0	29.894	24.00	1668	1.155×10^5	1.24×10^{-5}	5.86×10^{-9}	3.59×10^{-12}	1.57×10^{-9}	1.32×10^{15}	2.965×10^3	1.76×10^2	1.69×10	3.95×10^2	7.50	
8.000×10^5	151.5	29.756	24.00	1807	1.257×10^5	8.16×10^{-6}	3.86×10^{-9}	2.18×10^{-12}	9.54×10^{-10}	8.04×10^{14}	3.087×10^3	2.89×10^3	1.07×10	6.51×10^2	4.74	
8.500×10^5	161.0	29.619	24.00	1947	1.361×10^5	5.57×10^{-6}	2.63×10^{-9}	1.38×10^{-12}	6.04×10^{-10}	5.09×10^{14}	3.204×10^3	4.57×10^2	7.01	1.03×10^3	3.12	
9.000×10^5	170.4	29.482	24.00	2087	1.465×10^5	3.91×10^{-6}	1.85×10^{-9}	9.05×10^{-13}	3.96×10^{-10}	3.34×10^{14}	3.317×10^3	6.97×10^2	4.76	1.57×10^3	2.12	
9.500×10^5	179.9	29.347	24.00	2227	1.571×10^5	2.81×10^{-6}	1.33×10^{-9}	6.09×10^{-13}	2.66×10^{-10}	2.25×10^{14}	3.426×10^3	1.04×10^3	3.31	2.33×10^3	1.47	
1.000×10^6	189.4	29.212	24.00	2367	1.677×10^5	2.07×10^{-6}	9.79×10^{-10}	4.23×10^{-13}	1.85×10^{-10}	1.56×10^{14}	3.532×10^3	1.49×10^3	2.37	3.35×10^3	1.05	
1.050×10^6	198.9	29.079	24.00	2507	1.784×10^5	1.55×10^{-6}	7.33×10^{-10}	2.99×10^{-13}	1.31×10^{-10}	1.10×10^{14}	3.635×10^3	2.11×10^3	1.72	4.74×10^3	7.66×10^{-1}	
1.056×10^6	200.0	29.063	24.00	2523	1.797×10^5	1.50×10^{-6}	7.09×10^{-10}	2.87×10^{-13}	1.26×10^{-10}	1.06×10^{14}	3.647×10^3	2.20×10^3	1.66	4.94×10^3	7.38×10^{-1}	
1.100×10^6	208.3	28.946	24.00	2646	1.892×10^5	1.18×10^{-6}	5.58×10^{-10}	2.15×10^{-13}	9.41×10^{-11}	7.93×10^{13}	3.735×10^3	2.93×10^3	1.27	6.60×10^3	5.66×10^{-2}	
1.150×10^6	217.8	28.814	24.00	2786	2.001×10^5	9.12×10^{-7}	4.31×10^{-10}	1.58×10^{-13}	6.91×10^{-11}	5.83×10^{13}	3.832×10^3	3.99×10^3	9.60×10^{-1}	8.98×10^3	4.27×10^{-1}	
1.200×10^6	227.3	28.684	24.00	2926	2.111×10^5	7.15×10^{-7}	3.38×10^{-10}	1.18×10^{-13}	5.16×10^{-11}	4.35×10^{13}	3.927×10^3	5.34×10^3	7.35×10^{-1}	1.20×10^4	3.27×10^{-1}	
1.250×10^6	236.7	28.554	24.00	3066	2.222×10^5	5.68×10^{-7}	2.69×10^{-10}	8.95×10^{-14}	3.92×10^{-11}	3.30×10^{13}	4.020×10^3	7.04×10^3	5.71×10^{-1}	1.58×10^4	2.54×10^{-2}	
1.300×10^6	246.2	28.424	24.00	3206	2.334×10^5	4.56×10^{-7}	2.16×10^{-10}	6.87×10^{-14}	3.01×10^{-11}	2.53×10^{13}	4.110×10^3	9.18×10^3	4.48×10^{-2}	2.06×10^4	1.99×10^{-1}	
1.312×10^6	248.6	28.393	24.00	3240	2.362×10^5	4.33×10^{-7}	2.05×10^{-10}	6.45×10^{-14}	2.82×10^{-11}	2.38×10^{13}	4.132×10^3	9.77×10^3	4.23×10^{-1}	2.20×10^4	1.88×10^{-1}	

1 lb/ft² = 0.3591 mm of Hg

Table 3.13 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER Latitude 0°. Engineering Units. $p_0 = 2115$ lb/ft², $\rho_0 = 2.286 \times 10^{-3}$ slug/ft³. Table 11 of Ref. 3.20. (Concluded)

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Height h km	Height h mi	Apparent Gravity g' cm/sec²	Mean Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm³	Density Ratio σ ρ/ρ_0	Number Density n particles/cm³	Mean Particle Speed $\bar{v}$ cm/sec	$d = 3 \times 10^{-8}$cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$cm: Mean Collision Freq f 1/sec	Speed of Sound a cm/sec
0	0	978.03	28.90	299.0	8.787	1.013×10^{3}	1.0000	1.178×10^{-3}	1.0000	2.472×10^{19}	4.678×10^{4}	1.012×10^{-6}	4.622×10^{9}	2.277×10^{-6}	2.054×10^{9}	3.477×10^{4}
1.524	.947	977.56	28.90	290.5	8.540	8.496×10^{2}	.8389	1.018×10^{-3}	.8636	2.135×10^{19}	4.611×10^{4}	1.172×10^{-6}	3.934×10^{9}	2.637×10^{-6}	1.748×10^{9}	3.425×10^{4}
3.048	1.894	977.09	28.90	281.9	8.294	7.092×10^{2}	.7002	8.750×10^{-4}	.7426	1.836×10^{19}	4.543×10^{4}	1.363×10^{-6}	3.333×10^{9}	3.067×10^{-6}	1.481×10^{9}	3.374×10^{4}
4.572	2.841	976.62	28.90	273.4	8.047	5.888×10^{2}	.5813	7.491×10^{-4}	.6357	1.572×10^{19}	4.474×10^{4}	1.592×10^{-6}	2.810×10^{9}	3.582×10^{-6}	1.249×10^{9}	3.323×10^{4}
5.000	3.107	976.46	28.90	271.0	7.977	5.583×10^{2}	.5511	7.166×10^{-4}	.6081	1.503×10^{19}	4.454×10^{4}	1.665×10^{-6}	2.676×10^{9}	3.745×10^{-6}	1.189×10^{9}	3.308×10^{4}
6.096	3.788	976.16	28.90	263.2	7.751	4.856×10^{2}	.4795	6.419×10^{-4}	.5447	1.347×10^{19}	4.389×10^{4}	1.858×10^{-6}	2.362×10^{9}	4.181×10^{-6}	1.050×10^{9}	3.260×10^{4}
7.620	4.735	975.69	28.90	252.4	7.437	3.975×10^{2}	.3925	5.478×10^{-4}	.4649	1.149×10^{19}	4.298×10^{4}	2.177×10^{-6}	1.974×10^{9}	4.898×10^{-6}	8.775×10^{8}	3.193×10^{4}
9.144	5.682	975.22	28.90	241.6	7.120	3.226×10^{2}	.3185	4.645×10^{-4}	.3942	9.744×10^{18}	4.205×10^{4}	2.568×10^{-6}	1.638×10^{9}	5.778×10^{-6}	7.278×10^{8}	3.124×10^{4}
10.000	6.214	974.96	28.90	235.5	6.943	2.857×10^{2}	.2821	4.220×10^{-4}	.3581	8.853×10^{18}	4.152×10^{4}	2.826×10^{-6}	1.469×10^{9}	6.359×10^{-6}	6.529×10^{8}	3.084×10^{4}
10.668	6.629	974.75	28.90	230.5	6.797	2.593×10^{2}	.2560	3.912×10^{-4}	.3320	8.206×10^{18}	4.108×10^{4}	3.049×10^{-6}	1.347×10^{9}	6.861×10^{-6}	5.988×10^{8}	3.051×10^{4}
12.192	7.576	974.29	28.90	219.2	6.468	2.062×10^{2}	.2036	3.272×10^{-4}	.2777	6.864×10^{18}	4.006×10^{4}	3.645×10^{-6}	1.099×10^{9}	8.202×10^{-6}	4.884×10^{8}	2.976×10^{4}
13.716	8.523	973.82	28.90	207.9	6.139	1.619×10^{2}	.1599	2.709×10^{-4}	.2299	5.683×10^{18}	3.901×10^{4}	4.403×10^{-6}	8.861×10^{8}	9.906×10^{-6}	3.938×10^{8}	2.898×10^{4}
15.240	9.470	973.35	28.90	196.6	5.803	1.256×10^{2}	.1240	2.221×10^{-4}	.1885	4.660×10^{18}	3.794×10^{4}	5.370×10^{-6}	7.065×10^{8}	1.208×10^{-4}	3.140×10^{8}	2.818×10^{4}
16.000	9.942	973.12	28.90	191.0	5.642	1.100×10^{2}	.1086	2.003×10^{-4}	.1700	4.203×10^{18}	3.739×10^{4}	5.954×10^{-6}	6.280×10^{8}	1.340×10^{-4}	2.791×10^{8}	2.777×10^{4}
16.764	10.417	972.88	28.90	193.2	5.709	9.617×10	9.494×10^{-2}	1.732×10^{-4}	.1469	3.633×10^{18}	3.760×10^{4}	6.888×10^{-6}	5.459×10^{8}	1.550×10^{-4}	2.426×10^{8}	2.793×10^{4}
18.288	11.364	972.42	28.90	197.5	5.840	7.390×10	7.296×10^{-2}	1.301×10^{-4}	.1104	2.730×10^{18}	3.803×10^{4}	9.166×10^{-6}	4.149×10^{8}	2.062×10^{-4}	1.844×10^{8}	2.824×10^{4}
19.812	12.311	971.96	28.90	201.9	5.971	5.713×10	5.640×10^{-2}	9.842×10^{-5}	8.352×10^{-2}	2.065×10^{18}	3.844×10^{4}	1.212×10^{-4}	3.172×10^{8}	2.727×10^{-4}	1.410×10^{8}	2.855×10^{4}
21.336	13.258	971.49	28.90	206.2	6.102	4.441×10	4.385×10^{-2}	7.490×10^{-5}	6.356×10^{-2}	1.571×10^{18}	3.886×10^{4}	1.592×10^{-4}	2.440×10^{8}	3.583×10^{-4}	1.084×10^{8}	2.886×10^{4}
22.860	14.205	971.02	28.90	210.6	6.233	3.472×10	3.428×10^{-2}	5.735×10^{-5}	4.867×10^{-2}	1.203×10^{18}	3.926×10^{4}	2.080×10^{-4}	1.888×10^{8}	4.680×10^{-4}	8.390×10^{7}	2.916×10^{4}
24.384	15.152	970.56	28.90	215.0	6.367	2.729×10	2.694×10^{-2}	4.416×10^{-5}	3.747×10^{-2}	9.263×10^{17}	3.967×10^{4}	2.701×10^{-4}	1.468×10^{8}	6.078×10^{-4}	6.527×10^{7}	2.946×10^{4}
25.908	16.098	970.10	28.90	219.3	6.501	2.156×10	2.129×10^{-2}	3.420×10^{-5}	2.903×10^{-2}	7.175×10^{17}	4.007×10^{4}	3.487×10^{-4}	1.149×10^{8}	7.846×10^{-4}	5.106×10^{7}	2.976×10^{4}
27.432	17.045	969.63	28.90	223.7	6.629	1.711×10	1.689×10^{-2}	2.660×10^{-5}	2.258×10^{-2}	5.581×10^{17}	4.046×10^{4}	4.483×10^{-4}	9.025×10^{7}	1.009×10^{-3}	4.011×10^{7}	3.005×10^{4}
28.956	17.992	969.17	28.90	228.0	6.764	1.364×10	1.347×10^{-2}	2.081×10^{-5}	1.766×10^{-2}	4.366×10^{17}	4.085×10^{4}	5.731×10^{-4}	7.128×10^{7}	1.290×10^{-3}	3.168×10^{7}	3.035×10^{4}
30.000	18.641	968.85	28.90	231.0	6.855	1.171×10	1.156×10^{-2}	1.764×10^{-5}	1.497×10^{-2}	3.700×10^{17}	4.112×10^{4}	6.762×10^{-4}	6.081×10^{7}	1.521×10^{-3}	2.703×10^{7}	3.054×10^{4}
30.480	18.939	968.71	28.90	234.0	6.943	1.093×10	1.079×10^{-2}	1.624×10^{-5}	1.378×10^{-2}	3.408×10^{17}	4.138×10^{4}	7.342×10^{-4}	5.636×10^{7}	1.652×10^{-3}	2.505×10^{7}	3.074×10^{4}
32.004	19.886	968.24	28.90	243.4	7.227	8.815	8.703×10^{-3}	1.262×10^{-5}	1.071×10^{-2}	2.649×10^{17}	4.221×10^{4}	9.447×10^{-4}	4.468×10^{7}	2.126×10^{-3}	1.986×10^{7}	3.135×10^{4}
33.528	20.833	967.78	28.90	252.9	7.510	7.171	7.080×10^{-3}	9.864×10^{-6}	8.371×10^{-3}	2.069×10^{17}	4.302×10^{4}	1.209×10^{-3}	3.558×10^{7}	2.721×10^{-3}	1.581×10^{7}	3.196×10^{4}
35.052	21.780	967.32	28.90	262.3	7.794	5.879	5.804×10^{-3}	7.796×10^{-6}	6.616×10^{-3}	1.635×10^{17}	4.382×10^{4}	1.530×10^{-3}	2.864×10^{7}	3.442×10^{-3}	1.273×10^{7}	3.255×10^{4}
36.576	22.727	966.86	28.90	271.8	8.080	4.855	4.793×10^{-3}	6.214×10^{-6}	5.273×10^{-3}	1.304×10^{17}	4.460×10^{4}	1.919×10^{-3}	2.324×10^{7}	4.319×10^{-3}	1.033×10^{7}	3.313×10^{4}
38.100	23.674	966.40	28.90	281.2	8.364	4.037	3.985×10^{-3}	4.993×10^{-6}	4.237×10^{-3}	1.047×10^{17}	4.537×10^{4}	2.389×10^{-3}	1.899×10^{7}	5.375×10^{-3}	8.441×10^{6}	3.370×10^{4}
39.624	24.621	965.93	28.90	290.7	8.650	3.377	3.334×10^{-3}	4.041×10^{-6}	3.429×10^{-3}	8.478×10^{16}	4.613×10^{4}	2.951×10^{-3}	1.563×10^{7}	6.641×10^{-4}	6.946×10^{6}	3.426×10^{4}
41.148	25.568	965.47	28.90	300.1	8.937	2.842	2.806×10^{-3}	3.294×10^{-6}	2.795×10^{-3}	6.910×10^{16}	4.687×10^{4}	3.621×10^{-3}	1.294×10^{7}	8.148×10^{-3}	5.752×10^{6}	3.481×10^{4}
42.673	26.515	965.01	28.90	309.6	9.220	2.405	2.374×10^{-3}	2.702×10^{-6}	2.293×10^{-3}	5.669×10^{16}	4.760×10^{4}	4.414×10^{-3}	1.078×10^{7}	9.932×10^{-3}	4.793×10^{6}	3.536×10^{4}
44.197	27.462	964.55	28.90	319.0	9.504	2.046	2.020×10^{-3}	2.230×10^{-6}	1.893×10^{-3}	4.679×10^{16}	4.832×10^{4}	5.347×10^{-3}	9.037×10^{6}	1.203×10^{-2}	4.016×10^{6}	3.589×10^{4}
45.721	28.409	964.09	28.90	328.5	9.793	1.749	1.726×10^{-3}	1.852×10^{-6}	1.571×10^{-3}	3.884×10^{16}	4.903×10^{4}	6.442×10^{-3}	7.612×10^{6}	1.449×10^{-2}	3.383×10^{6}	3.642×10^{4}
47.245	29.356	963.63	28.90	337.9	10.08	1.502	1.482×10^{-3}	1.546×10^{-6}	1.312×10^{-3}	3.243×10^{16}	4.973×10^{4}	7.717×10^{-3}	6.445×10^{6}	1.736×10^{-2}	2.864×10^{6}	3.694×10^{4}
48.769	30.303	963.17	28.90	347.4	10.37	1.295	1.279×10^{-3}	1.297×10^{-6}	1.101×10^{-3}	2.721×10^{16}	5.043×10^{4}	9.196×10^{-3}	5.484×10^{6}	2.069×10^{-2}	2.437×10^{6}	3.745×10^{4}
50.000	31.068	962.80	28.90	355.0	10.60	1.153	1.138×10^{-3}	1.129×10^{-6}	9.584×10^{-4}	2.369×10^{16}	5.097×10^{4}	1.056×10^{-2}	4.827×10^{6}	2.376×10^{-2}	2.145×10^{6}	3.787×10^{4}
50.293	31.250	962.71	28.90	355.0	10.60	1.121	1.107×10^{-3}	1.099×10^{-6}	9.324×10^{-4}	2.305×10^{16}	5.097×10^{4}	1.086×10^{-2}	4.696×10^{6}	2.442×10^{-2}	2.087×10^{6}	3.787×10^{4}
51.817	32.197	962.25	28.90	355.0	10.60	9.714×10^{-1}	9.590×10^{-4}	9.517×10^{-7}	3.077×10^{-4}	1.997×10^{16}	5.097×10^{4}	1.253×10^{-2}	4.068×10^{6}	2.820×10^{-2}	1.808×10^{6}	3.787×10^{4}
53.341	33.144	961.79	28.90	355.0	10.61	8.416×10^{-1}	8.295×10^{-4}	8.246×10^{-7}	6.998×10^{-4}	1.730×10^{16}	5.097×10^{4}	1.446×10^{-2}	3.524×10^{6}	3.254×10^{-2}	1.566×10^{6}	3.787×10^{4}
54.865	34.091	961.34	28.90	355.0	10.62	7.293×10^{-1}	7.200×10^{-4}	7.145×10^{-7}	6.064×10^{-4}	1.499×10^{16}	5.097×10^{4}	1.669×10^{-2}	3.054×10^{6}	3.756×10^{-2}	1.357×10^{6}	3.787×10^{4}
56.389	35.038	960.88	28.90	355.0	10.62	6.320×10^{-1}	6.239×10^{-4}	6.192×10^{-7}	5.255×10^{-4}	1.299×10^{16}	5.097×10^{4}	1.926×10^{-2}	2.646×10^{6}	4.334×10^{-2}	1.176×10^{6}	3.787×10^{4}
57.913	35.985	960.42	28.90	355.0	10.63	5.477×10^{-1}	5.408×10^{-4}	5.367×10^{-7}	4.555×10^{-4}	1.126×10^{16}	5.097×10^{4}	2.222×10^{-2}	2.294×10^{6}	5.000×10^{-2}	1.020×10^{6}	3.787×10^{4}
59.437	36.932	959.96	28.90	355.0	10.63	4.748×10^{-1}	4.688×10^{-4}	4.653×10^{-7}	3.948×10^{-4}	9.760×10^{15}	5.097×10^{4}	2.564×10^{-2}	1.988×10^{6}	5.768×10^{-2}	8.837×10^{5}	3.787×10^{4}

Table 3.14 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER
Latitude 0°. Metric Units. $p_0 = 1013$ mb,
$\rho_0 = 1.178 \times 10^{-3}$ gm/cm³. Table 12 of Ref. 3.20.

Height h km	Height h mi	Apparent Gravity g' cm/sec^2	Mean Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm^3	Density Ratio σ ρ/ρ_0	Number Density n particles/cm^3	Mean Particle Speed $\bar{v}$ cm/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq 1/sec	Speed of Sound a cm/sec
60.000	37.282	959.80	28.90	355.0	10.63	4.504×10^{-1}	4.447×10^{-4}	4.413×10^{-7}	3.745×10^{-4}	9.258×10^{15}	5.097×10^{4}	2.703×10^{-2}	1.886×10^{6}	6.081×10^{-2}	8.383×10^{6}	3.787×10^{4}
60.961	37.879	959.51	28.90	348.9	10.45	4.112×10^{-1}	4.060×10^{-4}	4.100×10^{-7}	3.480×10^{-4}	8.602×10^{15}	5.053×10^{4}	2.909×10^{-2}	1.737×10^{6}	6.545×10^{-2}	7.720×10^{6}	3.754×10^{4}
62.485	38.826	959.05	28.90	339.1	10.17	3.548×10^{-1}	3.502×10^{-4}	3.639×10^{-7}	3.088×10^{-4}	7.634×10^{15}	4.962×10^{4}	3.278×10^{-2}	1.520×10^{6}	7.374×10^{-2}	6.756×10^{6}	3.701×10^{4}
64.009	39.773	958.60	28.90	329.4	9.879	3.048×10^{-1}	3.009×10^{-4}	3.219×10^{-7}	2.732×10^{-4}	6.753×10^{15}	4.910×10^{4}	3.705×10^{-2}	1.325×10^{6}	8.337×10^{-2}	5.890×10^{6}	3.647×10^{4}
65.533	40.720	958.14	28.90	319.7	9.589	2.607×10^{-1}	2.574×10^{-4}	2.837×10^{-7}	2.408×10^{-4}	5.952×10^{15}	4.837×10^{4}	4.204×10^{-2}	1.151×10^{6}	9.459×10^{-2}	5.114×10^{6}	3.593×10^{4}
67.057	41.667	957.68	28.90	309.9	9.302	2.220×10^{-1}	2.192×10^{-4}	2.491×10^{-7}	2.114×10^{-4}	5.227×10^{15}	4.763×10^{4}	4.788×10^{-2}	9.948×10^{5}	1.077×10^{-1}	4.422×10^{6}	3.538×10^{4}
68.581	42.614	957.23	28.90	300.2	9.013	1.881×10^{-1}	1.857×10^{-4}	2.179×10^{-7}	1.849×10^{-4}	4.571×10^{15}	4.688×10^{4}	5.473×10^{-2}	8.564×10^{5}	1.232×10^{-1}	3.806×10^{6}	3.482×10^{4}
70.105	43.561	956.77	28.90	290.4	8.726	1.585×10^{-1}	1.564×10^{-4}	1.898×10^{-7}	1.611×10^{-4}	3.981×10^{15}	4.611×10^{4}	6.285×10^{-2}	$7\ 336 \times 10^{5}$	1.414×10^{-1}	3.261×10^{6}	3.425×10^{4}
71.629	44.508	956.32	28.90	280.7	8.437	1.328×10^{-1}	1.311×10^{-4}	1.645×10^{-7}	1.396×10^{-4}	3.452×10^{15}	4.533×10^{4}	7.249×10^{-2}	6.253×10^{5}	1.631×10^{-1}	2.779×10^{6}	3.367×10^{4}
73.153	45.455	955.86	28.90	271.0	8.147	1.106×10^{-1}	1.092×10^{-4}	1.420×10^{-7}	1.205×10^{-4}	2.978×10^{15}	4.454×10^{4}	8.402×10^{-2}	5.301×10^{5}	1.890×10^{-1}	2.356×10^{6}	3.308×10^{4}
74.677	46.402	955.41	28.90	261.2	7.861	9.149×10^{-2}	9.033×10^{-5}	1.218×10^{-7}	1.034×10^{-4}	2.556×10^{15}	4.373×10^{4}	9.790×10^{-2}	4.466×10^{5}	2.203×10^{-1}	1.985×10^{6}	3.248×10^{4}
76.201	47.348	954.96	28.90	251.5	7.571	7.517×10^{-2}	7.421×10^{-5}	1.040×10^{-7}	8.823×10^{-5}	2.181×10^{15}	4.291×10^{4}	1.147×10^{-1}	3.740×10^{5}	2.581×10^{-1}	1.662×10^{6}	3.187×10^{4}
77.725	48.295	954.51	28.90	241.8	7.282	6.129×10^{-2}	6.051×10^{-5}	8.818×10^{-8}	7.484×10^{-5}	1.850×10^{15}	4.207×10^{4}	1.353×10^{-1}	3.110×10^{5}	3.043×10^{-1}	1.382×10^{6}	3.125×10^{4}
78.000	48.466	954.42	28.90	240.0	7.227	5.903×10^{-2}	5.828×10^{-5}	8.555×10^{-8}	7.260×10^{-5}	1.795×10^{15}	4.191×10^{4}	1.394×10^{-1}	3.006×10^{5}	3.137×10^{-1}	1.336×10^{6}	3.113×10^{4}
79.249	49.242	954.06	28.90	240.0	7.230	4.967×10^{-2}	4.902×10^{-5}	7.200×10^{-8}	6.110×10^{-5}	1.510×10^{15}	4.191×10^{4}	1.657×10^{-1}	2.530×10^{5}	3.728×10^{-1}	1.124×10^{6}	3.113×10^{4}
80.773	50.189	953.61	28.90	240.0	7.233	4.026×10^{-2}	3.972×10^{-5}	5.834×10^{-8}	4.951×10^{-5}	1.224×10^{15}	4.191×10^{4}	2.044×10^{-1}	2.050×10^{5}	4.600×10^{-1}	9.112×10^{5}	3.113×10^{4}
82.279	51.136	953.16	28.90	240.0	7.239	3.263×10^{-2}	3.220×10^{-5}	4.729×10^{-8}	4.013×10^{-5}	9.920×10^{14}	4.191×10^{4}	2.522×10^{-1}	1.662×10^{5}	5.675×10^{-1}	7.385×10^{5}	3.113×10^{4}
83.000	51.573	952.95	28.90	240.0	7.239	2.962×10^{-2}	2.922×10^{-5}	4.292×10^{-8}	3.642×10^{-5}	9.005×10^{14}	4.191×10^{4}	2.779×10^{-1}	1.508×10^{5}	6.252×10^{-1}	6.704×10^{5}	3.113×10^{4}
83.821	52.083	952.70	28.79	243.0	7.358	2.648×10^{-2}	2.612×10^{-5}	3.776×10^{-8}	3.205×10^{-5}	7.952×10^{14}	4.225×10^{4}	3.146×10^{-1}	1.343×10^{5}	7.080×10^{-1}	5.968×10^{5}	3.140×10^{4}
85.343	53.030	952.25	28.59	248.4	7.580	2.160×10^{-2}	2.132×10^{-5}	2.993×10^{-8}	2.540×10^{-5}	6.348×10^{14}	4.287×10^{4}	3.942×10^{-1}	1.088×10^{5}	8.869×10^{-1}	4.834×10^{5}	3.189×10^{4}
86.869	53.977	951.80	28.39	253.9	7.806	1.774×10^{-2}	1.750×10^{-5}	2.387×10^{-8}	2.025×10^{-5}	5.097×10^{14}	4.350×10^{4}	4.909×10^{-1}	8.861×10^{4}	1.105	3.938×10^{5}	3.238×10^{4}
88.393	54.924	951.35	28.19	259.4	8.035	1.464×10^{-2}	1.445×10^{-5}	1.915×10^{-8}	1.625×10^{-5}	4.119×10^{14}	4.412×10^{4}	6.075×10^{-1}	7.263×10^{4}	1.367	3.228×10^{5}	3.287×10^{4}
89.917	55.871	950.90	27.98	264.9	8.269	1.215×10^{-2}	1.199×10^{-5}	1.546×10^{-8}	1.312×10^{-5}	3.348×10^{14}	4.475×10^{4}	7.473×10^{-1}	5.988×10^{4}	1.681	2.661×10^{5}	3.336×10^{4}
90.441	56.818	950.45	27.78	270.3	8.504	1.014×10^{-2}	1.001×10^{-5}	1.254×10^{-8}	1.064×10^{-5}	2.737×10^{14}	4.537×10^{4}	9.141×10^{-1}	4.963×10^{4}	2.057	2.206×10^{5}	3.385×10^{4}
92.965	57.765	950.00	27.58	275.8	8.745	8.504×10^{-3}	8.391×10^{-6}	1.023×10^{-8}	8.685×10^{-6}	2.250×10^{14}	4.599×10^{4}	1.112	4.136×10^{4}	2.502	1.838×10^{5}	3.435×10^{4}
94.489	58.712	949.55	27.38	281.3	8.989	7.166×10^{-3}	7.071×10^{-6}	8.395×10^{-9}	7.124×10^{-6}	1.860×10^{14}	4.662×10^{4}	1.346	3.464×10^{4}	3.029	1.539×10^{5}	3.484×10^{4}
96.013	59.659	949.10	27.18	286.8	9.235	6.067×10^{-3}	5.986×10^{-6}	6.920×10^{-9}	5.872×10^{-6}	1.544×10^{14}	4.725×10^{4}	1.621	2.915×10^{4}	3.647	1.296×10^{5}	3.534×10^{4}
97.537	60.606	948.65	26.97	292.3	9.488	5.158×10^{-3}	5.089×10^{-6}	5.730×10^{-9}	4.862×10^{-6}	1.288×10^{14}	4.788×10^{4}	1.943	2.464×10^{4}	4.372	1.095×10^{5}	3.583×10^{4}
99.061	61.553	948.20	26.77	297.7	9.744	4.404×10^{-3}	4.346×10^{-6}	4.767×10^{-9}	4.045×10^{-6}	1.079×10^{14}	4.850×10^{4}	2.318	2.092×10^{4}	5.215	9.300×10^{4}	3.633×10^{4}
100.58	62.500	947.75	26.57	303.2	1.000×10	3.777×10^{-3}	3.727×10^{-6}	3.983×10^{-9}	3.380×10^{-6}	9.089×10^{13}	4.913×10^{4}	2.753	1.785×10^{4}	6.194	7.932×10^{4}	3.683×10^{4}
102.11	63.447	947.30	26.37	308.7	1.027×10	3.251×10^{-3}	3.208×10^{-6}	3.343×10^{-9}	2.837×10^{-6}	7.686×10^{13}	4.977×10^{4}	3.256	1.528×10^{4}	7.325	6.794×10^{4}	3.734×10^{4}
103.63	64.394	946.86	26.17	314.2	1.053×10	2.810×10^{-3}	2.773×10^{-6}	2.817×10^{-9}	2.390×10^{-6}	6.526×10^{13}	5.040×10^{4}	3.834	1.314×10^{4}	8.626	5.842×10^{4}	3.784×10^{4}
105.16	65.341	946.41	25.97	319.6	1.081×10	2.437×10^{-3}	2.405×10^{-6}	2.383×10^{-9}	2.022×10^{-6}	5.563×10^{13}	5.103×10^{4}	4.497	1.135×10^{4}	1.012×10	5.043×10^{4}	3.835×10^{4}
106.68	66.288	945.97	25.76	325.1	1.108×10	2.122×10^{-3}	2.093×10^{-6}	2.023×10^{-9}	1.717×10^{-6}	4.761×10^{13}	5.167×10^{4}	5.255	9.832×10^{3}	1.182×10	4.370×10^{4}	3.886×10^{4}
108.20	67.235	945.51	25.56	330.6	1.136×10	1.853×10^{-3}	1.829×10^{-6}	1.725×10^{-9}	1.464×10^{-6}	4.090×10^{13}	5.231×10^{4}	6.118	8.550×10^{3}	1.376×10	3.800×10^{4}	3.937×10^{4}
109.73	68.182	945.07	25.35	336.1	1.165×10	1.624×10^{-3}	1.603×10^{-6}	1.475×10^{-9}	1.252×10^{-6}	3.526×10^{13}	5.294×10^{4}	7.096	7.460×10^{3}	1.596×10	3.316×10^{4}	3.988×10^{4}
111.25	69.129	944.62	25.16	341.6	1.194×10	1.428×10^{-3}	1.409×10^{-6}	1.266×10^{-9}	1.074×10^{-6}	3.051×10^{13}	5.359×10^{4}	8.201	6.535×10^{3}	1.845×10	2.904×10^{4}	4.040×10^{4}
112.78	70.076	944.18	24.96	347.0	1.223×10	1.260×10^{-3}	1.243×10^{-6}	1.090×10^{-9}	9.252×10^{-7}	2.649×10^{13}	5.424×10^{4}	9.447	5.741×10^{3}	2.126×10	2.552×10^{4}	4.092×10^{4}
114.30	71.023	943.73	24.75	352.5	1.254×10	1.114×10^{-3}	1.100×10^{-6}	9.419×10^{-10}	7.994×10^{-7}	2.307×10^{13}	5.489×10^{4}	1.085×10	5.060×10^{3}	2.440×10	2.249×10^{4}	4.144×10^{4}
115.82	71.970	943.29	24.55	358.0	1.284×10	9.889×10^{-4}	9.758×10^{-7}	8.163×10^{-10}	6.927×10^{-7}	2.016×10^{13}	5.554×10^{4}	1.241×10	4.474×10^{3}	2.793×10	1.988×10^{4}	4.196×10^{4}
117.35	72.917	942.84	24.35	363.5	1.315×10	8.799×10^{-4}	8.687×10^{-7}	7.095×10^{-10}	6.021×10^{-7}	1.767×10^{13}	5.619×10^{4}	1.416×10	3.967×10^{3}	3.187×10	1.763×10^{4}	4.249×10^{4}
118.87	73.864	942.40	24.15	369.0	1.347×10	7.851×10^{-4}	7.751×10^{-7}	6.185×10^{-10}	5.249×10^{-7}	1.553×10^{13}	5.685×10^{4}	1.611×10	3.528×10^{3}	3.626×10	1.568×10^{4}	4.302×10^{4}
120.00	74.564	942.07	24.00	373.0	1.370×10	7.034×10^{-4}	6.944×10^{-7}	5.447×10^{-10}	4.622×10^{-7}	1.376×10^{13}	5.734×10^{4}	1.818×10	3.153×10^{3}	4.092×10	1.401×10^{4}	4.342×10^{4}
120.40	74.811	941.95	24.00	375.0	1.378×10	6.833×10^{-4}	6.746×10^{-7}	5.263×10^{-10}	4.466×10^{-7}	1.330×10^{13}	5.749×10^{4}	1.882×10	3.055×10^{3}	4.235×10	1.358×10^{4}	4.354×10^{4}
121.92	75.758	941.50	24.00	382.8	1.407×10	6.125×10^{-4}	6.047×10^{-7}	4.622×10^{-10}	3.923×10^{-7}	1.168×10^{13}	5.809×10^{4}	2.143×10	2.711×10^{3}	4.821×10	1.205×10^{4}	4.398×10^{4}

Table 3.14 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER
Latitude 0°. Metric Units. $p_0 = 1013$ mb,
$\rho_0 = 1.178 \times 10^{-3}$ gm/cm^3. Table 12 of Ref. 3.20. (Continued)

Height h km	Height h mi	Apparent Gravity g' cm/sec^2	Mean Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm^3	Density Ratio σ ρ/ρ_0	Number Density n particles/cm^3	Mean Particle Speed $\bar{v}$ cm/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	Speed of Sound a cm/sec
137.2	85.23	937.08	24.00	460.5	1.701×10	2.30×10^{-4}	2.27×10^{-7}	1.44×10^{-10}	1.22×10^{-7}	3.64×10^{13}	6.37×10^{4}	6.86×10	9.28×10^{2}	1.54×10^{2}	4.13×10^{3}	4.82×10^{4}
154.2	94.70	932.69	24.00	538.1	1.997×10	1.02×10^{-4}	1.00×10^{-7}	5.46×10^{-11}	4.64×10^{-8}	1.38×10^{12}	6.89×10^{4}	1.81×10^{2}	3.80×10^{2}	4.08×10^{2}	1.69×10^{3}	5.21×10^{4}
160.9	100.0	930.25	24.00	531.6	2.164×10	6.71×10^{-5}	6.62×10^{-8}	3.32×10^{-11}	2.82×10^{-8}	8.40×10^{11}	7.16×10^{4}	2.98×10^{2}	2.40×10^{2}	6.70×10^{2}	1.07×10^{3}	5.42×10^{4}
167.6	104.2	928.33	24.00	615.8	2.296×10	4.98×10^{-5}	4.92×10^{-8}	2.33×10^{-11}	1.98×10^{-8}	5.90×10^{11}	7.37×10^{4}	4.24×10^{2}	1.74×10^{2}	9.55×10^{2}	7.72×10	
182.9	113.6	924.00	24.00	693.5	2.598×10	2.67×10^{-5}	2.63×10^{-8}	1.11×10^{-11}	9.41×10^{-9}	2.80×10^{11}	7.82×10^{4}	8.94×10^{2}	8.75×10	2.01×10^{3}	3.89×10	
198.1	123.1	919.67	24.00	771.1	2.902×10	1.53×10^{-5}	1.51×10^{-8}	5.72×10^{-12}	4.86×10^{-9}	1.44×10^{11}	8.24×10^{4}	1.73×10^{3}	4.76×10	3.90×10^{3}	2.12×10	
213.4	132.6	915.41	24.00	848.8	3.210×10	9.29×10^{-6}	9.17×10^{-9}	3.16×10^{-12}	2.68×10^{-9}	7.98×10^{10}	8.65×10^{4}	3.13×10^{3}	2.76×10	7.05×10^{3}	1.23×10	
228.6	142.0	911.17	24.00	926.5	3.520×10	5.94×10^{-6}	5.86×10^{-9}	1.85×10^{-12}	1.57×10^{-9}	4.66×10^{10}	9.04×10^{4}	5.35×10^{3}	1.69×10	1.20×10^{4}	7.50	
243.8	151.5	906.93	24.00	1004	3.832×10	3.91×10^{-6}	3.86×10^{-9}	1.12×10^{-12}	9.54×10^{-10}	2.84×10^{10}	9.41×10^{4}	8.82×10^{3}	1.07×10	1.98×10^{4}	4.74	
259.1	161.0	902.76	24.00	1082	4.148×10	2.67×10^{-6}	2.63×10^{-9}	7.11×10^{-13}	6.04×10^{-10}	1.80×10^{10}	9.76×10^{4}	1.39×10^{4}	7.01	3.13×10^{4}	3.12	
274.3	170.4	898.61	24.00	1160	4.466×10	1.87×10^{-6}	1.85×10^{-9}	4.66×10^{-13}	3.96×10^{-10}	1.18×10^{10}	1.01×10^{5}	2.12×10^{4}	4.76	4.78×10^{4}	2.12	
289.6	179.9	894.50	24.00	1237	4.787×10	1.35×10^{-6}	1.33×10^{-9}	3.14×10^{-13}	2.66×10^{-10}	7.95×10^{9}	1.04×10^{5}	3.16×10^{4}	3.31	7.10×10^{4}	1.47	
304.8	189.4	890.38	24.00	1315	5.111×10	9.91×10^{-7}	9.79×10^{-10}	2.18×10^{-13}	1.85×10^{-10}	5.51×10^{9}	1.08×10^{5}	4.54×10^{4}	2.37	1.02×10^{5}	1.05	
320.0	198.9	886.33	24.00	1393	5.438×10	7.42×10^{-7}	7.33×10^{-10}	1.54×10^{-13}	1.31×10^{-10}	3.88×10^{9}	1.11×10^{5}	6.43×10^{4}	1.72	1.45×10^{5}	7.66×10^{-1}	
321.9	200.0	885.84	24.00	1402	5.478×10	7.18×10^{-7}	7.09×10^{-10}	1.48×10^{-13}	1.26×10^{-10}	3.74×10^{9}	1.11×10^{5}	6.70×10^{4}	1.66	1.51×10^{5}	7.38×10^{-1}	
335.3	208.3	882.27	24.00	1470	5.768×10	5.65×10^{-7}	5.58×10^{-10}	1.11×10^{-13}	9.41×10^{-11}	2.80×10^{9}	1.14×10^{5}	8.94×10^{4}	1.27	2.01×10^{5}	5.66×10^{-1}	
350.5	217.8	878.28	24.00	1548	6.100×10	4.37×10^{-7}	4.31×10^{-10}	8.14×10^{-14}	6.91×10^{-11}	2.06×10^{9}	1.17×10^{5}	1.22×10^{5}	9.60×10^{-1}	2.74×10^{5}	4.27×10^{-1}	
365.8	227.3	874.26	24.00	1626	6.436×10	3.42×10^{-7}	3.38×10^{-10}	6.08×10^{-14}	5.16×10^{-11}	1.54×10^{9}	1.20×10^{5}	1.63×10^{5}	7.35×10^{-1}	3.66×10^{5}	3.27×10^{-1}	
381.0	236.7	870.30	24.00	1703	6.774×10	2.72×10^{-7}	2.69×10^{-10}	4.61×10^{-14}	3.92×10^{-11}	1.17×10^{9}	1.23×10^{5}	2.15×10^{5}	5.71×10^{-1}	4.83×10^{5}	2.54×10^{-1}	
396.2	246.2	866.39	24.00	1781	7.115×10	2.18×10^{-7}	2.16×10^{-10}	3.54×10^{-14}	3.01×10^{-11}	8.93×10^{8}	1.25×10^{5}	2.80×10^{5}	4.48×10^{-1}	6.29×10^{5}	1.99×10^{-1}	
400.0	248.6	865.42	24.00	1800	7.199×10	2.07×10^{-7}	2.05×10^{-10}	3.32×10^{-14}	2.82×10^{-11}	8.40×10^{8}	1.26×10^{5}	2.98×10^{5}	4.23×10^{-1}	6.70×10^{5}	1.88×10^{-1}	

1 millibar (mb) = 10^3 dynes/cm^2 = 0.750 mm of Hg

Table 3.14 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER Latitude 0°. Metric Units. $p_0 = 1013$ mb, $\rho_0 = 1.178 \times 10^{-3}$ gm/cm^3. Table 12 of Ref. 3.20. (Concluded)

Height h ft	Height h mi	Apparent Gravity g' ft/sec²	Mean Mol Wt M	Temp T °R	Scale Height H ft	Pressure P lb/ft²	Pressure Ratio p/p_0	Density ρ slug/ft³	Density Ratio σ ρ/ρ_0	Number Density n particles/ft³	Mean Particle Speed $\bar{v}$ ft/sec	$d = 3 \times 10^{-8}$cm: Mean Free Path λ ft	$d = 3 \times 10^{-8}$cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$cm: Mean Free Path λ ft	$d = 2 \times 10^{-8}$cm: Mean Collision Freq f 1/sec	Speed of Sound a ft/sec
0	0	32.174	28.90	518.4	2.770×10^4	2116	1.0000	2.375×10^{-3}	1.0000	7.272×10^{23}	1.506×10^3	3.197×10^{-7}	4.712×10^8	7.193×10^{-7}	2.094×10^9	1.119×10^3
5,000	.947	32.159	28.90	500.6	2.676×10^4	1761	.8322	2.047×10^{-3}	.8619	6.268×10^{23}	1.480×10^3	3.709×10^{-7}	3.991×10^8	8.345×10^{-7}	1.774×10^9	1.100×10^3
10,000	1.894	32.144	28.90	482.7	2.582×10^4	1456	.6882	1.755×10^{-3}	.7390	5.374×10^{23}	1.454×10^3	4.325×10^{-7}	3.362×10^8	9.732×10^{-7}	1.494×10^9	1.080×10^3
15,000	2.841	32.128	28.90	464.9	2.487×10^4	1196	.5650	1.496×10^{-3}	.6301	4.582×10^{23}	1.427×10^3	5.074×10^{-7}	2.813×10^8	1.142×10^{-6}	1.250×10^9	1.060×10^3
20,000	3.788	32.113	28.90	447.1	2.393×10^4	974.6	.4605	1.268×10^{-3}	.5340	3.883×10^{23}	1.399×10^3	5.986×10^{-7}	2.337×10^8	1.347×10^{-6}	1.039×10^9	1.039×10^3
25,000	4.735	32.097	28.90	429.2	2.299×10^4	787.8	.3723	1.068×10^{-3}	.4496	3.269×10^{23}	1.371×10^3	7.111×10^{-7}	1.928×10^8	1.600×10^{-6}	8.569×10^8	1.018×10^3
30,000	5.682	32.082	28.90	411.4	2.204×10^4	631.2	.2983	8.926×10^{-4}	.3758	2.733×10^{23}	1.342×10^3	8.505×10^{-7}	1.578×10^8	1.914×10^{-6}	7.013×10^8	9.968×10^2
35,000	6.629	32.066	28.90	393.6	2.110×10^4	500.9	.2367	7.404×10^{-4}	.3118	2.267×10^{23}	1.313×10^3	1.025×10^{-6}	1.280×10^8	2.307×10^{-6}	5.689×10^8	9.750×10^2
35,332	6.692	32.065	28.90	392.4	2.104×10^4	493.1	.2330	7.311×10^{-4}	.3078	2.239×10^{23}	1.311×10^3	1.038×10^{-6}	1.262×10^8	2.337×10^{-6}	5.609×10^8	9.735×10^2
40,000	7.576	32.051	28.90	392.4	2.104×10^4	395.0	.1867	5.856×10^{-4}	.2466	1.793×10^{23}	1.311×10^3	1.296×10^{-6}	1.011×10^8	2.917×10^{-6}	4.493×10^8	9.735×10^2
45,000	8.523	32.036	28.90	392.4	2.105×10^4	311.6	.1472	4.619×10^{-4}	.1945	1.414×10^{23}	1.311×10^3	1.644×10^{-6}	7.976×10^7	3.698×10^{-6}	3.545×10^8	9.735×10^2
50,000	9.470	32.020	28.90	392.4	2.106×10^4	245.8	.1161	3.644×10^{-4}	.1534	1.116×10^{23}	1.311×10^3	2.084×10^{-6}	6.292×10^7	4.688×10^{-6}	2.796×10^8	9.735×10^2
55,000	10.417	32.005	28.90	392.4	2.107×10^4	193.9	9.164×10^{-2}	2.875×10^{-4}	.1211	8.804×10^{22}	1.311×10^3	2.640×10^{-6}	4.965×10^7	5.941×10^{-6}	2.207×10^8	9.735×10^2
60,000	11.364	31.990	28.90	392.4	2.108×10^4	153.1	7.232×10^{-3}	2.269×10^{-4}	9.554×10^{-2}	6.948×10^{22}	1.311×10^3	3.346×10^{-6}	3.918×10^7	7.528×10^{-6}	1.741×10^8	9.735×10^2
65,000	12.311	31.974	28.90	392.4	2.110×10^4	120.8	5.709×10^{-3}	1.791×10^{-4}	7.542×10^{-2}	5.484×10^{22}	1.311×10^3	4.238×10^{-6}	3.093×10^7	9.536×10^{-6}	1.375×10^8	9.735×10^2
70,000	13.258	31.959	28.89	392.4	2.111×10^4	95.46	4.511×10^{-2}	1.415×10^{-4}	5.957×10^{-2}	4.333×10^{22}	1.311×10^3	5.364×10^{-6}	2.444×10^7	1.207×10^{-5}	1.086×10^8	9.737×10^2
75,000	14.205	31.944	28.88	392.4	2.113×10^4	75.46	3.566×10^{-3}	1.118×10^{-4}	4.706×10^{-2}	3.425×10^{22}	1.311×10^3	6.787×10^{-6}	1.931×10^7	1.527×10^{-5}	8.582×10^7	9.739×10^2
80,000	15.152	31.929	28.86	392.4	2.115×10^4	59.67	2.820×10^{-3}	8.836×10^{-5}	3.720×10^{-2}	2.709×10^{22}	1.311×10^3	8.582×10^{-6}	1.528×10^7	1.931×10^{-5}	6.791×10^7	9.741×10^2
85,000	16.098	31.913	28.85	392.4	2.117×10^4	47.21	2.231×10^{-2}	6.988×10^{-5}	2.942×10^{-2}	2.143×10^{22}	1.312×10^3	1.085×10^{-5}	1.210×10^7	2.441×10^{-5}	5.378×10^7	9.743×10^2
90,000	17.045	31.898	28.84	392.4	2.119×10^4	37.36	1.765×10^{-3}	5.528×10^{-5}	2.327×10^{-2}	1.696×10^{22}	1.312×10^3	1.371×10^{-5}	9.572×10^6	3.084×10^{-5}	4.254×10^7	9.745×10^2
95,000	17.992	31.883	28.83	392.4	2.121×10^4	29.59	1.398×10^{-2}	4.376×10^{-5}	1.842×10^{-2}	1.343×10^{22}	1.312×10^3	1.731×10^{-5}	7.580×10^6	3.894×10^{-5}	3.369×10^7	9.747×10^2
100,000	18.939	31.868	28.82	392.4	2.123×10^4	23.44	1.107×10^{-2}	3.462×10^{-5}	1.459×10^{-2}	1.063×10^{22}	1.312×10^3	2.187×10^{-5}	6.002×10^6	4.920×10^{-5}	2.668×10^7	9.749×10^2
104,986	19.884	31.852	28.80	392.4	2.125×10^4	18.58	8.781×10^{-3}	2.746×10^{-5}	1.156×10^{-2}	8.437×10^{21}	1.313×10^3	2.755×10^{-5}	4.765×10^6	6.200×10^{-5}	2.118×10^7	9.751×10^2
105,000	19.886	31.852	28.80	392.5	2.125×10^4	18.57	8.775×10^{-3}	2.744×10^{-5}	1.155×10^{-2}	8.429×10^{21}	1.313×10^3	2.758×10^{-5}	4.761×10^6	6.205×10^{-5}	2.116×10^7	9.752×10^2
110,000	20.833	31.837	28.79	413.3	2.240×10^4	14.77	6.979×10^{-3}	2.071×10^{-5}	8.720×10^{-3}	6.365×10^{21}	1.348×10^3	3.652×10^{-5}	3.691×10^6	8.218×10^{-5}	1.640×10^7	1.001×10^3
115,000	21.780	31.822	28.78	434.2	2.355×10^4	11.88	5.615×10^{-3}	1.586×10^{-5}	6.676×10^{-3}	4.875×10^{21}	1.381×10^3	4.768×10^{-5}	2.896×10^6	1.073×10^{-4}	1.287×10^7	1.026×10^3
120,000	22.727	31.807	28.77	455.1	2.471×10^4	9.665	4.567×10^{-3}	1.230×10^{-5}	5.178×10^{-3}	3.783×10^{21}	1.415×10^3	6.145×10^{-5}	2.303×10^6	1.383×10^{-4}	1.024×10^7	1.051×10^3
125,000	23.674	31.792	28.76	476.0	2.586×10^4	7.936	3.750×10^{-3}	9.651×10^{-6}	4.063×10^{-3}	2.970×10^{21}	1.447×10^3	7.827×10^{-5}	1.849×10^6	1.761×10^{-4}	8.218×10^6	1.075×10^3
130,000	24.621	31.776	28.74	496.9	2.702×10^4	6.574	3.106×10^{-3}	7.655×10^{-6}	3.223×10^{-3}	2.357×10^{21}	1.479×10^3	9.863×10^{-5}	1.499×10^6	2.219×10^{-4}	6.662×10^6	1.098×10^3
135,000	25.568	31.761	28.73	517.7	2.818×10^4	5.490	2.594×10^{-3}	6.133×10^{-6}	2.582×10^{-3}	1.889×10^{21}	1.510×10^3	1.231×10^{-4}	1.227×10^6	2.769×10^{-4}	5.453×10^6	1.122×10^3
140,000	26.515	31.746	28.72	538.6	2.935×10^4	4.620	2.183×10^{-3}	4.958×10^{-6}	2.088×10^{-3}	1.528×10^{21}	1.540×10^3	1.522×10^{-4}	1.012×10^6	3.423×10^{-4}	4.498×10^6	1.144×10^3
145,000	27.462	31.731	28.71	559.5	3.051×10^4	3.914	1.850×10^{-3}	4.043×10^{-6}	1.702×10^{-3}	1.246×10^{21}	1.570×10^3	1.865×10^{-4}	8.417×10^5	4.197×10^{-4}	3.741×10^6	1.166×10^3
150,000	28.409	31.716	28.69	580.4	3.168×10^4	3.338	1.577×10^{-3}	3.322×10^{-6}	1.399×10^{-3}	1.024×10^{21}	1.600×10^3	2.269×10^{-4}	7.051×10^5	5.106×10^{-4}	3.134×10^6	1.188×10^3
155,000	29.356	31.701	28.68	601.2	3.285×10^4	2.863	1.353×10^{-3}	2.449×10^{-6}	1.158×10^{-3}	8.482×10^{20}	1.628×10^3	2.740×10^{-4}	5.941×10^5	6.166×10^{-4}	2.640×10^6	1.210×10^3
160,000	30.303	31.686	28.67	622.1	3.402×10^4	2.470	1.167×10^{-3}	2.291×10^{-6}	9.647×10^{-4}	7.071×10^{20}	1.657×10^3	3.287×10^{-4}	5.041×10^5	7.396×10^{-4}	2.240×10^6	1.231×10^3
164,040	31.068	31.673	28.66	639.0	3.497×10^4	2.200	1.040×10^{-3}	1.986×10^{-6}	8.364×10^{-4}	6.133×10^{20}	1.679×10^3	3.790×10^{-4}	4.430×10^5	8.528×10^{-4}	1.969×10^6	1.248×10^3
165,000	31.250	31.670	28.66	639.0	3.497×10^4	2.140	1.011×10^{-3}	1.933×10^{-6}	8.138×10^{-4}	5.967×10^{20}	1.679×10^3	3.896×10^{-4}	4.310×10^5	8.765×10^{-4}	1.916×10^6	1.248×10^3
170,000	32.197	31.655	28.66	639.0	3.499×10^4	1.856	8.768×10^{-4}	1.675×10^{-6}	7.054×10^{-4}	5.177×10^{20}	1.679×10^3	4.494×10^{-4}	3.736×10^5	1.011×10^{-3}	1.660×10^6	1.248×10^3
175,000	33.144	31.640	28.66	639.0	3.501×10^4	1.609	7.601×10^{-4}	1.452×10^{-6}	6.115×10^{-4}	4.484×10^{20}	1.679×10^3	5.183×10^{-4}	3.239×10^5	1.166×10^{-3}	1.440×10^6	1.248×10^3
180,000	34.091	31.625	28.66	639.0	3.502×10^4	1.395	6.591×10^{-4}	1.259×10^{-6}	5.303×10^{-4}	3.888×10^{20}	1.679×10^3	5.978×10^{-4}	2.809×10^5	1.345×10^{-3}	1.248×10^6	1.248×10^3
185,000	35.038	31.610	28.66	639.0	3.504×10^4	1.210	5.716×10^{-4}	1.092×10^{-6}	4.599×10^{-4}	3.372×10^{20}	1.679×10^3	6.893×10^{-4}	2.436×10^5	1.551×10^{-3}	1.083×10^6	1.248×10^3
190,000	35.985	31.595	28.66	639.0	3.506×10^4	1.049	4.958×10^{-4}	9.473×10^{-7}	3.988×10^{-4}	2.925×10^{20}	1.679×10^3	7.948×10^{-4}	2.113×10^5	1.788×10^{-3}	9.391×10^5	1.248×10^3
195,000	36.932	31.580	28.66	639.0	3.507×10^4	.9101	4.300×10^{-4}	8.217×10^{-7}	3.460×10^{-4}	2.537×10^{20}	1.679×10^3	9.163×10^{-4}	1.832×10^5	2.062×10^{-3}	8.142×10^5	1.248×10^3
196,848	37.282	31.574	28.66	639.0	3.508×10^4	.8635	4.080×10^{-4}	7.797×10^{-7}	3.283×10^{-4}	2.407×10^{20}	1.679×10^3	9.657×10^{-4}	1.739×10^5	2.173×10^{-3}	7.729×10^5	1.248×10^3
200,000	37.879	31.565	28.66	628.0	3.448×10^4	.7887	3.727×10^{-4}	7.246×10^{-7}	3.051×10^{-4}	2.237×10^{20}	1.668×10^3	1.039×10^{-3}	1.605×10^5	2.338×10^{-3}	7.133×10^5	1.237×10^3

Table 3.15 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER
Latitude 45°. Engineering Units. $p_0 = 2116$ lb/ft², $\rho_0 = 2.375 \times 10^{-3}$ slug/ft³. Table 13 of Ref. 3.20.

Height h ft	Height h mi	Apparent Gravity g' ft/sec^2	Mean Mol Wt M	Temp T °R	Scale Height H ft	Pressure p lb/ft^2	Pressure Ratio p/p_0	Density ρ slug/ft^3	Density Ratio σ ρ/ρ_0	Number Density n particles/ft^3	Mean Particle Speed $\bar{v}$ ft/sec	$d = 3 \times 10^{-8}$cm: Mean Free Path λ ft	$d = 3 \times 10^{-8}$cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$cm: Mean Free Path λ ft	$d = 2 \times 10^{-8}$cm: Mean Collision Freq f 1/sec	Speed of Sound a ft/sec
205,000	38.826	31.550	28.66	610.4	3.354×10^4	.6809	3.218×10^{-4}	6.436×10^{-7}	2.710×10^{-4}	1.987×10^{20}	1.641×10^3	1.170×10^{-3}	1.403×10^8	2.632×10^{-3}	6.236×10^8	1.219×10^3
210,000	39.773	31.535	28.66	592.9	3.259×10^4	.5854	2.766×10^{-4}	5.697×10^{-7}	2.399×10^{-4}	1.759×10^{20}	1.618×10^3	1.322×10^{-3}	1.224×10^8	2.974×10^{-3}	5.440×10^8	1.202×10^3
215,000	40.720	31.520	28.66	575.4	3.164×10^4	.5011	2.368×10^{-4}	5.025×10^{-7}	2.116×10^{-4}	1.552×10^{20}	1.594×10^3	1.498×10^{-3}	1.064×10^8	3.371×10^{-3}	4.729×10^8	1.184×10^3
220,000	41.667	31.505	28.66	557.8	3.069×10^4	.4270	2.018×10^{-4}	4.416×10^{-7}	1.859×10^{-4}	1.363×10^{20}	1.569×10^3	1.705×10^{-3}	9.202×10^8	3.836×10^{-3}	4.090×10^8	1.166×10^3
225,000	42.614	31.490	28.66	540.3	2.974×10^4	.3633	1.717×10^{-4}	3.880×10^{-7}	1.634×10^{-4}	1.198×10^{20}	1.544×10^3	1.941×10^{-3}	7.956×10^8	4.367×10^{-3}	3.536×10^8	1.147×10^3
230,000	43.561	31.475	28.66	522.8	2.879×10^4	.3053	1.443×10^{-4}	3.369×10^{-7}	1.418×10^{-4}	1.040×10^{20}	1.519×10^3	2.235×10^{-3}	6.797×10^8	5.028×10^{-3}	3.021×10^8	1.128×10^3
235,000	44.508	31.460	28.66	505.3	2.784×10^4	.2560	1.210×10^{-4}	2.923×10^{-7}	1.231×10^{-4}	9.025×10^{19}	1.493×10^3	2.576×10^{-3}	5.796×10^8	5.795×10^{-3}	2.576×10^8	1.109×10^3
240,000	45.455	31.445	28.66	487.7	2.689×10^4	.2134	1.008×10^{-4}	2.524×10^{-7}	1.063×10^{-4}	7.792×10^{19}	1.467×10^3	2.983×10^{-3}	4.918×10^8	6.712×10^{-3}	2.186×10^8	1.090×10^3
245,000	46.402	31.430	28.66	470.2	2.593×10^4	.1767	8.349×10^{-5}	2.168×10^{-7}	9.128×10^{-6}	6.693×10^{19}	1.441×10^3	3.473×10^{-3}	4.149×10^8	7.814×10^{-3}	1.844×10^8	1.070×10^3
250,000	47.348	31.415	28.66	452.7	2.497×10^4	.1453	6.865×10^{-5}	1.852×10^{-7}	7.797×10^{-6}	5.717×10^{19}	1.414×10^3	4.066×10^{-3}	3.478×10^8	9.148×10^{-3}	1.546×10^8	1.050×10^3
255,000	48.295	31.400	28.66	435.2	2.402×10^4	.1186	5.603×10^{-5}	1.572×10^{-7}	6.619×10^{-6}	4.854×10^{19}	1.386×10^3	4.789×10^{-3}	2.894×10^8	1.078×10^{-2}	1.286×10^8	1.029×10^3
255,902	48.466	31.398	28.66	432.0	2.385×10^4	.1142	5.396×10^{-5}	1.525×10^{-7}	6.422×10^{-6}	4.709×10^{19}	1.381×10^3	4.937×10^{-3}	2.797×10^8	1.111×10^{-2}	1.243×10^8	1.026×10^3
260,000	49.242	31.385	28.66	432.0	2.386×10^4	9.618×10^{-2}	4.545×10^{-5}	1.284×10^{-7}	5.408×10^{-6}	3.966×10^{19}	1.381×10^3	5.862×10^{-3}	2.356×10^8	1.319×10^{-2}	1.047×10^8	1.026×10^3
265,000	50.189	31.371	28.66	432.0	2.387×10^4	7.801×10^{-2}	3.686×10^{-5}	1.042×10^{-7}	4.386×10^{-6}	3.217×10^{19}	1.381×10^3	7.227×10^{-3}	1.911×10^8	1.626×10^{-2}	8.493×10^7	1.026×10^3
270,000	51.136	31.356	28.66	432.0	2.388×10^4	6.328×10^{-2}	2.990×10^{-5}	8.451×10^{-8}	3.558×10^{-6}	2.609×10^{19}	1.381×10^3	8.908×10^{-3}	1.550×10^8	2.004×10^{-2}	6.889×10^7	1.026×10^3
272.306	51.573	31.349	28.66	432.0	2.389×10^4	5.746×10^{-2}	2.715×10^{-5}	7.674×10^{-8}	3.231×10^{-6}	2.369×10^{19}	1.381×10^3	9.811×10^{-3}	1.408×10^8	2.207×10^{-2}	6.258×10^7	1.026×10^3
275,000	52.083	31.341	28.56	437.4	2.427×10^4	5.139×10^{-2}	2.428×10^{-5}	6.756×10^{-8}	2.845×10^{-6}	2.093×10^{19}	1.392×10^3	1.110×10^{-2}	1.253×10^8	2.499×10^{-2}	5.570×10^7	1.034×10^3
280,000	53.030	31.326	28.39	447.4	2.499×10^4	4.197×10^{-2}	1.983×10^{-5}	5.361×10^{-8}	2.257×10^{-6}	1.671×10^{19}	1.412×10^3	1.391×10^{-2}	1.015×10^8	3.130×10^{-2}	4.512×10^7	1.050×10^3
285,000	53.977	31.311	28.21	457.4	2.573×10^4	3.449×10^{-2}	1.630×10^{-5}	4.282×10^{-8}	1.803×10^{-6}	1.343×10^{19}	1.432×10^3	1.731×10^{-2}	8.274×10^7	3.894×10^{-2}	3.677×10^7	1.066×10^3
290,000	54.924	31.296	28.03	467.4	2.647×10^4	2.849×10^{-2}	1.364×10^{-5}	3.440×10^{-8}	1.448×10^{-6}	1.086×10^{19}	1.452×10^3	2.141×10^{-2}	6.782×10^7	4.817×10^{-2}	3.014×10^7	1.082×10^3
295,000	55.871	31.281	27.85	477.4	2.722×10^4	2.367×10^{-2}	1.118×10^{-5}	2.779×10^{-8}	1.170×10^{-6}	8.830×10^{18}	1.472×10^3	2.633×10^{-2}	5.593×10^7	5.924×10^{-2}	2.486×10^7	1.098×10^3
300,000	56.818	31.266	27.68	487.4	2.798×10^4	1.976×10^{-2}	9.336×10^{-6}	2.258×10^{-8}	9.508×10^{-7}	7.220×10^{18}	1.493×10^3	3.220×10^{-2}	4.636×10^7	7.244×10^{-2}	2.069×10^7	1.114×10^3
305,000	57.765	31.252	27.50	497.4	2.875×10^4	1.657×10^{-2}	7.832×10^{-6}	1.844×10^{-8}	7.766×10^{-7}	5.935×10^{18}	1.513×10^3	3.917×10^{-2}	3.862×10^7	8.813×10^{-2}	1.716×10^7	1.130×10^3
310,000	58.712	31.237	27.32	507.5	2.954×10^4	1.397×10^{-2}	6.610×10^{-6}	1.514×10^{-8}	6.375×10^{-7}	4.904×10^{18}	1.533×10^3	4.741×10^{-2}	3.234×10^7	1.067×10^{-1}	1.437×10^7	1.146×10^3
315,000	59.659	31.222	27.14	517.5	3.033×10^4	1.183×10^{-2}	5.588×10^{-6}	1.249×10^{-8}	5.258×10^{-7}	4.071×10^{18}	1.553×10^3	5.710×10^{-2}	2.720×10^7	1.285×10^{-1}	1.209×10^7	1.161×10^3
320,000	60.606	31.207	26.97	527.5	3.114×10^4	1.006×10^{-2}	4.752×10^{-6}	1.035×10^{-8}	4.358×10^{-7}	3.396×10^{18}	1.573×10^3	6.844×10^{-2}	2.298×10^7	1.540×10^{-1}	1.021×10^7	1.177×10^3
325,000	61.553	31.193	26.79	537.5	3.195×10^4	8.588×10^{-3}	4.058×10^{-6}	8.616×10^{-9}	3.628×10^{-7}	2.846×10^{18}	1.593×10^3	8.168×10^{-2}	1.950×10^7	1.838×10^{-1}	8.668×10^6	1.193×10^3
330,000	62.500	31.178	26.61	547.5	3.278×10^4	7.362×10^{-3}	3.479×10^{-6}	7.204×10^{-9}	3.033×10^{-7}	2.395×10^{18}	1.613×10^3	9.704×10^{-2}	1.662×10^7	2.184×10^{-1}	7.387×10^6	1.209×10^3
335,000	63.447	31.163	26.43	557.5	3.362×10^4	6.336×10^{-3}	2.994×10^{-6}	6.048×10^{-9}	2.546×10^{-7}	2.024×10^{18}	1.633×10^3	1.148×10^{-1}	1.422×10^7	2.584×10^{-1}	6.320×10^6	1.226×10^3
340,000	64.394	31.148	26.26	567.5	3.447×10^4	5.474×10^{-3}	2.586×10^{-6}	5.098×10^{-9}	2.146×10^{-7}	1.718×10^{18}	1.654×10^3	1.353×10^{-1}	1.222×10^7	3.044×10^{-1}	5.431×10^6	1.242×10^3
345,000	65.341	31.134	26.08	577.5	3.533×10^4	4.746×10^{-3}	2.242×10^{-6}	4.314×10^{-9}	1.816×10^{-7}	1.464×10^{18}	1.674×10^3	1.568×10^{-1}	1.054×10^7	3.573×10^{-1}	4.684×10^6	1.258×10^3
350,000	66.288	31.119	25.90	587.5	3.621×10^4	4.129×10^{-3}	1.951×10^{-6}	3.664×10^{-9}	1.543×10^{-7}	1.252×10^{18}	1.694×10^3	1.857×10^{-1}	9.122×10^6	4.178×10^{-1}	4.054×10^6	1.274×10^3
355,000	67.235	31.104	25.72	597.5	3.710×10^4	3.604×10^{-3}	1.703×10^{-6}	3.123×10^{-9}	1.315×10^{-7}	1.074×10^{18}	1.714×10^3	2.164×10^{-1}	7.921×10^6	4.069×10^{-1}	3.520×10^6	1.290×10^3
360,000	68.182	31.090	25.55	607.5	3.000×10^4	3.156×10^{-3}	1.491×10^{-6}	2.672×10^{-9}	1.125×10^{-7}	9.253×10^{17}	1.734×10^3	2.512×10^{-1}	6.902×10^6	5.652×10^{-1}	3.068×10^6	1.306×10^3
365,000	69.129	31.075	25.37	617.6	3.892×10^4	2.773×10^{-3}	1.310×10^{-6}	2.293×10^{-9}	9.654×10^{-7}	7.998×10^{17}	1.755×10^3	2.906×10^{-1}	6.038×10^6	6.540×10^{-1}	2.684×10^6	1.323×10^3
370,000	70.076	31.060	25.19	627.6	3.984×10^4	2.443×10^{-3}	1.154×10^{-6}	1.974×10^{-9}	8.312×10^{-7}	6.935×10^{17}	1.775×10^3	3.352×10^{-1}	5.295×10^6	7.542×10^{-1}	2.353×10^6	1.339×10^3
375,000	71.023	31.046	25.01	637.6	4.078×10^4	2.159×10^{-3}	1.020×10^{-6}	1.705×10^{-9}	7.180×10^{-7}	6.033×10^{17}	1.796×10^3	3.853×10^{-1}	4.661×10^6	8.670×10^{-1}	2.072×10^6	1.356×10^3
380,000	71.970	31.031	24.84	647.6	4.174×10^4	1.914×10^{-3}	9.043×10^{-7}	1.478×10^{-9}	6.221×10^{-7}	5.264×10^{17}	1.816×10^3	4.416×10^{-1}	4.112×10^6	9.936×10^{-1}	1.828×10^6	1.372×10^3
385,000	72.917	31.016	24.66	657.6	4.271×10^4	1.701×10^{-3}	8.037×10^{-7}	1.284×10^{-9}	5.406×10^{-7}	4.607×10^{17}	1.837×10^3	5.045×10^{-1}	3.641×10^6	1.135	1.618×10^6	1.389×10^3
390,000	73.864	31.002	24.48	667.6	4.370×10^4	1.516×10^{-3}	7.162×10^{-7}	1.119×10^{-9}	4.711×10^{-7}	4.044×10^{17}	1.857×10^3	5.748×10^{-1}	3.231×10^6	1.293	1.436×10^6	1.406×10^3
393,696	74.564	31.991	24.35	675.0	4.444×10^4	1.394×10^{-3}	6.587×10^{-7}	1.012×10^{-9}	4.263×10^{-7}	3.679×10^{17}	1.873×10^3	6.318×10^{-1}	2.964×10^6	1.422	1.317×10^6	1.418×10^3
395,000	74.811	30.987	24.35	677.9	4.463×10^4	1.354×10^{-3}	6.397×10^{-7}	9.790×10^{-10}	4.122×10^{-7}	3.558×10^{17}	1.890×10^3	6.534×10^{-1}	2.893×10^6	1.470	1.286×10^6	1.421×10^3
400,000	75.758	30.972	24.35	688.9	4.538×10^4	1.212×10^{-3}	5.725×10^{-7}	8.620×10^{-10}	3.629×10^{-7}	3.132×10^{17}	1.898×10^3	7.421×10^{-1}	2.558×10^6	1.670	1.137×10^6	1.432×10^3

Table 3.15 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER
Latitude 45°. Engineering Units. $p_0 = 2116$ lb/ft^2,
$\rho_0 = 2.375 \times 10^{-3}$ slug/ft^3. Table 13 of Ref. 3.20. (Continued)

Height h ft	Height h mi	Apparent Gravity g ft/sec^2	Mean Mol Wt M	Temp T °R	Scale Height H ft	Pressure p lb/ft^2	Pressure Ratio p/p_0	Density ρ slug/ft^3	Density Ratio σ ρ/ρ_0	Number Density n particles/ft^3	Mean Particle Speed v ft/sec	$d = 3 \times 10^{-8}$cm Mean Free Path λ ft	$d = 3 \times 10^{-8}$cm Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$cm Mean Free Path λ ft	$d = 2 \times 10^{-8}$cm Mean Collision Freq f 1/sec	Speed of Sound a ft/sec
4.500×10^5	85.227	30.827	24.35	799.4	5.291×10^4	4.37×10^{-4}	2.06×10^{-7}	2.68×10^{-10}	1.13×10^{-7}	9.75×10^{15}	2.04×10^3	2.38	8.55×10^3	5.36	3.80×10^3	1.54×10^3
5.000×10^5	94.697	30.682	24.35	909.9	6.050×10^4	1.81×10^{-4}	8.55×10^{-8}	9.75×10^{-11}	4.11×10^{-8}	3.55×10^{15}	2.17×10^3	6.55	3.32×10^3	1.47×10	1.48×10^3	1.64×10^3
5.280×10^5	100.00	30.602	24.35	971.8	6.478×10^4	1.16×10^{-4}	5.48×10^{-8}	5.82×10^{-11}	2.45×10^{-8}	2.12×10^{15}	2.25×10^3	1.10×10	2.05×10^2	2.47×10	9.11×10	1.70×10^3
5.500×10^5	104.17	30.539	24.35	1020	6.817×10^4	8.30×10^{-5}	3.92×10^{-8}	3.99×10^{-11}	1.68×10^{-8}	1.45×10^{15}	2.30×10^3	1.60×10	1.44×10^2	3.61×10	6.38×10	
6.000×10^5	113.64	30.396	24.35	1131	7.590×10^4	4.14×10^{-5}	1.96×10^{-8}	1.79×10^{-11}	7.54×10^{-9}	6.51×10^{15}	2.42×10^3	3.57×10	6.79×10	8.03×10	3.02×10	
6.500×10^5	123.11	30.255	24.35	1241	8.371×10^4	2.21×10^{-5}	1.04×10^{-8}	8.73×10^{-12}	3.68×10^{-9}	3.17×10^{15}	2.54×10^3	7.33×10	3.46×10	1.65×10^2	1.54×10	
7.000×10^5	132.58	30.114	24.35	1352	9.158×10^4	1.25×10^{-5}	5.91×10^{-9}	4.53×10^{-12}	1.91×10^{-9}	1.65×10^{15}	2.65×10^3	1.41×10^2	1.88×10	3.17×10^2	8.35	
7.500×10^5	142.05	29.975	24.35	1462	9.953×10^4	7.40×10^{-6}	3.50×10^{-9}	2.48×10^{-12}	1.04×10^{-9}	9.02×10^{14}	2.76×10^3	2.58×10^2	1.07×10	5.80×10^3	4.75	
8.000×10^5	151.57	29.836	24.35	1573	1.075×10^5	4.57×10^{-6}	2.16×10^{-9}	1.42×10^{-12}	5.98×10^{-10}	5.16×10^{14}	2.86×10^3	4.50×10^2	6.35	1.01×10^3	2.82	
8.500×10^5	160.98	29.699	24.35	1683	1.156×10^5	2.92×10^{-6}	1.38×10^{-9}	8.50×10^{-13}	3.58×10^{-10}	3.09×10^{14}	2.96×10^3	7.52×10^2	3.93	1.69×10^3	1.75	
9.000×10^5	170.45	29.562	24.35	1794	1.238×10^5	1.92×10^{-6}	9.07×10^{-10}	5.25×10^{-13}	2.21×10^{-10}	1.91×10^{14}	3.05×10^3	1.22×10^3	2.51	2.74×10^3	1.11	
9.500×10^5	179.92	29.426	24.35	1904	1.320×10^5	1.30×10^{-6}	6.14×10^{-10}	3.35×10^{-13}	1.41×10^{-10}	1.22×10^{14}	3.15×10^3	1.91×10^3	1.65	4.29×10^3	7.34×10^{-1}	
9.842×10^5	186.41	29.334	24.35	1980	1.377×10^5	1.01×10^{-6}	4.77×10^{-10}	2.50×10^{-13}	1.05×10^{-10}	9.09×10^{13}	3.21×10^3	2.56×10^3	1.25	5.75×10^3	5.57×10^{-1}	

1 lb/ft^2 = 0.3591 mm of Hg

Table 3.15 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER Latitude 45°. Engineering Units. $p_0 = 2116$ lb/ft^2, $\rho_0 = 2.375 \times 10^{-3}$ slug/ft^3. Table 13 of Ref. 3.20. (Concluded)

Height h km	Height h mi	Apparent Gravity g' cm/sec²	Mean Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm³	Density Ratio σ ρ/ρ_0	Number Density n particles/cm³	Mean Particle Speed $\bar{v}$ cm/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	Speed of Sound a cm/sec
0	0	980.69	28.90	288.0	8.443	1014	1.0000	1.223×10^{-3}	1.0000	2.568×10^{19}	4.590×10^{4}	9.744×10^{-6}	4.712×10^{9}	2.192×10^{-6}	2.094×10^{9}	3.410×10^{4}
1.524	.947	980.22	28.90	278.1	8.157	843.5	.8322	1.055×10^{-3}	.8619	2.213×10^{19}	4.511×10^{4}	1.130×10^{-5}	3.991×10^{9}	2.544×10^{-5}	1.774×10^{9}	3.351×10^{4}
3.048	1.894	979.74	28.90	268.2	7.870	697.5	.6882	9.047×10^{-4}	.7390	1.898×10^{19}	4.432×10^{4}	1.318×10^{-5}	3.362×10^{9}	2.966×10^{-5}	1.494×10^{9}	3.291×10^{4}
4.572	2.841	979.27	28.90	258.3	7.580	572.7	.5650	7.713×10^{-4}	.6301	1.618×10^{19}	4.350×10^{4}	1.546×10^{-5}	2.813×10^{9}	3.479×10^{-5}	1.250×10^{9}	3.230×10^{4}
6.096	3.788	978.80	28.90	248.4	7.294	466.8	.4605	6.537×10^{-4}	.5340	1.371×10^{19}	4.264×10^{4}	1.825×10^{-5}	2.337×10^{9}	4.106×10^{-5}	1.039×10^{9}	3.167×10^{4}
7.620	4.735	970.34	28.90	238.5	7.007	377.3	.3723	5.503×10^{-4}	.4496	1.155×10^{19}	4.179×10^{4}	2.167×10^{-5}	1.928×10^{9}	4.876×10^{-5}	8.569×10^{8}	3.104×10^{4}
9.144	5.682	977.87	28.90	228.6	6.718	302.3	.2983	4.601×10^{-4}	.3758	9.652×10^{18}	4.090×10^{4}	2.592×10^{-5}	1.578×10^{9}	5.833×10^{-5}	7.013×10^{8}	3.038×10^{4}
10.668	6.629	977.40	28.90	218.7	6.431	239.9	.2367	3.816×10^{-4}	.3118	8.006×10^{18}	4.002×10^{4}	3.125×10^{-5}	1.280×10^{9}	7.032×10^{-5}	5.689×10^{8}	2.972×10^{4}
10.769	6.692	977.37	28.90	218.0	6.413	236.2	.2330	3.768×10^{-4}	.3078	7.905×10^{18}	3.996×10^{4}	3.165×10^{-5}	1.262×10^{9}	7.122×10^{-5}	5.609×10^{8}	2.967×10^{4}
12.192	7.576	976.93	28.90	218.0	6.413	189.2	.1867	3.019×10^{-4}	.2466	6.333×10^{18}	3.996×10^{4}	3.951×10^{-5}	1.011×10^{9}	8.890×10^{-5}	4.493×10^{8}	2.967×10^{4}
13.716	8.523	976.46	28.90	218.0	6.416	149.2	.1472	2.381×10^{-4}	.1945	4.995×10^{18}	3.996×10^{4}	5.010×10^{-5}	7.976×10^{8}	1.127×10^{-4}	3.545×10^{8}	2.967×10^{4}
15.240	9.470	975.99	28.90	218.0	6.419	117.7	.1161	1.878×10^{-4}	.1534	3.940×10^{18}	3.996×10^{4}	6.351×10^{-5}	6.292×10^{8}	1.429×10^{-4}	2.796×10^{8}	2.967×10^{4}
16.764	10.417	975.52	28.90	218.0	6.422	92.88	9.164×10^{-2}	1.482×10^{-4}	.1211	3.109×10^{18}	3.996×10^{4}	8.048×10^{-5}	4.965×10^{8}	1.811×10^{-4}	2.207×10^{8}	2.967×10^{4}
18.288	11.364	975.06	28.90	218.0	6.425	73.30	7.232×10^{-2}	1.170×10^{-4}	9.554×10^{-2}	2.454×10^{18}	3.996×10^{4}	1.020×10^{-4}	3.918×10^{8}	2.295×10^{-4}	1.741×10^{8}	2.967×10^{4}
19.812	12.311	974.59	28.90	218.0	6.431	57.86	5.709×10^{-2}	9.232×10^{-5}	7.542×10^{-2}	1.937×10^{18}	3.996×10^{4}	1.292×10^{-4}	3.093×10^{8}	2.907×10^{-4}	1.375×10^{8}	2.967×10^{4}
21.336	13.258	974.12	28.89	218.0	6.434	45.72	4.511×10^{-2}	7.292×10^{-5}	5.957×10^{-2}	1.530×10^{18}	3.996×10^{4}	1.635×10^{-4}	2.444×10^{8}	3.679×10^{-4}	1.086×10^{8}	2.968×10^{4}
22.860	14.205	973.66	28.88	218.0	6.440	36.14	3.566×10^{-2}	5.761×10^{-5}	4.706×10^{-2}	1.210×10^{18}	3.996×10^{4}	2.069×10^{-4}	1.931×10^{8}	4.654×10^{-4}	8.582×10^{7}	2.968×10^{4}
24.384	15.152	973.19	28.86	218.0	6.447	28.58	2.820×10^{-2}	4.554×10^{-5}	3.720×10^{-2}	9.566×10^{17}	3.996×10^{4}	2.616×10^{-4}	1.528×10^{8}	5.886×10^{-4}	6.791×10^{7}	2.969×10^{4}
25.908	16.098	972.72	28.85	218.0	6.453	22.61	2.231×10^{-2}	3.602×10^{-5}	2.942×10^{-2}	7.568×10^{17}	3.999×10^{4}	3.306×10^{-4}	1.210×10^{8}	7.439×10^{-4}	5.378×10^{7}	2.970×10^{4}
27.432	17.045	972.26	28.84	218.0	6.459	17.89	1.765×10^{-2}	2.849×10^{-5}	2.327×10^{-2}	5.989×10^{17}	3.999×10^{4}	4.170×10^{-4}	9.572×10^{7}	9.400×10^{-4}	4.254×10^{7}	2.970×10^{4}
28.956	17.992	971.80	28.83	218.0	6.465	14.17	1.398×10^{-2}	2.255×10^{-5}	1.842×10^{-2}	4.743×10^{17}	3.999×10^{4}	5.276×10^{-4}	7.580×10^{7}	1.187×10^{-3}	3.369×10^{7}	2.971×10^{4}
30.480	18.939	971.33	28.82	218.0	6.471	11.23	1.107×10^{-2}	1.784×10^{-5}	1.459×10^{-2}	3.754×10^{17}	4.001×10^{4}	6.665×10^{-4}	6.002×10^{7}	1.500×10^{-3}	2.668×10^{7}	2.972×10^{4}
32.000	19.884	970.87	28.80	218.0	6.477	8.901	8.781×10^{-3}	1.415×10^{-5}	1.156×10^{-2}	2.979×10^{17}	4.002×10^{4}	8.399×10^{-4}	4.765×10^{7}	1.890×10^{-3}	2.118×10^{7}	2.972×10^{4}
32.004	19.886	970.40	28.80	218.0	6.477	8.894	8.775×10^{-3}	1.414×10^{-5}	1.155×10^{-2}	2.977×10^{17}	4.002×10^{4}	8.406×10^{-4}	4.761×10^{7}	1.891×10^{-3}	2.116×10^{7}	2.972×10^{4}
33.528	20.833	970.40	28.79	229.6	6.828	7.073	6.979×10^{-3}	1.067×10^{-5}	8.720×10^{-2}	2.248×10^{17}	4.109×10^{4}	1.113×10^{-3}	3.691×10^{7}	2.505×10^{-3}	1.640×10^{7}	3.051×10^{4}
35.052	21.780	969 94	28.78	241.2	7.178	5.692	5.615×10^{-3}	8.173×10^{-6}	6.676×10^{-3}	1.722×10^{17}	4.209×10^{4}	1.453×10^{-3}	2.896×10^{7}	3.270×10^{-3}	1.287×10^{7}	3.128×10^{4}
36.576	22.727	969.47	28.77	252.8	7.532	4.629	4.567×10^{-3}	6.339×10^{-6}	5.178×10^{-2}	1.336×10^{17}	4.313×10^{4}	1.873×10^{-3}	2.303×10^{7}	4.214×10^{-2}	1.021×10^{7}	3.203×10^{4}
38.100	23.674	969.00	28.76	264.4	7.882	3.801	3.750×10^{-2}	4.974×10^{-6}	4.063×10^{-2}	1.049×10^{17}	4.410×10^{4}	2.386×10^{-3}	1.849×10^{7}	5.368×10^{-3}	8.218×10^{6}	3.276×10^{4}
39.624	24.621	968.54	28.74	276.0	8.236	3.148	3.106×10^{-3}	3.946×10^{-6}	3.223×10^{-3}	8.323×10^{16}	4.508×10^{4}	3.006×10^{-3}	1.499×10^{7}	6.764×10^{-2}	6.662×10^{6}	3.348×10^{4}
41.148	25.568	968.08	28.73	287.6	8.589	2.630	2.594×10^{-3}	3.161×10^{-6}	2.582×10^{-3}	6.671×10^{16}	4.602×10^{4}	3.751×10^{-3}	1.227×10^{7}	8.440×10^{-2}	5.453×10^{6}	3.418×10^{4}
42.673	26.515	967.62	28.72	299.2	8.946	2.212	2.183×10^{-3}	2.556×10^{-6}	2.088×10^{-2}	5.395×10^{16}	4.694×10^{4}	4.638×10^{-3}	1.012×10^{7}	1.043×10^{-2}	4.498×10^{6}	3.487×10^{4}
44.197	27.462	967.15	28.71	310.8	9.299	1.875	1.850×10^{-3}	2.084×10^{-6}	1.702×10^{-3}	4.401×10^{16}	4.785×10^{4}	5.685×10^{-3}	8.417×10^{6}	1.279×10^{-2}	3.741×10^{6}	3.555×10^{4}
45.721	28.409	966.69	28.69	322.4	9.656	1.599	1.577×10^{-3}	1.712×10^{-6}	1.399×10^{-3}	3.618×10^{16}	4.877×10^{4}	6.917×10^{-3}	7.051×10^{6}	1.556×10^{-2}	3.134×10^{6}	3.621×10^{4}
47.245	29.356	966.23	28.68	334.0	1.001×10	1.371	1.353×10^{-3}	1.417×10^{-6}	1.158×10^{-3}	2.995×10^{16}	4.962×10^{4}	8.353×10^{-3}	5.941×10^{6}	1.879×10^{-2}	2.640×10^{6}	3.687×10^{4}
48.769	30.303	965.77	28.67	345.6	1.037×10	1.183	1.167×10^{-3}	1.181×10^{-6}	9.647×10^{-4}	2.497×10^{16}	5.051×10^{4}	1.002×10^{-2}	5.041×10^{6}	2.254×10^{-2}	2.240×10^{6}	3.751×10^{4}
50.000	31.068	965.40	28.66	355.0	1.066×10	1.054	1.040×10^{-3}	1.024×10^{-6}	8.364×10^{-4}	2.166×10^{16}	5.118×10^{4}	1.155×10^{-2}	4.430×10^{6}	2.599×10^{-2}	1.969×10^{6}	3.802×10^{4}
50.293	31.250	965.31	28.66	355.0	1.066×10	1.025	1.011×10^{-3}	9.962×10^{-7}	8.138×10^{-4}	2.107×10^{16}	5.118×10^{4}	1.180×10^{-2}	4.310×10^{6}	2.672×10^{-2}	1.916×10^{6}	3.802×10^{4}
51.817	32.197	964.85	28.66	355.0	1.066×10	8.887×10^{-1}	8.768×10^{-4}	8.635×10^{-7}	7.054×10^{-4}	1.827×10^{16}	5.118×10^{4}	1.370×10^{-2}	3.736×10^{6}	3.082×10^{-2}	1.660×10^{6}	3.802×10^{4}
53.341	33.144	964.39	28.66	355.0	1.067×10	7.705×10^{-1}	7.601×10^{-4}	7.486×10^{-7}	6.115×10^{-4}	1.584×10^{16}	5.118×10^{4}	1.580×10^{-2}	3.239×10^{6}	3.555×10^{-2}	1.440×10^{6}	3.802×10^{4}
54.865	34.091	963.93	28.66	355.0	1.067×10	6.681×10^{-1}	6.591×10^{-4}	6.491×10^{-7}	5.303×10^{-4}	1.373×10^{16}	5.118×10^{4}	1.822×10^{-2}	2.809×10^{6}	4.100×10^{-2}	1.248×10^{6}	3.802×10^{4}
56.389	35.038	963.48	28.66	355.0	1.068×10	5.794×10^{-1}	5.716×10^{-4}	5.630×10^{-7}	4.599×10^{-4}	1.191×10^{16}	5.118×10^{4}	2.101×10^{-2}	2.436×10^{6}	4.728×10^{-2}	1.083×10^{6}	3.002×10^{4}
57.913	35.985	963.01	28.66	355.0	1.069×10	5.025×10^{-1}	4.958×10^{-4}	4.883×10^{-7}	3.988×10^{-4}	1.033×10^{16}	5.118×10^{4}	2.423×10^{-2}	2.113×10^{6}	5.451×10^{-2}	9.391×10^{5}	3.802×10^{4}
59.437	36.932	962.56	28.66	355.0	1.069×10	4.359×10^{-1}	4.300×10^{-4}	4.235×10^{-7}	3.460×10^{-4}	8.959×10^{15}	5.118×10^{4}	2.793×10^{-2}	1.832×10^{6}	6.284×10^{-2}	8.142×10^{5}	3.802×10^{4}
60.000	37.282	962.39	28.66	355.0	1.069×10	4.136×10^{-1}	4.080×10^{-4}	4.019×10^{-7}	3.283×10^{-4}	8.501×10^{15}	5.118×10^{4}	2.943×10^{-2}	1.739×10^{6}	6.623×10^{-2}	7.729×10^{5}	3.802×10^{4}
60.961	37.879	962.10	28.66	348.9	1.051×10	3.777×10^{-1}	3.727×10^{-4}	3.735×10^{-7}	3.051×10^{-4}	7.901×10^{15}	5.084×10^{4}	3.167×10^{-2}	1.605×10^{6}	7.126×10^{-2}	7.133×10^{5}	3.769×10^{4}

Table 3.16 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER
Latitude 45°. Metric Units. p_0 = 1014 mb,
$\rho_0 = 1.223 \times 10^{-3}$ gm/cm³. Table 14 of Ref. 3.20.

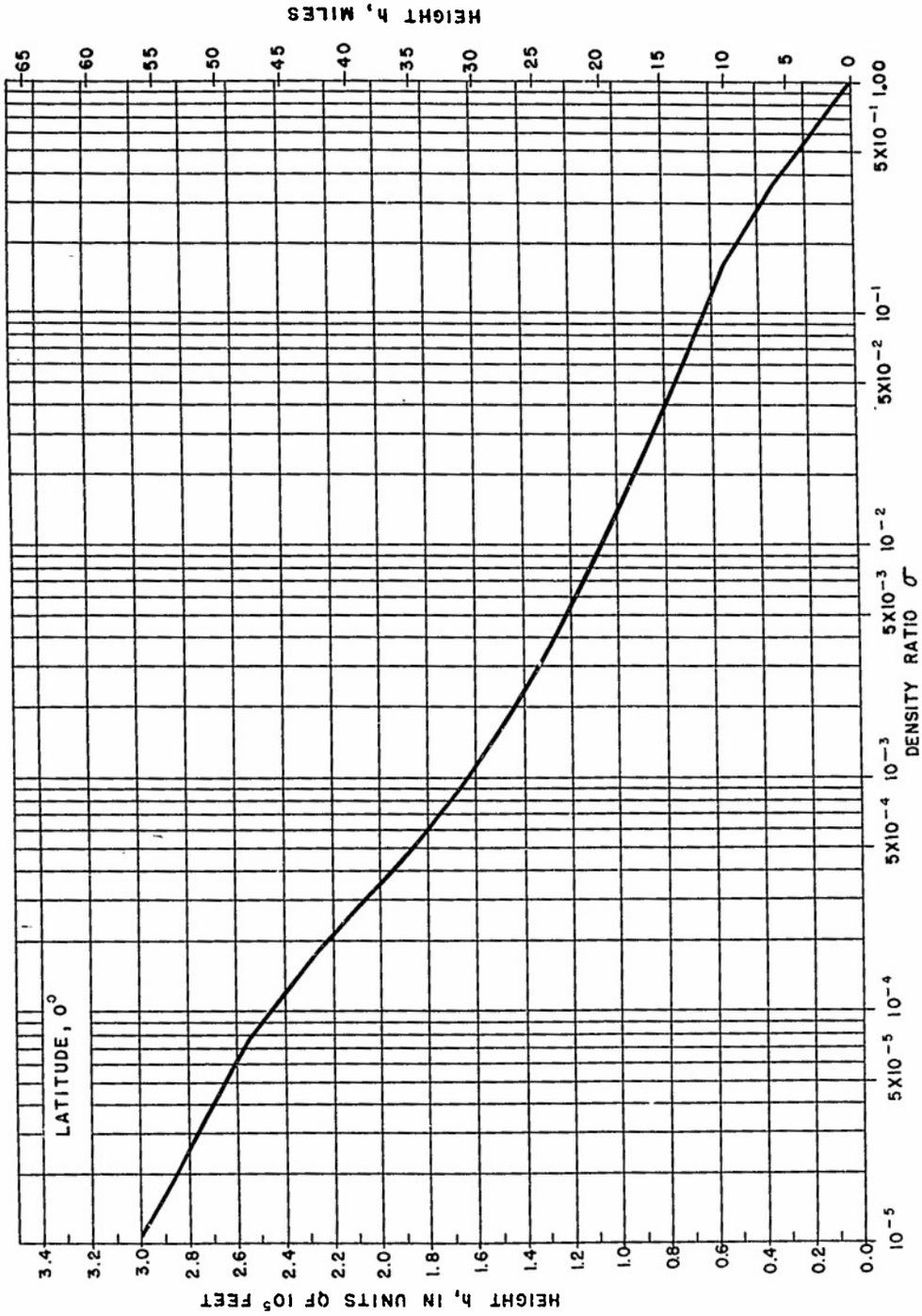
Height h km	Height h mi	Apparent Gravity g' cm/sec^2	Mean Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm^3	Density Ratio $\sigma = \rho/\rho_0$	Number Density n particles/cm^3	Mean Particle Speed $\bar{v}$ cm/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	Speed of Sound a cm/sec
62.485	38.826	961.64	28.66	339.1	1.022 × 10	3.261 × 10^{-1}	3.218 × 10^{-4}	3.317 × 10^{-7}	2.710 × 10^{-4}	7.017 × 10^{15}	5.002 × 10^{4}	3.566 × 10^{-2}	1.403 × 10^{6}	8.023 × 10^{-2}	6.236 × 10^{5}	3.716 × 10^{4}
64.009	39.773	961.18	28.66	329.4	9.933	2.804 × 10^{-1}	2.766 × 10^{-4}	2.936 × 10^{-7}	2.399 × 10^{-4}	6.212 × 10^{15}	4.932 × 10^{4}	4.028 × 10^{-2}	1.224 × 10^{6}	9.064 × 10^{-2}	5.440 × 10^{5}	3.662 × 10^{4}
65.553	40.720	960.72	28.66	319.7	9.644	2.400 × 10^{-1}	2.368 × 10^{-4}	2.590 × 10^{-7}	2.116 × 10^{-4}	5.479 × 10^{15}	4.859 × 10^{4}	4.567 × 10^{-2}	1.064 × 10^{6}	1.028 × 10^{-1}	4.729 × 10^{5}	3.608 × 10^{4}
67.057	41.667	960.27	28.66	309.9	9.354	2.045 × 10^{-1}	2.018 × 10^{-4}	2.276 × 10^{-7}	1.859 × 10^{-4}	4.815 × 10^{15}	4.782 × 10^{4}	5.197 × 10^{-2}	9.202 × 10^{5}	1.169 × 10^{-1}	4.090 × 10^{5}	3.553 × 10^{4}
68.581	42.614	959.81	28.66	300.2	9.065	1.740 × 10^{-1}	1.717 × 10^{-4}	2.000 × 10^{-7}	1.634 × 10^{-4}	4.230 × 10^{15}	4.706 × 10^{4}	5.915 × 10^{-2}	7.956 × 10^{5}	1.331 × 10^{-1}	3.536 × 10^{5}	3.496 × 10^{4}
70.105	43.561	959.36	28.66	290.4	8.775	1.462 × 10^{-1}	1.443 × 10^{-4}	1.736 × 10^{-7}	1.418 × 10^{-4}	3.673 × 10^{15}	4.630 × 10^{4}	6.811 × 10^{-2}	6.797 × 10^{5}	1.533 × 10^{-1}	3.021 × 10^{5}	3.439 × 10^{4}
71.629	44.508	958.90	28.66	280.7	8.486	1.226 × 10^{-1}	1.210 × 10^{-4}	1.507 × 10^{-7}	1.231 × 10^{-4}	3.187 × 10^{15}	4.551 × 10^{4}	7.851 × 10^{-2}	5.796 × 10^{5}	1.766 × 10^{-1}	2.576 × 10^{5}	3.381 × 10^{4}
73.153	45.455	958.45	28.66	271.0	8.196	1.022 × 10^{-1}	1.008 × 10^{-4}	1.301 × 10^{-7}	1.063 × 10^{-4}	2.752 × 10^{15}	4.471 × 10^{4}	9.093 × 10^{-2}	4.918 × 10^{5}	2.046 × 10^{-1}	2.186 × 10^{5}	3.322 × 10^{4}
74.677	46.402	957.99	28.66	261.2	7.903	8.462 × 10^{-2}	8.349 × 10^{-5}	1.117 × 10^{-7}	9.128 × 10^{-5}	2.364 × 10^{15}	4.392 × 10^{4}	1.059 × 10^{-1}	4.149 × 10^{5}	2.382 × 10^{-1}	1.844 × 10^{5}	3.262 × 10^{4}
76.201	47.348	957.54	28.66	251.5	7.611	6.958 × 10^{-2}	6.865 × 10^{-5}	9.544 × 10^{-8}	7.797 × 10^{-5}	2.019 × 10^{15}	4.310 × 10^{4}	1.239 × 10^{-1}	3.478 × 10^{5}	2.788 × 10^{-1}	1.546 × 10^{5}	3.200 × 10^{4}
77.725	48.295	957.08	28.66	241.8	7.321	5.679 × 10^{-2}	5.603 × 10^{-5}	8.103 × 10^{-8}	6.619 × 10^{-5}	1.714 × 10^{15}	4.225 × 10^{4}	1.460 × 10^{-1}	2.894 × 10^{5}	3.285 × 10^{-1}	1.286 × 10^{5}	3.138 × 10^{4}
78.000	48.466	957.00	28.66	240.0	7.269	5.469 × 10^{-2}	5.396 × 10^{-5}	7.860 × 10^{-8}	6.422 × 10^{-5}	1.663 × 10^{15}	4.209 × 10^{4}	1.505 × 10^{-1}	2.797 × 10^{5}	3.386 × 10^{-1}	1.243 × 10^{5}	3.126 × 10^{4}
79.249	49.242	956.63	28.66	240.0	7.273	4.606 × 10^{-2}	4.545 × 10^{-5}	6.620 × 10^{-8}	5.408 × 10^{-5}	1.400 × 10^{15}	4.209 × 10^{4}	1.787 × 10^{-1}	2.356 × 10^{5}	4.020 × 10^{-1}	1.047 × 10^{5}	3.126 × 10^{4}
80.773	50.189	956.18	28.66	240.0	7.276	3.736 × 10^{-2}	3.686 × 10^{-5}	5.370 × 10^{-8}	4.386 × 10^{-5}	1.136 × 10^{15}	4.209 × 10^{4}	2.203 × 10^{-1}	1.911 × 10^{5}	4.956 × 10^{-1}	8.493 × 10^{4}	3.126 × 10^{4}
82.297	51.136	955.72	28.66	240.0	7.279	3.031 × 10^{-2}	2.990 × 10^{-5}	4.356 × 10^{-8}	3.558 × 10^{-5}	9.215 × 10^{14}	4.209 × 10^{4}	2.715 × 10^{-1}	1.550 × 10^{5}	6.110 × 10^{-1}	6.869 × 10^{4}	3.126 × 10^{4}
83.000	51.573	955.51	28.66	240.0	7.281	2.752 × 10^{-2}	2.715 × 10^{-5}	3.956 × 10^{-8}	3.231 × 10^{-5}	8.367 × 10^{14}	4.209 × 10^{4}	2.990 × 10^{-1}	1.408 × 10^{5}	6.728 × 10^{-1}	6.256 × 10^{4}	3.126 × 10^{4}
83.821	52.083	955.26	28.56	243.0	7.398	2.461 × 10^{-2}	2.428 × 10^{-5}	3.482 × 10^{-8}	2.845 × 10^{-5}	7.391 × 10^{14}	4.243 × 10^{4}	3.385 × 10^{-1}	1.253 × 10^{5}	7.617 × 10^{-1}	5.570 × 10^{4}	3.152 × 10^{4}
85.345	53.030	954.81	28.39	248.6	7.618	2.010 × 10^{-2}	1.983 × 10^{-5}	2.763 × 10^{-8}	2.257 × 10^{-5}	5.901 × 10^{14}	4.304 × 10^{4}	4.240 × 10^{-1}	1.015 × 10^{5}	9.540 × 10^{-1}	4.512 × 10^{4}	3.201 × 10^{4}
86.869	53.977	954.36	28.21	254.1	7.841	1.652 × 10^{-2}	1.630 × 10^{-5}	2.207 × 10^{-8}	1.803 × 10^{-5}	4.743 × 10^{14}	4.365 × 10^{4}	5.276 × 10^{-1}	8.274 × 10^{4}	1.187	3.677 × 10^{4}	3.249 × 10^{4}
88.393	54.924	953.91	28.03	259.7	8.067	1.365 × 10^{-2}	1.364 × 10^{-5}	1.773 × 10^{-8}	1.448 × 10^{-5}	3.834 × 10^{14}	4.426 × 10^{4}	6.526 × 10^{-1}	6.782 × 10^{4}	1.468	3.014 × 10^{4}	3.298 × 10^{4}
89.917	55.871	953.45	27.85	265.2	8.297	1.133 × 10^{-2}	1.118 × 10^{-5}	1.432 × 10^{-8}	1.170 × 10^{-5}	3.118 × 10^{14}	4.488 × 10^{4}	8.025 × 10^{-1}	5.593 × 10^{4}	1.806	2.486 × 10^{4}	3.346 × 10^{4}
91.441	56.818	953.00	27.68	270.8	8.529	9.462 × 10^{-3}	9.336 × 10^{-6}	1.164 × 10^{-8}	9.508 × 10^{-6}	2.550 × 10^{14}	4.549 × 10^{4}	9.813 × 10^{-1}	4.636 × 10^{4}	2.208	2.060 × 10^{4}	3.394 × 10^{4}
92.965	57.765	952.55	27.50	276.4	8.764	7.938 × 10^{-3}	7.832 × 10^{-6}	9.507 × 10^{-9}	7.766 × 10^{-5}	2.096 × 10^{14}	4.612 × 10^{4}	1.194	3.862 × 10^{4}	2.686	1.716 × 10^{4}	3.443 × 10^{4}
94.489	58.712	952.10	27.32	281.9	9.003	6.690 × 10^{-3}	6.610 × 10^{-6}	7.804 × 10^{-6}	6.375 × 10^{-6}	1.732 × 10^{14}	4.673 × 10^{4}	1.445	3.234 × 10^{4}	3.251	1.437 × 10^{4}	3.492 × 10^{4}
96.013	59.659	951.65	27.14	287.5	9.245	5.664 × 10^{-3}	5.588 × 10^{-6}	6.437 × 10^{-6}	5.258 × 10^{-5}	1.438 × 10^{14}	4.734 × 10^{4}	1.740	2.720 × 10^{4}	3.916	1.209 × 10^{4}	3.540 × 10^{4}
97.537	60.606	951.20	26.97	293.0	9.491	4.817 × 10^{-3}	4.752 × 10^{-6}	5.335 × 10^{-8}	4.358 × 10^{-5}	1.199 × 10^{14}	4.795 × 10^{4}	2.086	2.298 × 10^{4}	4.694	1.021 × 10^{4}	3.589 × 10^{4}
99.061	61.553	950.75	26.79	298.6	9.739	4.113 × 10^{-3}	4.058 × 10^{-6}	4.441 × 10^{-8}	3.628 × 10^{-5}	1.005 × 10^{14}	4.856 × 10^{4}	2.490	1.950 × 10^{4}	5.602	8.668 × 10^{3}	3.638 × 10^{4}
100.58	62.500	950.30	26.61	304.2	9.991	3.526 × 10^{-3}	3.479 × 10^{-6}	3.713 × 10^{-8}	3.033 × 10^{-5}	8.459 × 10^{13}	4.916 × 10^{4}	2.958	1.662 × 10^{4}	6.655	7.387 × 10^{3}	3.686 × 10^{4}
102.11	63.447	949.85	26.43	309.7	1.025 × 10	3.034 × 10^{-3}	2.994 × 10^{-6}	3.117 × 10^{-8}	2.546 × 10^{-5}	7.149 × 10^{13}	4.977 × 10^{4}	3.500	1.422 × 10^{4}	7.875	6.320 × 10^{3}	3.735 × 10^{4}
103.63	64.394	949.40	26.26	315.3	1.051 × 10	2.621 × 10^{-3}	2.586 × 10^{-6}	2.628 × 10^{-8}	2.146 × 10^{-5}	6.067 × 10^{13}	5.040 × 10^{4}	4.124	1.222 × 10^{4}	9.280	5.431 × 10^{3}	3.784 × 10^{4}
105.16	65.341	948.96	26.08	320.8	1.077 × 10	2.273 × 10^{-3}	2.242 × 10^{-6}	2.223 × 10^{-8}	1.816 × 10^{-5}	5.169 × 10^{13}	5.102 × 10^{4}	4.841	1.054 × 10^{4}	1.089 × 10	4.684 × 10^{3}	3.834 × 10^{4}
106.68	66.288	948.50	25.90	326.4	1.104 × 10	1.977 × 10^{-3}	1.951 × 10^{-6}	1.889 × 10^{-8}	1.543 × 10^{-5}	4.421 × 10^{13}	5.163 × 10^{4}	5.660	9.122 × 10^{3}	1.274 × 10	4.054 × 10^{3}	3.883 × 10^{4}
108.20	67.235	948.06	25.72	332.0	1.131 × 10	1.726 × 10^{-3}	1.703 × 10^{-6}	1.610 × 10^{-8}	1.315 × 10^{-5}	3.794 × 10^{13}	5.224 × 10^{4}	6.595	7.921 × 10^{3}	1.484 × 10	3.520 × 10^{3}	3.933 × 10^{4}
109.73	68.182	947.61	25.55	337.5	1.158 × 10	1.512 × 10^{-3}	1.491 × 10^{-6}	1.377 × 10^{-8}	1.125 × 10^{-5}	3.268 × 10^{13}	5.285 × 10^{4}	7.657	6.902 × 10^{3}	1.723 × 10	3.068 × 10^{3}	3.982 × 10^{4}
111.25	69.129	947.16	25.37	343.1	1.186 × 10	1.328 × 10^{-3}	1.310 × 10^{-6}	1.182 × 10^{-8}	9.654 × 10^{-7}	2.824 × 10^{13}	5.349 × 10^{4}	8.859	6.038 × 10^{3}	1.993 × 10	2.684 × 10^{3}	4.032 × 10^{4}
112.78	70.076	946.72	25.19	348.6	1.214 × 10	1.170 × 10^{-3}	1.154 × 10^{-6}	1.018 × 10^{-8}	8.312 × 10^{-7}	2.449 × 10^{13}	5.410 × 10^{4}	1.022 × 10	5.295 × 10^{3}	2.299 × 10	2.353 × 10^{3}	4.082 × 10^{4}
114.30	71.023	946.27	25.01	354.2	1.243 × 10	1.034 × 10^{-3}	1.020 × 10^{-6}	8.790 × 10^{-10}	7.180 × 10^{-7}	2.130 × 10^{13}	5.474 × 10^{4}	1.175 × 10	4.661 × 10^{3}	2.643 × 10	2.072 × 10^{3}	4.132 × 10^{4}
115.82	71.970	945.82	24.84	359.8	1.272 × 10	9.166 × 10^{-4}	9.043 × 10^{-7}	7.615 × 10^{-10}	6.221 × 10^{-7}	1.859 × 10^{13}	5.535 × 10^{4}	1.346 × 10	4.112 × 10^{3}	3.028 × 10	1.828 × 10^{3}	4.182 × 10^{4}
117.35	72.917	945.38	24.66	365.3	1.302 × 10	8.146 × 10^{-4}	8.037 × 10^{-7}	6.618 × 10^{-10}	5.406 × 10^{-7}	1.627 × 10^{13}	5.599 × 10^{4}	1.538 × 10	3.641 × 10^{3}	3.460 × 10	1.618 × 10^{3}	4.233 × 10^{4}
118.87	73.864	944.93	24.48	370.9	1.332 × 10	7.259 × 10^{-4}	7.162 × 10^{-7}	5.767 × 10^{-10}	4.711 × 10^{-7}	1.428 × 10^{13}	5.660 × 10^{4}	1.752 × 10	3.231 × 10^{3}	3.942 × 10	1.436 × 10^{3}	4.284 × 10^{4}
120.00	74.564	944.60	24.35	375.0	1.354 × 10	6.677 × 10^{-4}	6.587 × 10^{-7}	5.218 × 10^{-10}	4.263 × 10^{-7}	1.299 × 10^{13}	5.708 × 10^{4}	1.926 × 10	2.964 × 10^{3}	4.333 × 10	1.317 × 10^{3}	4.322 × 10^{4}
120.40	74.811	944.49	24.35	376.6	1.360 × 10	6.484 × 10^{-4}	6.397 × 10^{-7}	5.046 × 10^{-10}	4.122 × 10^{-7}	1.256 × 10^{13}	5.761 × 10^{4}	1.992 × 10	2.893 × 10^{3}	4.481 × 10	1.286 × 10^{3}	4.331 × 10^{4}
121.92	75.758	944.04	24.35	382.7	1.383 × 10	5.802 × 10^{-4}	5.725 × 10^{-7}	4.443 × 10^{-10}	3.629 × 10^{-7}	1.106 × 10^{13}	5.785 × 10^{4}	2.262 × 10	2.558 × 10^{3}	5.089 × 10	1.137 × 10^{3}	4.365 × 10^{4}
137.16	85.227	939.60	24.35	444.1	1.613 × 10	2.09 × 10^{-4}	2.06 × 10^{-7}	1.38 × 10^{-10}	1.13 × 10^{-7}	3.44 × 10^{12}	6.21 × 10^{4}	7.27 × 10	8.55 × 10^{2}	1.64 × 10^{2}	3.80 × 10^{2}	4.70 × 10^{4}
152.40	94.697	935.20	24.35	505.5	1.844 × 10	8.67 × 10^{-6}	8.55 × 10^{-8}	5.02 × 10^{-11}	4.11 × 10^{-8}	1.25 × 10^{12}	6.63 × 10^{4}	2.00 × 10^{2}	3.32 × 10^{2}	4.49 × 10^{2}	1.48 × 10^{2}	5.02 × 10^{4}

Table 3.16 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER
Latitude 45°. Metric Units. p_0 = 1014 mb,
ρ_0 = 1.223 x 10^{-3} gm/cm3. Table 14 of Ref. 3.20. (Continued)

Height h km	Height h mi	Apparent Gravity g' cm/sec^2	Mean Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm^3	Density Ratio σ ρ/ρ_0	Number Density n particles/cm^3	Mean Particle Speed v cm/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	Speed of Sound a cm/sec
160.94	100.00	932.75	24.35	539.9	1.975×10	5.53×10^{-5}	5.48×10^{-8}	3.00×10^{-11}	2.45×10^{-8}	7.49×10^{11}	6.85×10^{4}	3.34×10^{2}	2.05×10^{2}	7.52×10^{2}	9.11×10	5.19×10^{4}
167.64	104.17	930.83	24.35	566.9	2.078×10	3.98×10^{-5}	3.92×10^{-8}	2.05×10^{-11}	1.68×10^{-8}	5.12×10^{11}	7.02×10^{4}	4.89×10^{2}	1.44×10^{2}	1.10×10^{3}	6.38×10	
182.88	113.64	926.48	24.35	628.3	2.313×10	1.98×10^{-5}	1.96×10^{-8}	9.22×10^{-12}	7.54×10^{-9}	2.30×10^{11}	7.39×10^{4}	1.09×10^{3}	6.79×10	2.45×10^{3}	3.02×10	
198.12	123.11	922.17	24.35	689.7	2.551×10	1.06×10^{-5}	1.04×10^{-8}	4.50×10^{-12}	3.68×10^{-9}	1.12×10^{11}	7.74×10^{4}	2.24×10^{3}	3.46×10	5.03×10^{3}	1.54×10	
213.36	132.58	917.88	24.35	751.0	2.791×10	5.99×10^{-6}	5.91×10^{-9}	2.33×10^{-12}	1.91×10^{-9}	5.83×10^{10}	8.07×10^{4}	4.29×10^{3}	1.88×10	9.66×10^{3}	8.35	
228.60	142.05	913.63	24.35	812.4	3.034×10	3.54×10^{-6}	3.50×10^{-9}	1.28×10^{-12}	1.04×10^{-9}	3.19×10^{10}	8.40×10^{4}	7.86×10^{3}	1.07×10	1.77×10^{4}	4.75	
243.84	151.57	909.41	24.35	873.8	3.278×10	2.19×10^{-6}	2.16×10^{-9}	7.31×10^{-13}	5.98×10^{-10}	1.82×10^{10}	8.71×10^{4}	1.37×10^{4}	6.35×10	3.09×10^{4}	2.82	
259.08	160.98	905.21	24.35	935.2	3.525×10	1.40×10^{-6}	1.38×10^{-9}	4.38×10^{-13}	3.58×10^{-10}	1.09×10^{10}	9.01×10^{4}	2.29×10^{4}	3.93×10	5.16×10^{4}	1.75	
274.32	170.45	901.05	24.35	996.6	3.773×10	9.20×10^{-7}	9.07×10^{-10}	2.70×10^{-13}	2.21×10^{-10}	6.75×10^{9}	9.30×10^{4}	3.71×10^{4}	2.51×10	8.35×10^{4}	1.11	
289.56	179.92	896.91	24.35	1058	4.024×10	6.23×10^{-7}	6.14×10^{-10}	1.73×10^{-13}	1.41×10^{-10}	4.31×10^{9}	9.59×10^{4}	5.81×10^{4}	1.65×10	1.31×10^{5}	7.34×10^{-1}	
300.00	186.41	894.09	24.35	1100	4.197×10	4.84×10^{-7}	4.77×10^{-10}	1.29×10^{-13}	1.05×10^{-10}	3.21×10^{9}	9.78×10^{4}	7.79×10^{4}	1.25×10	1.75×10^{5}	5.57×10^{-1}	

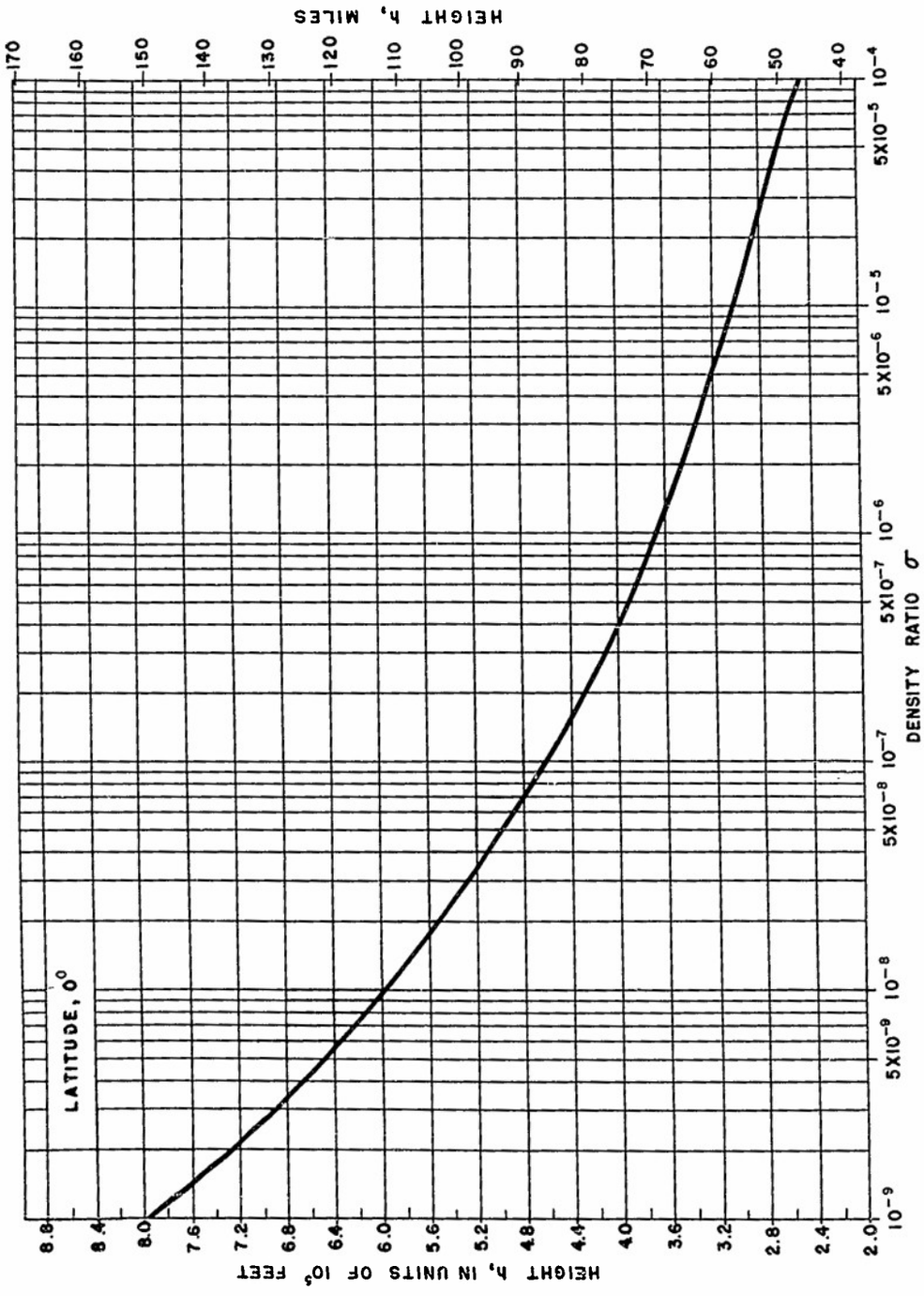
1 millibar (mb) = 10^3 dynes/cm^2 = 0.750 mm of Hg

Table 3.16 VALUES OF TEMPERATURE, PRESSURE AND DENSITY UP TO THE F_2-LAYER Latitude 45°. Metric Units. $p_0 = 1014$ mb, $\rho_0 = 1.223 \times 10^{-3}$ gm/cm^3. Table 14 of Ref. 3.20 (Concluded)



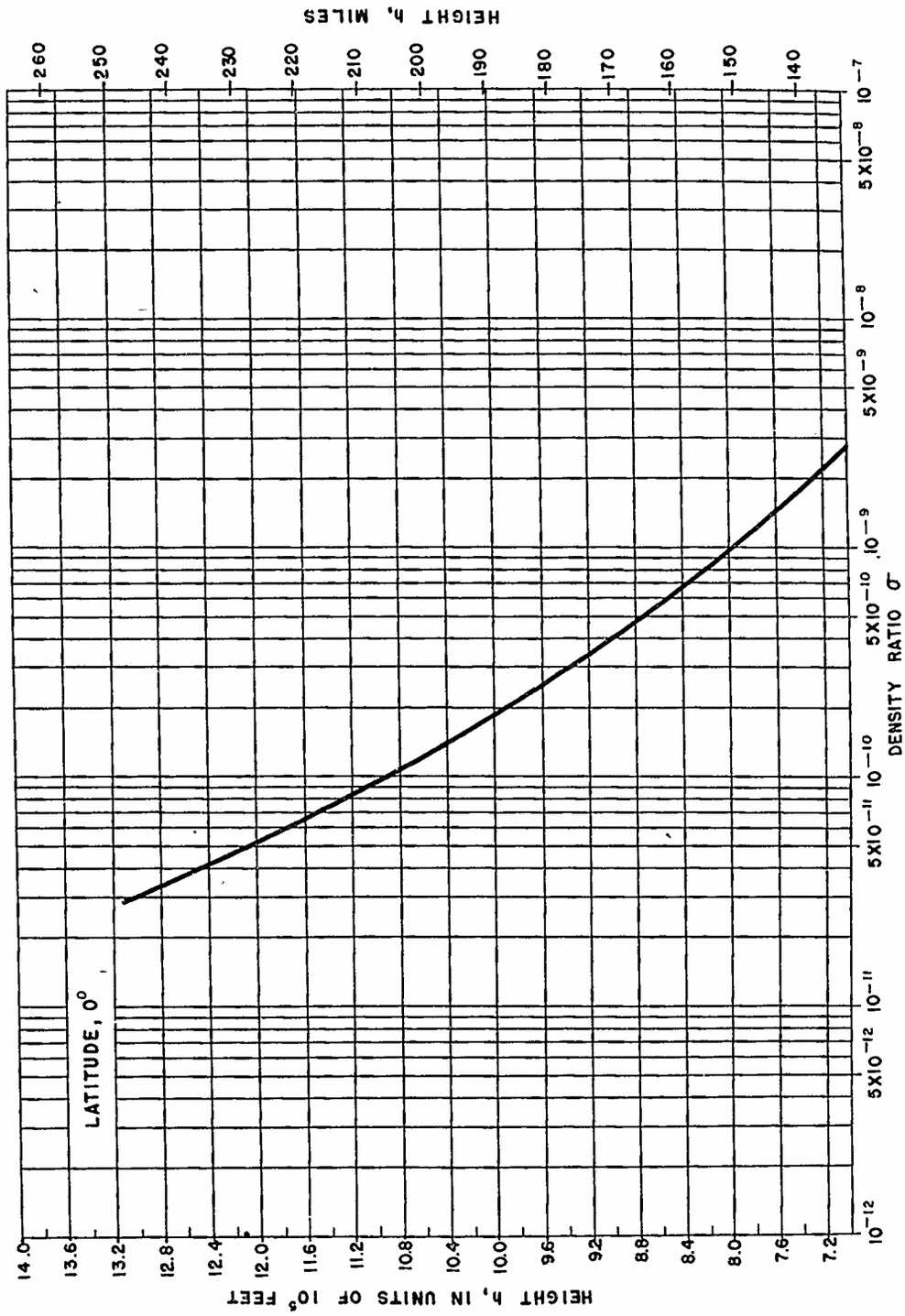
(a) Height (0 to 3.0 x 10^5 feet) vs Density Ratio

Fig. 3.29 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2- LAYER
Latitude 0°. Engineering Units. Fig. 10(a) of Ref. 3.20.



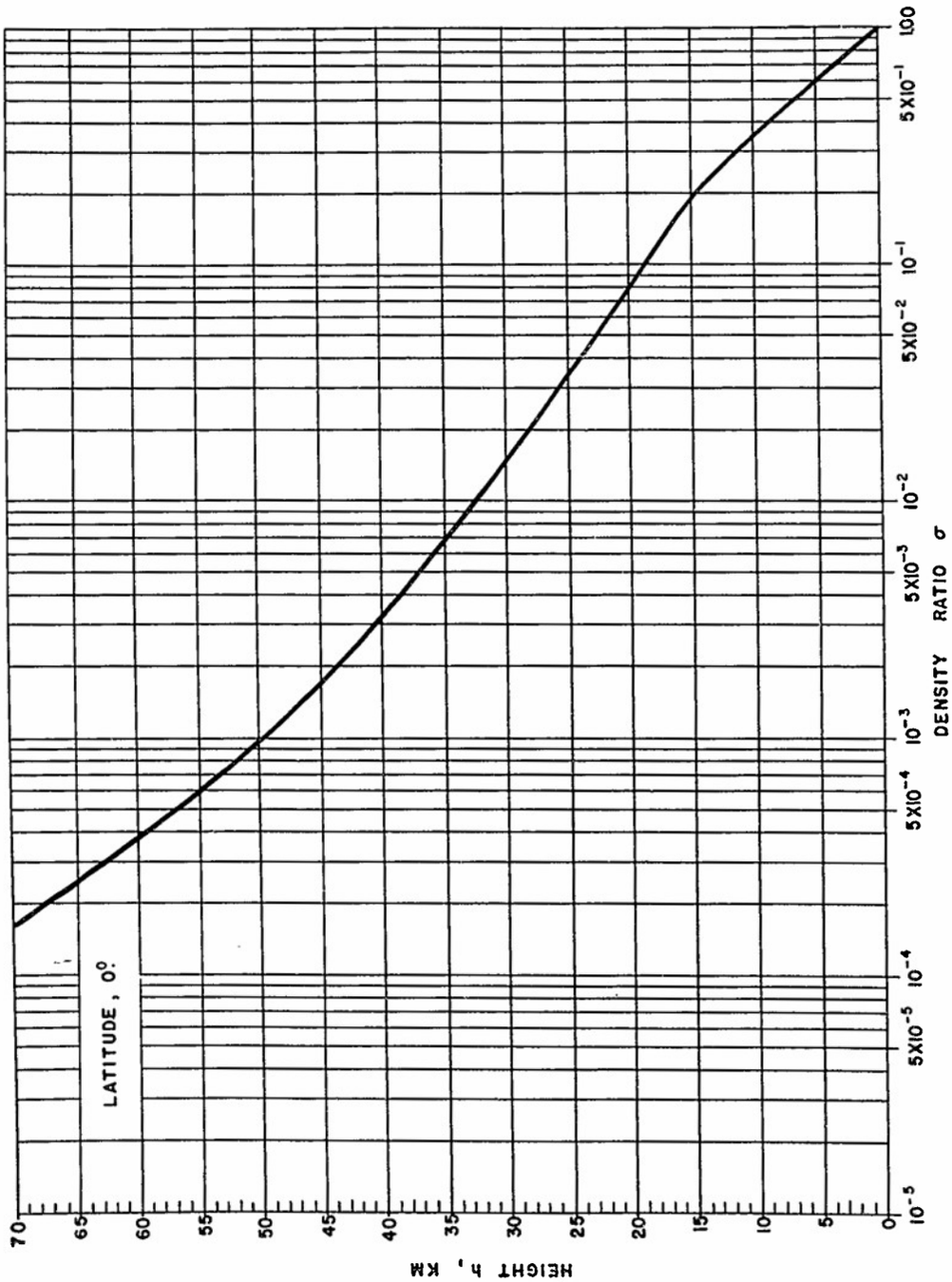
(b) Height (2.5 x 105 to 8.0 x 105 feet) vs Density Ratio

Fig. 3.29 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2- LAYER
Latitude 0°. Engineering Units. Fig. 10(b) of Ref. 3.20.
(Continued)



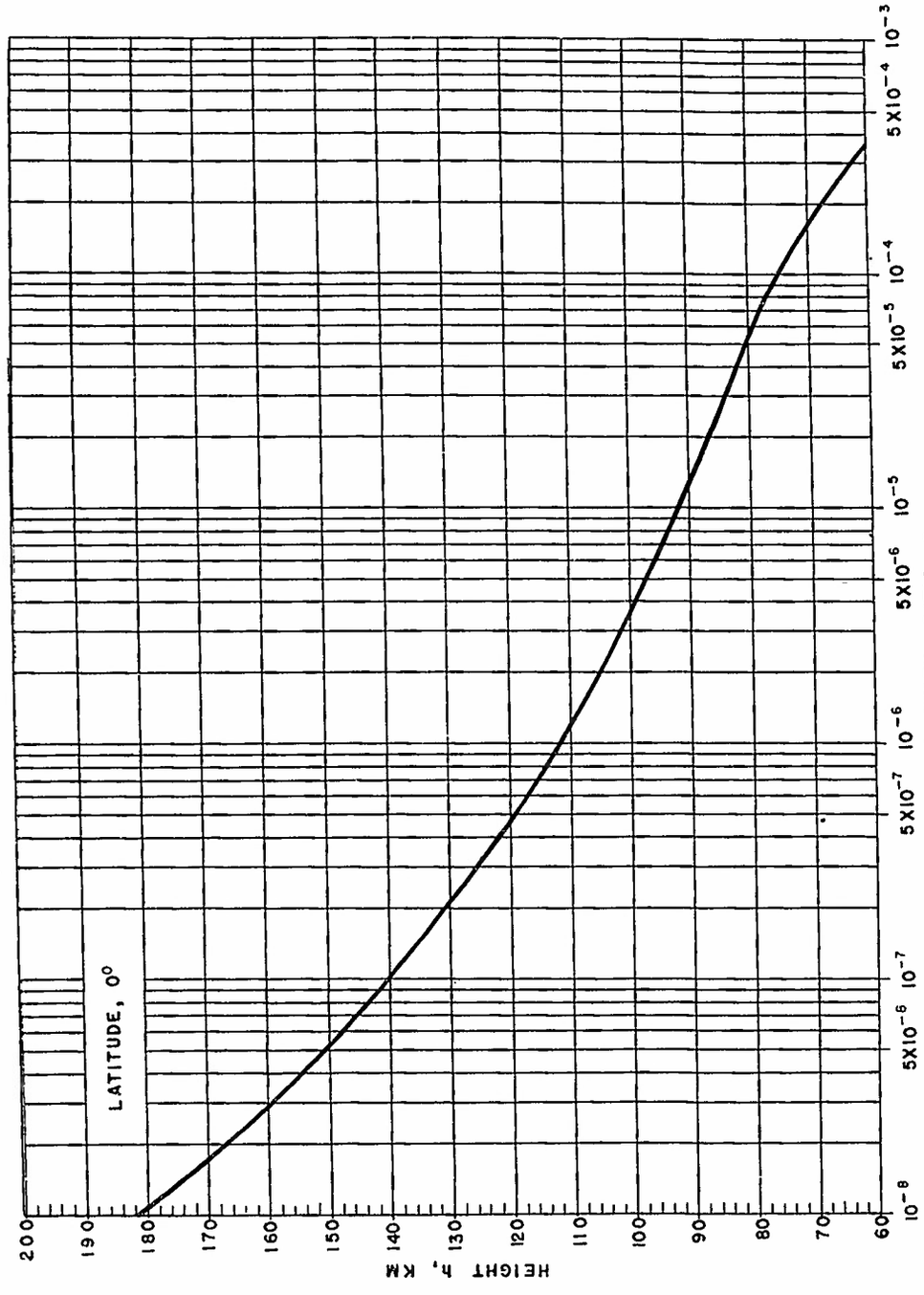
(c) Height (7.0×10^5 to 13.1×10^5 feet) vs Density Ratio

Fig. 3.29 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2- LAYER
Latitude 0°. Engineering Units. Fig. 10(c) of Ref. 3.20.
(Concluded)



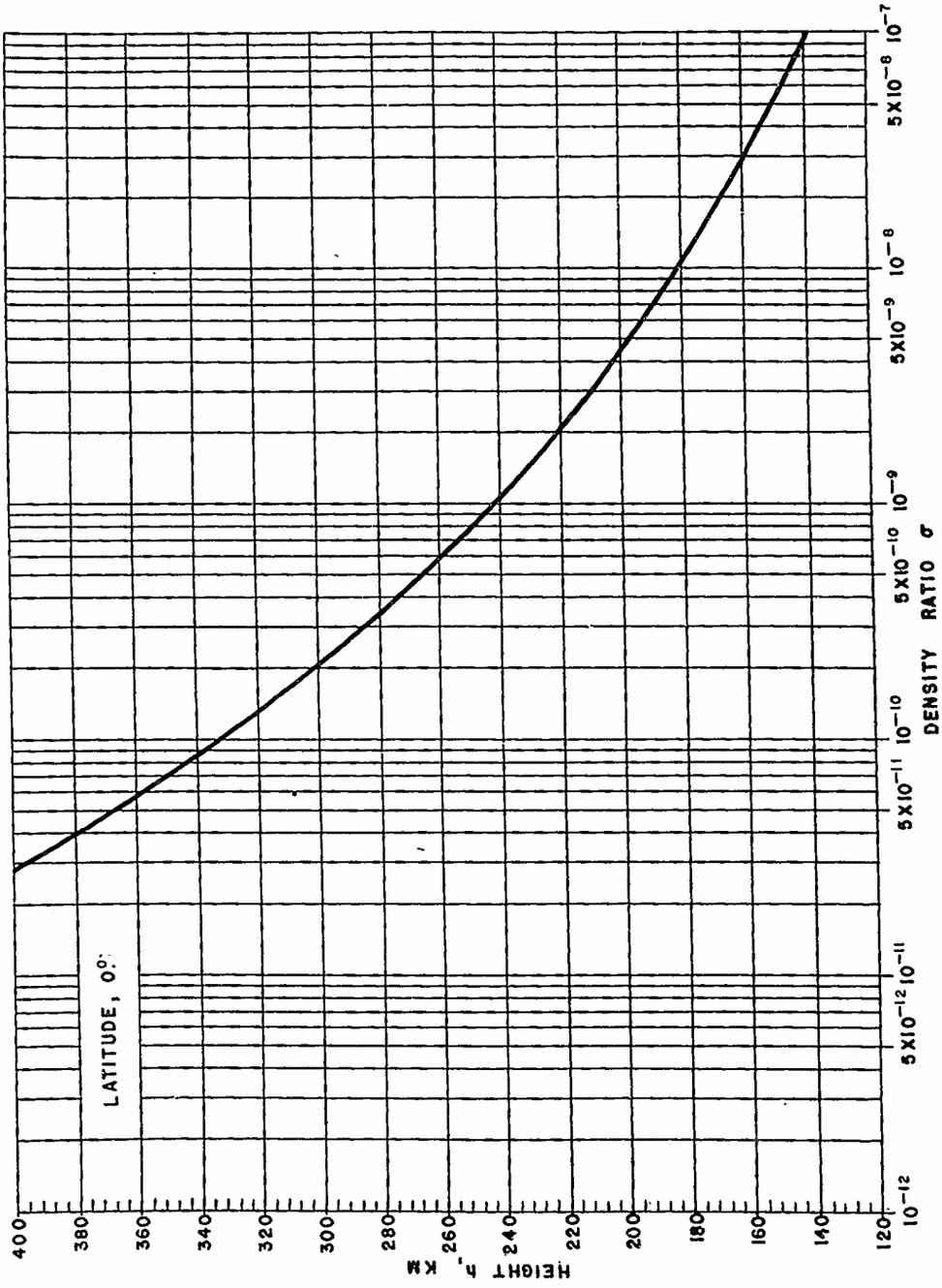
(a) Height (0 to 70 Km) vs Density Ratio

Fig. 3.30 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2-LAYER
Latitude 0°. Metric Units. Fig. 11(a) of Ref. 3.20.



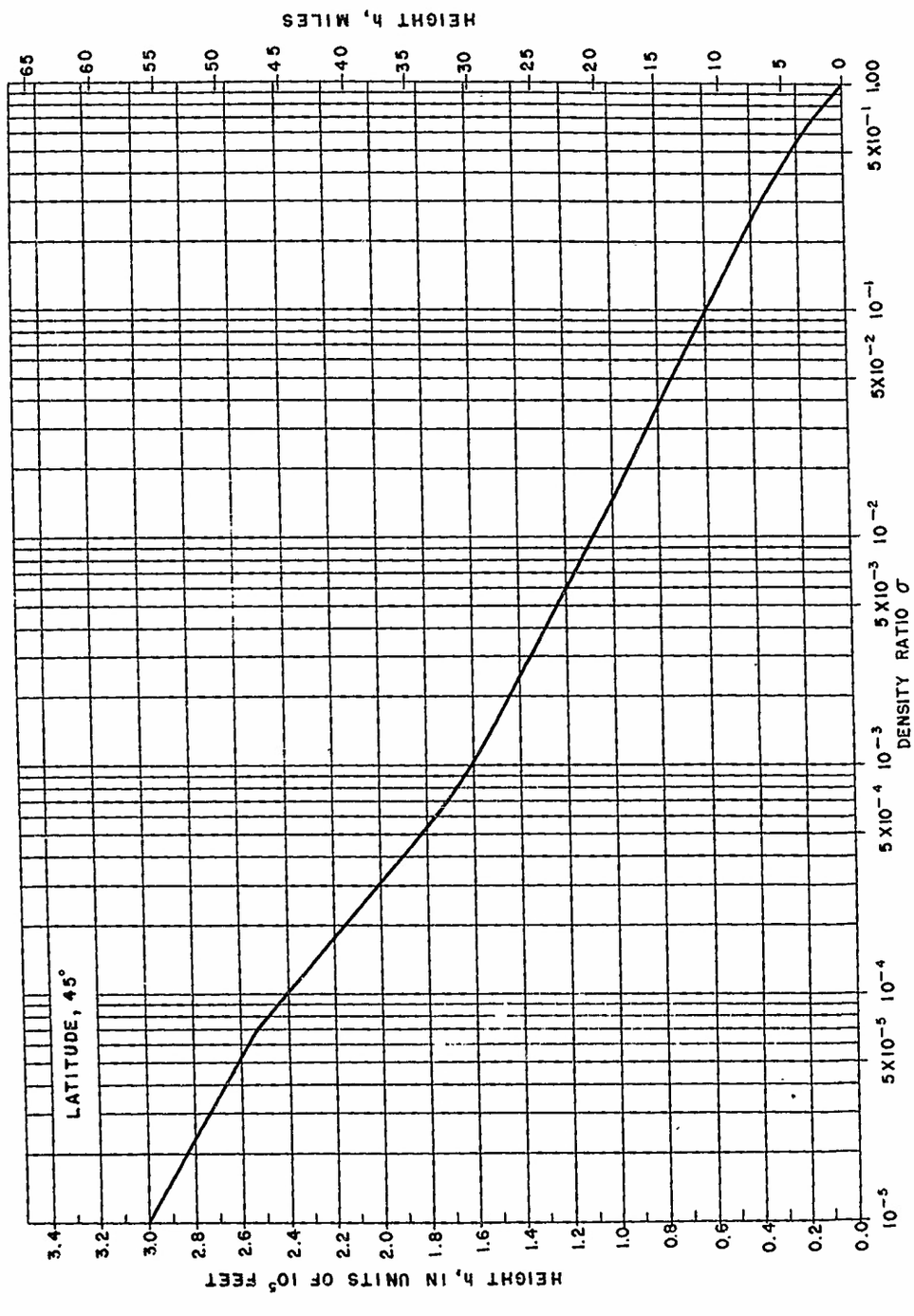
(b) Height (60 to 182 Km) vs Density Ratio

Fig. 3.30 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2-LAYER
Latitude 0°. Metric Units. Fig. 11(b) of Ref. 3.20.
(Continued)



(c) Height (140 to 400 Km) vs Density Ratio

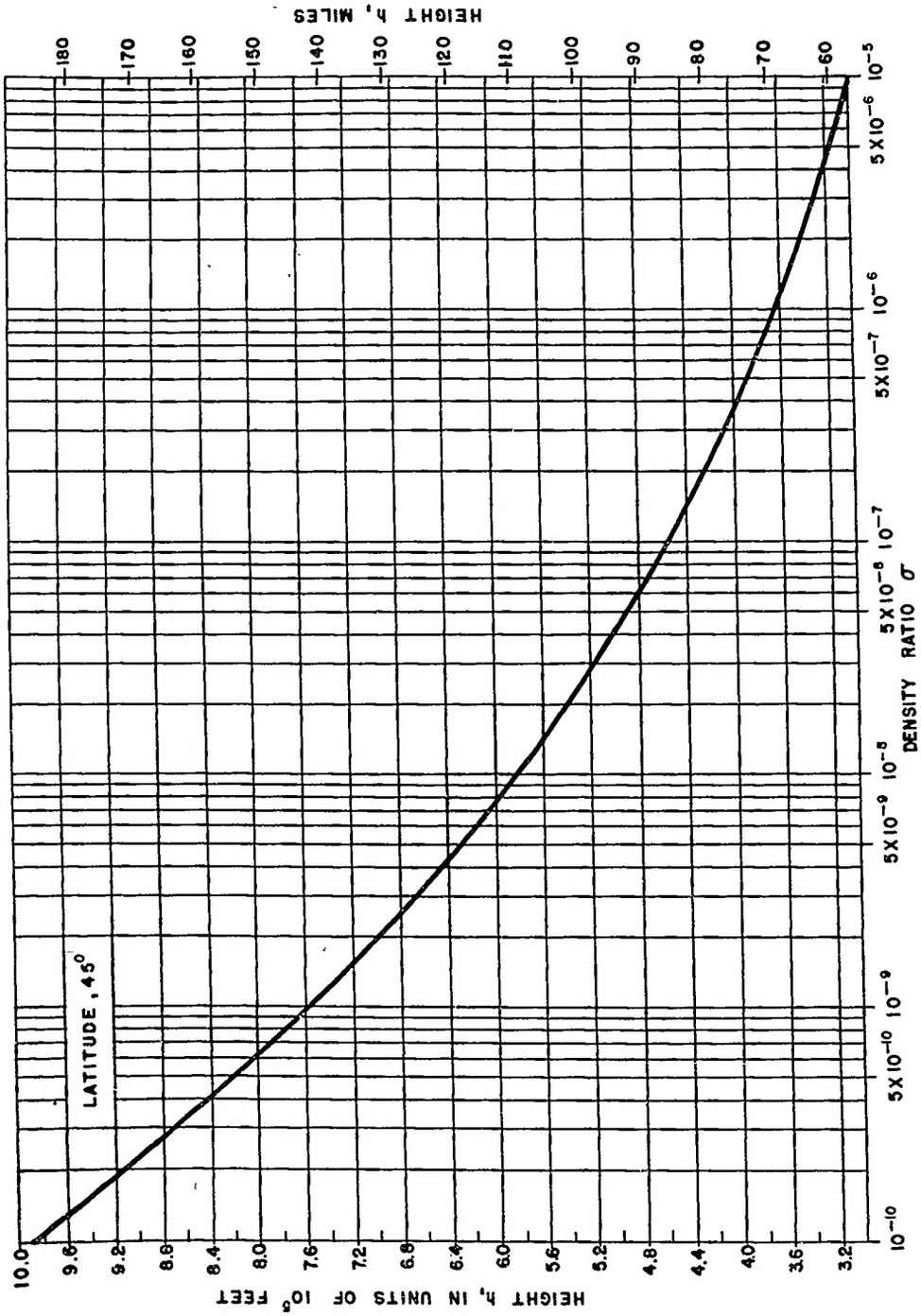
Fig. 3.30 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2-LAYER
Latitude 0°. Metric Units. Fig. 11(c) of Ref. 3.20.
(Concluded)



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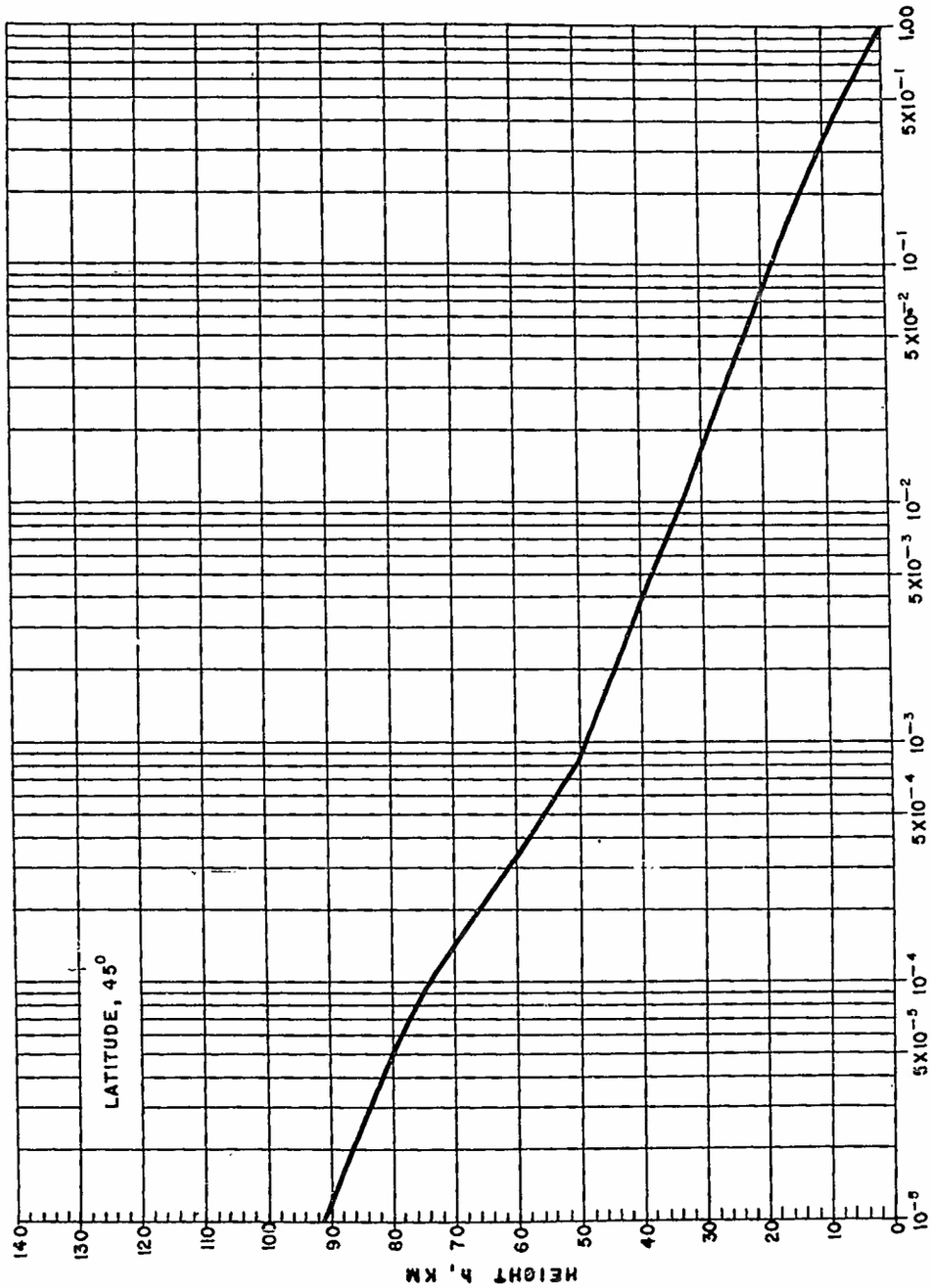
(a) Height (0 to 3.0 x 10^5 feet) vs Density Ratio

Fig. 3.31 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2-LAYER
Latitude 45°. Engineering Units. Fig. 12(a) of Ref. 3.20.



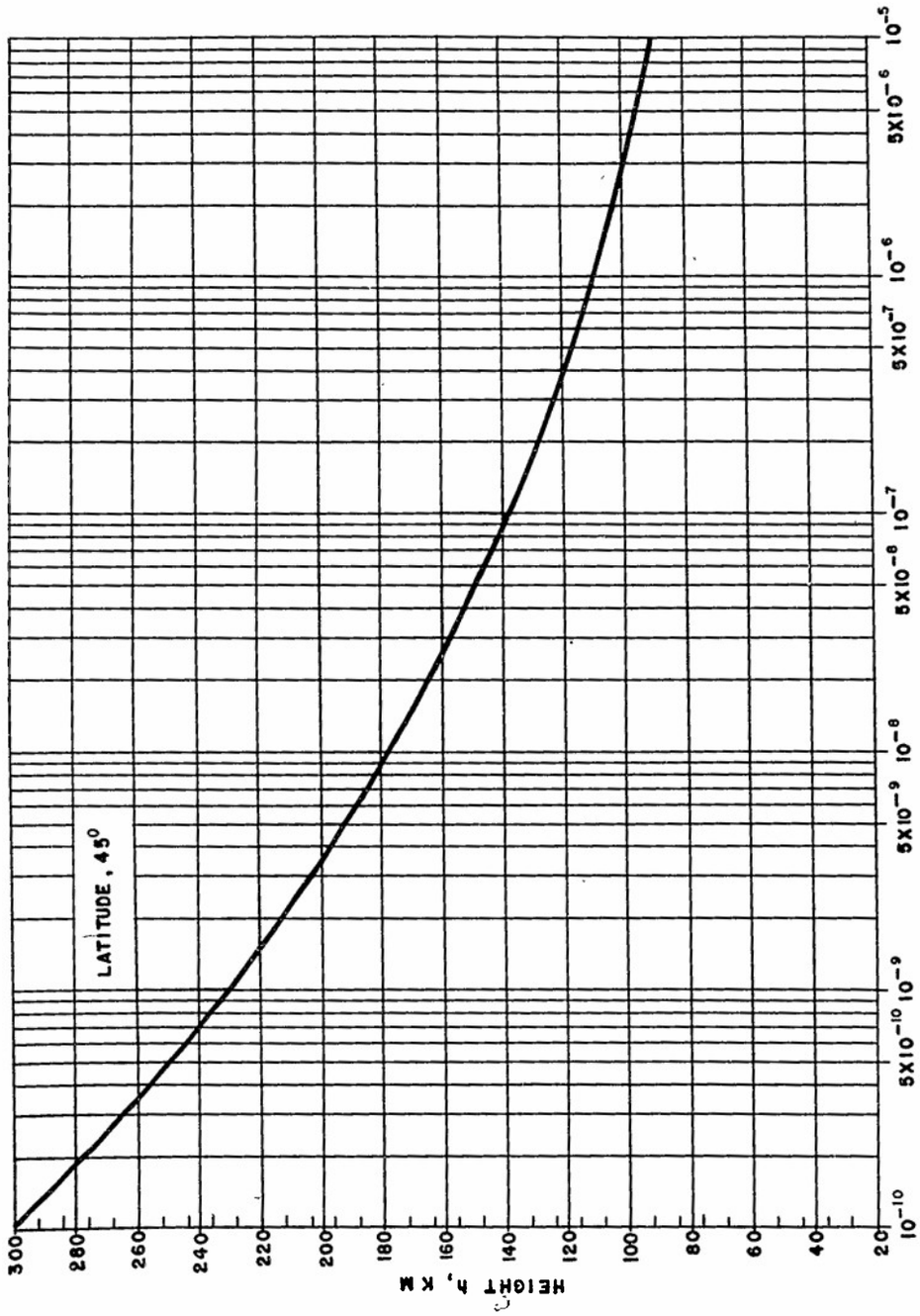
(b) Height (3.0 x 10⁵ to 9.9 x 10⁵ feet) vs Density Ratio

Fig. 3.31 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2-LAYER
Latitude 45°. Engineering Units. Fig. 12(b) of Ref. 3.20.
(Concluded)



(a) Height (0 to 91 Km) vs Density Ratio

Fig. 3.32 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2-LAYER
Latitude 45°. Metric Units. Fig. 13(a) of Ref. 3.20.



(b) Height (90 to 300 Km) vs Density Ratio

Fig. 3.32 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM SEA LEVEL UP TO THE F_2-LAYER
Latitude 45°. Metric Units. Fig. 13(b) of Ref. 3.20.
(Concluded)

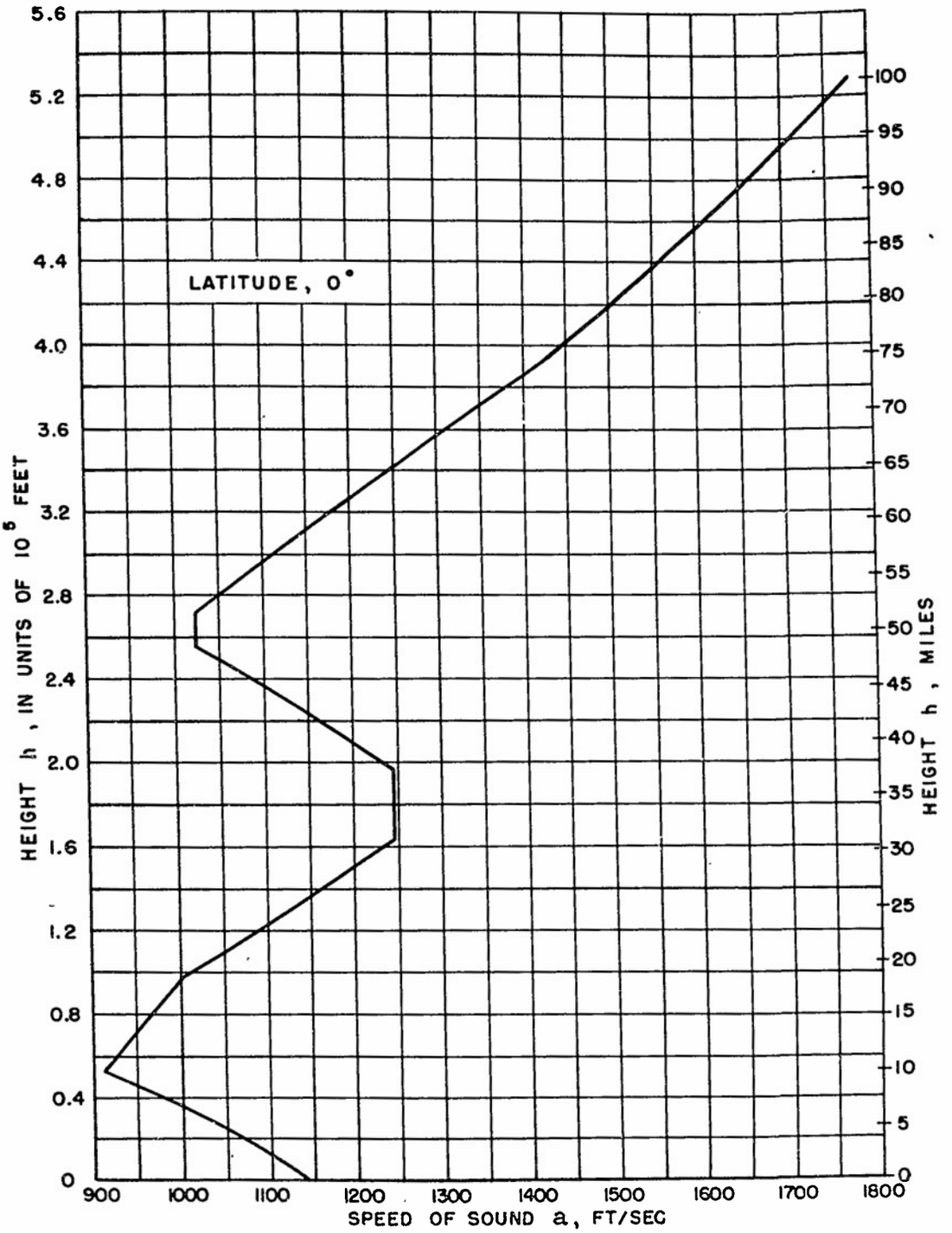


Fig. 3.33 VERTICAL DISTRIBUTION OF THE SONIC VELOCITY FROM SEA LEVEL UP TO 100 MILES
Latitude 0°. Engineering Units. Fig. 14 of Ref. 3.20.

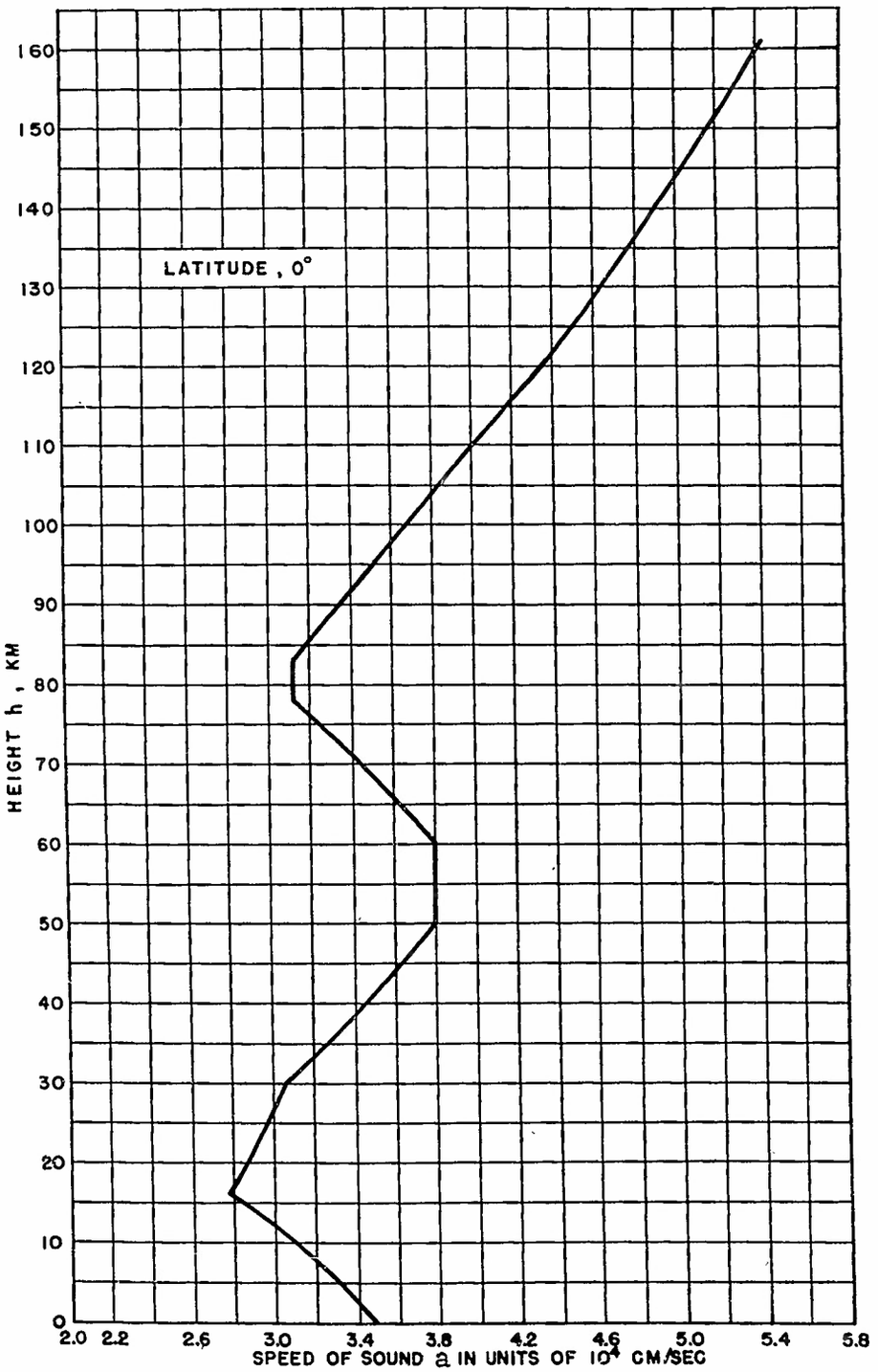


Fig. 3.34 VERTICAL DISTRIBUTION OF THE SONIC VELOCITY FROM SEA LEVEL UP TO 160 KM
Latitude 0°. Metric Units. Fig. 15 of Ref. 3.20.

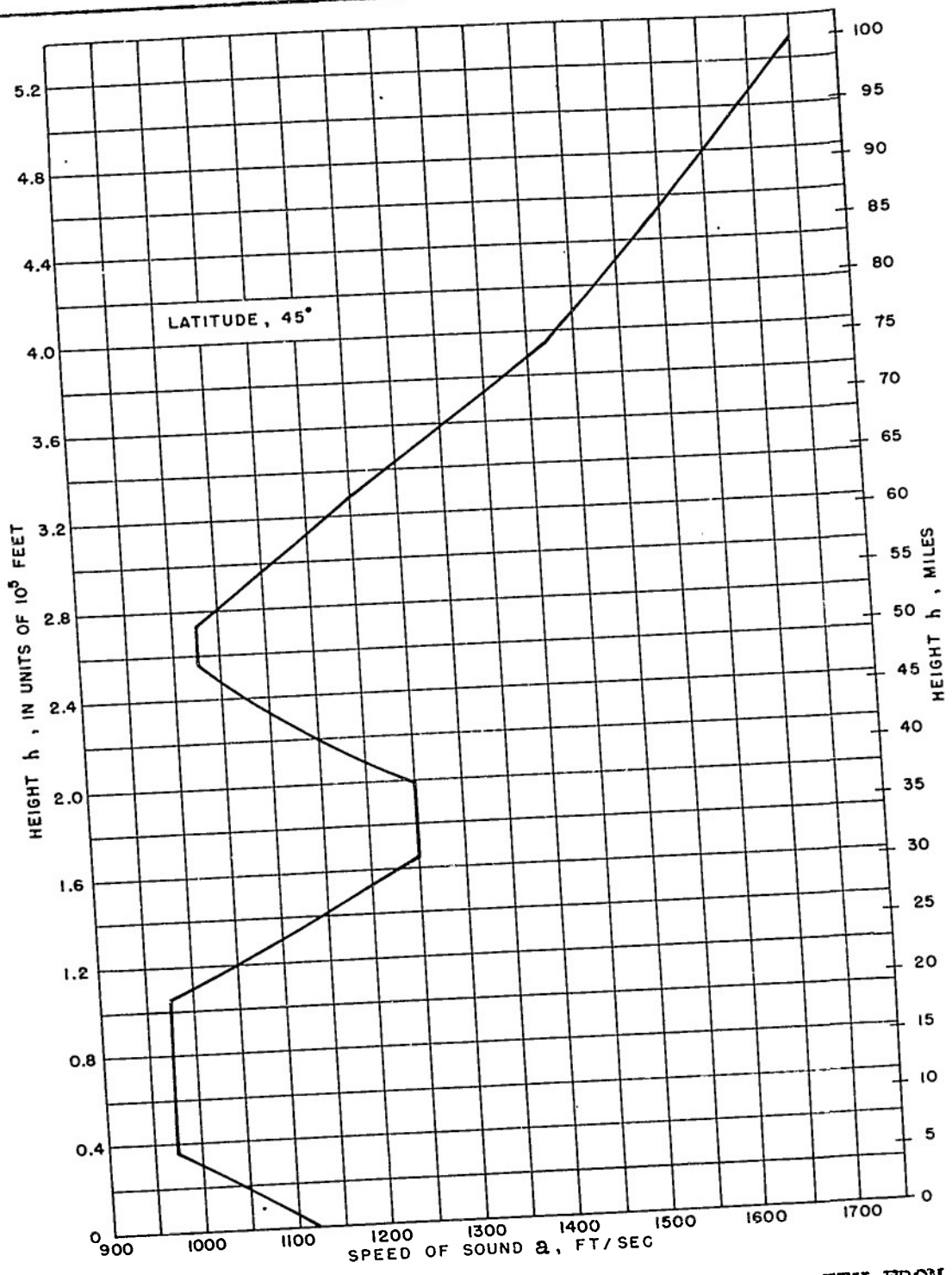


Fig. 3.35 VERTICAL DISTRIBUTION OF THE SONIC VELOCITY FROM SEA LEVEL UP TO 100 MILES
Latitude 45°. Engineering Units. Fig. 16 of Ref. 3.20.

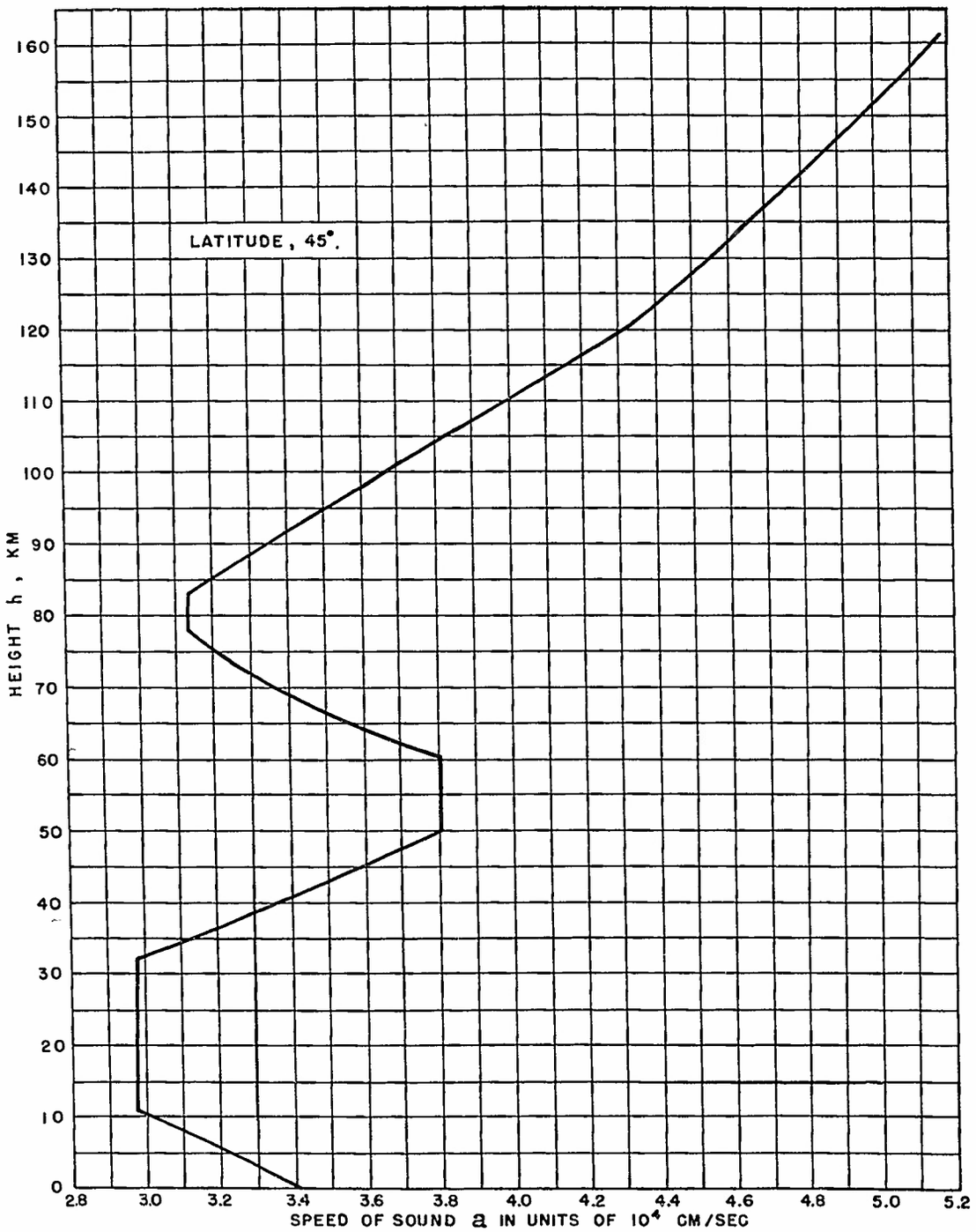


Fig. 3.36 VERTICAL DISTRIBUTION OF THE SONIC VELOCITY FROM SEA LEVEL UP TO 160 KM
Latitude 45°. Metric Units. Fig. 17 of Ref. 3.20.

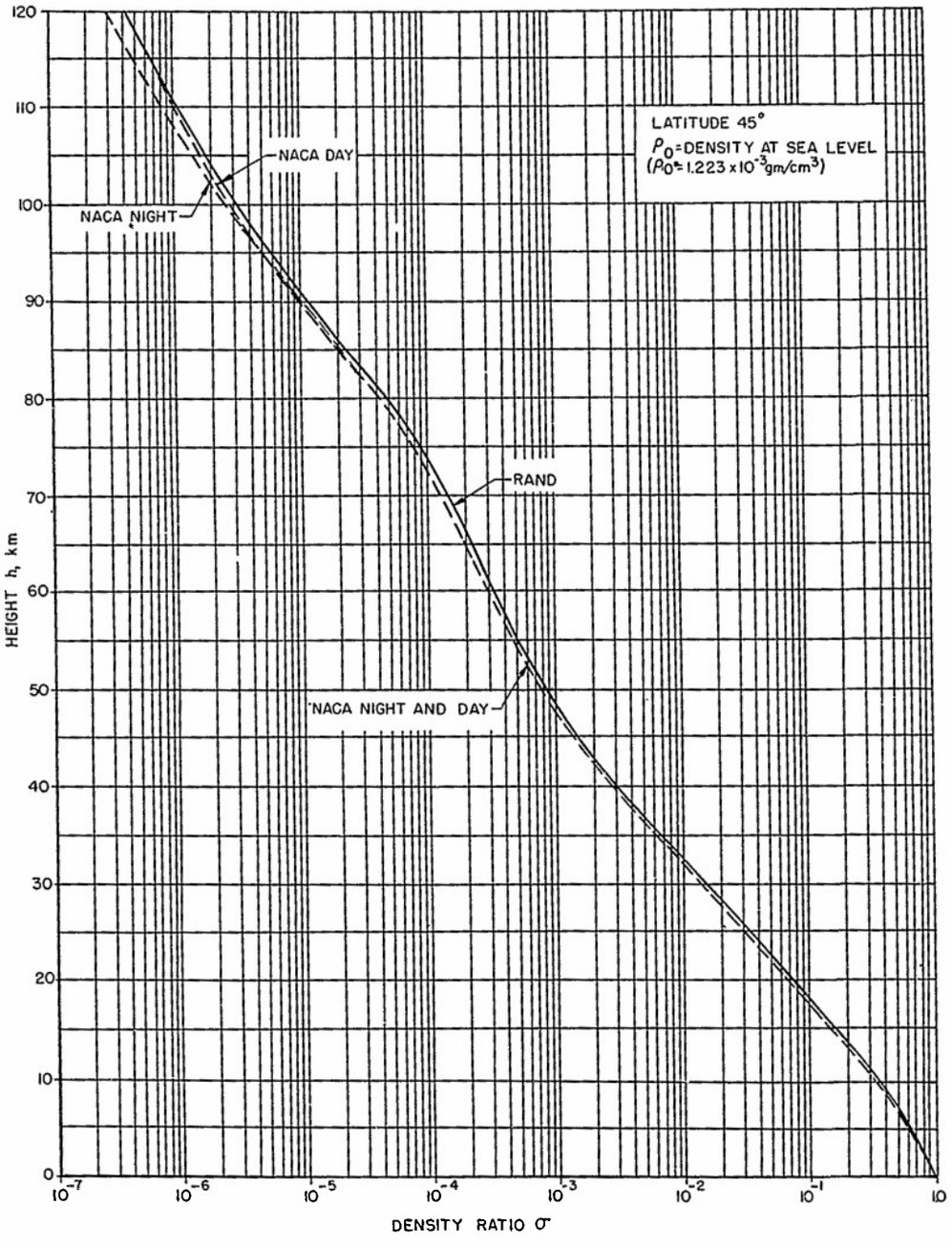


Fig. 3.37 VERTICAL DISTRIBUTION OF DENSITY RATIO (σ) FROM SEA LEVEL UP TO 120 KM
Latitude 45°. Metric Units. Fig. 39 of Ref. 3.20.

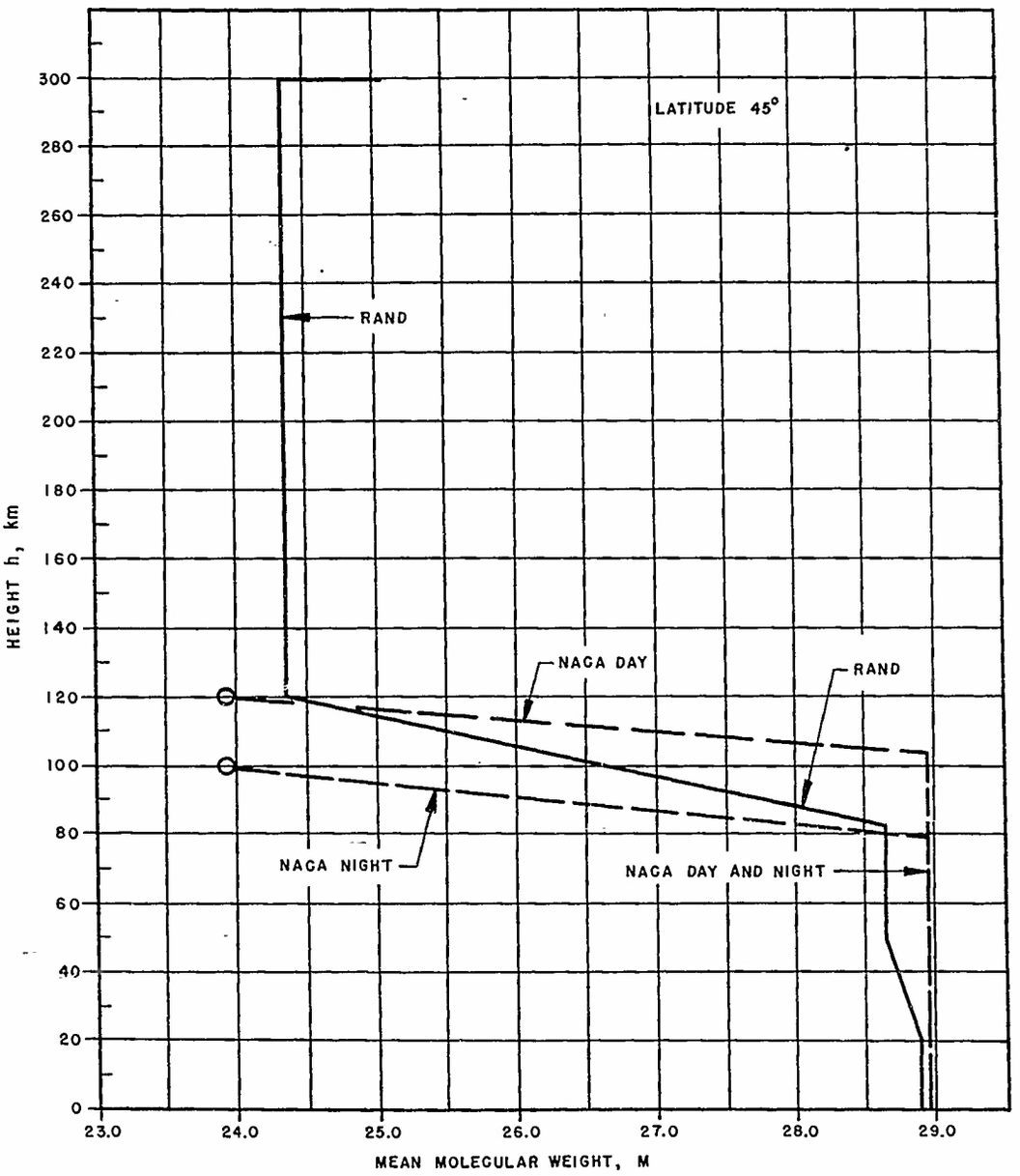


Fig. 3.38 VERTICAL DISTRIBUTION OF MEAN MOLECULAR WEIGHT FROM SEA LEVEL UP TO THE F_2-LAYER
Latitude 45°. Metric Units. Fig. 40 of Ref. 3.20.

c. The atmosphere above the F_2-layer.

Above the F_2-layer there is little if any information available concerning the atmosphere. Although the mass of atmosphere in this region is extremely small compared to the total atmospheric mass, yet the vertical extent of this region of the atmosphere may be relatively large compared to the height of the F_2-layer. In fact, as far as the knowledge of the atmosphere is concerned, it might well be divided into two major regions, the region below the F_2-layer and that above.

In view of the uncertainties and lack of information concerning the properties of the atmosphere above the F_2-layer, it becomes necessary to analyze this region on the basis of whatever concepts or hypotheses appear reasonable or possible; and it is hardly likely, owing to the present lack of knowledge, that any single concept would prove entirely satisfactory at the present time. The manner in which this region of the atmosphere is analyzed here is based on three different atmospheric models or concepts which are intended to serve as a preliminary approach to the problem.

The first atmospheric model is based on the concept that there is a limiting region far beyond the F_2-layer where the atmosphere is in thermal equilibrium with the interstellar gas.

The second model is based on the concept that at a sufficient height (h_*) above the F_2-layer the particles begin to move as free bodies in a gravitational field, rising and falling over large distances without colliding with another particle, and that this region is isothermal.

In Model III an attempt is made to combine the idea of an isothermal dynamical orbit region - used in Model II - with the effects of diffusion equilibrium, treating the latter on a more rational basis than was employed for Model I. Further consideration will be given to the temperature above the F_2-layer and, in particular, to the temperature T_* of the dynamical orbit region and the height h_* where it may be considered to begin.

Editor's Note: In the RAND Report (Ref. 3.20) evidence is presented and calculations made which, for Model I, lead to the values set forth in Tables 3.17-3.20 and Figures 3.39-3.46. For Model II, the values are as given in Tables 3.21-3.24 and Figures 3.48-3.51. For Model III, the values are given in Tables 3.25-3.28 and Figures 3.52-3.57. For Model I, we present here only those data which arise from $M_L = 7$, where M_L denotes the molecular weight of the atmosphere at its outer limit. $M_L = 7$ corresponds to a composition state of the atmosphere at its outer limit in which there is diffusion equilibrium, hydrogen and helium are absent and nitrogen is dissociated and ionized. For the effect of different values of M_L on density ratio see Figure 3.47.

Height h		Potential Φ	Apparent Gravity g'	Mean Mol Wt M	Temp T	Scale Height H	Pressure p	Pressure Ratio p/p_0	Density ρ	Density Ratio σ	Number Density n	Mean Particle Speed v	$d = 3\times10^{-8}$ cm		$d = 2\times10^{-8}$ cm	
													Mean Free Path λ	Mean Collision Freq f	Mean Free Path λ	Mean Collision Freq f
mi	ft	ft-lb	ft/sec^2		°R	ft	lb/ft^2		slug/ft^2	ρ/ρ_0	particles/ft^3	ft/sec	ft	1/sec	ft	1/sec
248.6	1.312×10^6	0.000	28.393	24.00	3,240	2.362×10^5	4.33×10^{-7}	2.05×10^{-10}	6.46×10^{-14}	2.83×10^{-11}	2.38×10^{13}	4.13×10^2	9.77×10^3	4.23×10^{-1}	2.20×10^4	1.88×10^{-1}
300	1.584×10^6	7.613×10^6	27.719	23.70	3,498	2.645×10^5	1.46×10^{-7}	6.90×10^{-11}	1.99×10^{-14}	8.71×10^{-12}	7.43×10^{12}	4.32×10^2	3.13×10^4	1.38×10^{-1}	7.04×10^4	6.14×10^{-2}
350	1.848×10^6	1.484×10^7	27.078	23.42	3,743	2.932×10^5	5.67×10^{-8}	2.68×10^{-11}	7.14×10^{-15}	3.12×10^{-12}	2.70×10^{12}	4.50×10^2	8.61×10^4	5.23×10^{-2}	1.94×10^5	2.32×10^{-2}
400	2.112×10^6	2.191×10^7	26.459	23.14	3,983	3.232×10^5	2.41×10^{-8}	1.14×10^{-11}	2.82×10^{-15}	1.23×10^{-12}	1.08×10^{12}	4.67×10^2	2.15×10^5	2.17×10^{-2}	4.84×10^5	9.64×10^{-3}
450	2.376×10^6	2.881×10^7	25.861	22.87	4,217	3.542×10^5	1.10×10^{-8}	5.20×10^{-12}	1.20×10^{-15}	5.25×10^{-12}	4.64×10^{11}	4.83×10^2	5.01×10^5	9.64×10^{-2}	1.13×10^6	4.28×10^{-2}
500	2.640×10^6	3.557×10^7	25.284	22.61	4,447	3.864×10^5	5.40×10^{-9}	2.55×10^{-12}	5.53×10^{-16}	2.42×10^{-12}	2.16×10^{11}	4.99×10^2	1.08×10^6	4.64×10^{-2}	2.42×10^6	2.06×10^{-2}
600	3.168×10^6	4.862×10^7	24.184	22.10	4,889	4.544×10^5	1.53×10^{-9}	7.23×10^{-13}	1.39×10^{-16}	6.08×10^{-14}	5.57×10^{10}	5.29×10^2	4.17×10^6	1.27×10^{-2}	9.39×10^6	5.63×10^{-4}
700	3.696×10^6	6.112×10^7	23.155	21.61	5,313	5.275×10^5	5.21×10^{-10}	2.46×10^{-13}	4.27×10^{-17}	1.87×10^{-14}	1.75×10^{10}	5.58×10^2	1.33×10^7	4.20×10^{-4}	2.99×10^7	1.87×10^{-4}
800	4.224×10^6	7.309×10^7	22.190	21.14	5,719	6.056×10^5	2.05×10^{-10}	9.69×10^{-14}	1.53×10^{-17}	6.69×10^{-15}	6.40×10^9	5.85×10^2	3.63×10^7	1.61×10^{-4}	8.17×10^7	7.16×10^{-5}
900	4.752×10^6	8.457×10^7	21.284	20.70	6,109	6.888×10^5	9.03×10^{-11}	4.27×10^{-14}	6.16×10^{-18}	2.69×10^{-15}	2.63×10^9	6.11×10^2	8.84×10^7	6.91×10^{-5}	1.99×10^8	3.07×10^{-5}
1,000	5.280×10^6	9.559×10^7	20.432	20.27	6,482	7.775×10^5	4.39×10^{-11}	2.08×10^{-14}	2.76×10^{-18}	1.21×10^{-15}	1.20×10^9	6.36×10^2	1.92×10^8	3.31×10^{-6}	4.32×10^8	1.47×10^{-5}
1,200	6.336×10^6	1.163×10^8	18.904	19.46	7,185	9.702×10^5	1.30×10^{-11}	6.15×10^{-15}	7.09×10^{-19}	3.10×10^{-16}	3.22×10^8	6.83×10^2	7.22×10^8	9.46×10^{-6}	1.62×10^8	4.20×10^{-6}
1,400	7.392×10^6	1.356×10^8	17.520	18.70	7,840	1.189×10^6	4.87×10^{-12}	2.30×10^{-15}	2.34×10^{-19}	1.02×10^{-16}	1.11×10^9	7.28×10^2	2.09×10^8	3.48×10^{-6}	4.71×10^8	1.55×10^{-6}
1,500	7.920×10^6	1.446×10^8	16.885	18.35	8,145	1.306×10^6	3.19×10^{-12}	1.51×10^{-15}	1.45×10^{-19}	6.34×10^{-17}	6.99×10^7	7.49×10^2	3.33×10^8	2.25×10^{-6}	7.48×10^8	1.00×10^{-6}
1,750	9.240×10^6	1.659×10^8	15.440	17.52	8,867	1.628×10^6	1.29×10^{-12}	6.10×10^{-16}	5.13×10^{-20}	2.24×10^{-17}	2.59×10^7	8.00×10^2	8.98×10^8	8.91×10^{-7}	2.02×10^{10}	3.96×10^{-7}
2,000	1.056×10^7	1.854×10^8	14.173	16.76	9,529	1.993×10^6	6.20×10^{-13}	2.93×10^{-16}	2.20×10^{-20}	9.62×10^{-18}	1.16×10^7	8.48×10^3	2.00×10^{10}	4.23×10^{-7}	4.51×10^{10}	1.88×10^{-7}
2,500	1.320×10^7	2.200×10^8	12.720	15.40	10,703	2.714×10^6	2.05×10^{-13}	9.69×10^{-17}	5.94×10^{-21}	2.60×10^{-18}	3.41×10^6	9.38×10^3	6.82×10^{10}	1.38×10^{-7}	1.53×10^{11}	6.12×10^{-8}
3,000	1.584×10^7	2.495×10^8	10.398	14.25	11,703	3.924×10^6	9.32×10^{-14}	4.41×10^{-17}	2.28×10^{-21}	9.97×10^{-19}	1.42×10^6	1.02×10^4	1.64×10^{11}	6.23×10^{-8}	3.68×10^{11}	2.77×10^{-8}
4,000	2.112×10^7	2.975×10^8	7.953	12.38	13,331	6.721×10^6	3.32×10^{-14}	1.57×10^{-17}	6.21×10^{-22}	2.72×10^{-19}	4.44×10^5	1.17×10^5	5.24×10^{11}	2.23×10^{-8}	1.18×10^{12}	9.93×10^{-9}
5,000	2.640×10^7	3.349×10^8	6.281	10.92	14,600	1.057×10^7	1.78×10^{-14}	8.42×10^{-18}	2.68×10^{-22}	1.17×10^{-19}	2.17×10^2	1.30×10^4	1.07×10^{12}	1.21×10^{-8}	2.41×10^{12}	5.39×10^{-9}
6,000	3.168×10^7	3.647×10^8	5.086	9.75	15,611	1.564×10^7	1.18×10^{-14}	5.58×10^{-18}	1.48×10^{-22}	6.47×10^{-20}	1.34×10^3	1.42×10^4	1.73×10^{12}	8.19×10^{-9}	3.90×10^{12}	3.64×10^{-9}
7,000	3.696×10^7	3.891×10^8	4.203	8.80	16,439	2.208×10^7	8.85×10^{-15}	4.18×10^{-18}	9.54×10^{-23}	4.17×10^{-20}	9.59×10^4	1.54×10^4	2.42×10^{12}	6.35×10^{-9}	5.45×10^{12}	2.82×10^{-9}
8,000	4.224×10^7	4.095×10^8	3.531	8.00	17,131	3.013×10^7	7.21×10^{-15}	3.41×10^{-18}	6.78×10^{-23}	2.97×10^{-20}	7.50×10^4	1.65×10^4	3.10×10^{12}	5.32×10^{-9}	6.97×10^{12}	2.37×10^{-9}
9,000	4.752×10^7	4.267×10^8	3.009	7.33	17,714	3.990×10^7	6.19×10^{-15}	2.93×10^{-18}	5.16×10^{-23}	2.26×10^{-20}	6.23×10^4	1.75×10^4	3.73×10^{12}	4.69×10^{-9}	8.40×10^{12}	2.08×10^{-9}
9,553	5.044×10^7	4.351×10^8	2.768	7.00	18,000	4.615×10^7	5.78×10^{-15}	2.73×10^{-18}	4.43×10^{-23}	1.94×10^{-20}	5.66×10^4	1.80×10^4	4.11×10^{12}	4.38×10^{-9}	9.24×10^{12}	1.95×10^{-9}

1 lb/ft^2 = 0.3591 mm of Hg

Table 3.17 ATMOSPHERIC MODEL I. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER, BASED ON $M_L = 7$ Latitude 0°. Engineering Units. $p_0 = 2115$ lb/ft^2, $\rho_0 = 2.286 \times 10^{-3}$ slug/ft^3. Table 21 of Ref. 3.20.

Height h km	Height h mi	Potential ϕ ergs	Apparent Gravity g' cm/sec^2	Mean Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm^3	Density Ratio σ ρ/ρ_0	Number Density n particles/cm^3	Mean Particle Speed $\bar{v}$ cm/sec	$d = 3 \times 10^{-8}$cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$cm: Mean Collision Freq f 1/sec
400.0	248.6	0	865.42	24.00	1800	7.199×10	2.07×10^{-7}	2.05×10^{-10}	3.33×10^{-14}	2.83×10^{-11}	8.40×10^{5}	1.26×10^{5}	2.98×10^{5}	4.23×10^{-1}	6.70×10^{5}	1.88×10^{-1}
482.8	300	1.032×10^{14}	845.18	23.70	1943	8.062×10	6.99×10^{-8}	6.90×10^{-11}	1.02×10^{-14}	8.71×10^{-12}	2.62×10^{5}	1.32×10^{5}	9.54×10^{5}	1.38×10^{-1}	2.15×10^{5}	6.14×10^{-2}
563.3	350	2.012×10^{14}	825.69	23.42	2079	8.937×10	2.72×10^{-8}	2.68×10^{-11}	3.68×10^{-15}	3.12×10^{-12}	9.54×10^{4}	1.37×10^{5}	2.62×10^{5}	5.23×10^{-2}	5.90×10^{5}	2.32×10^{-2}
643.8	400	2.971×10^{14}	807.76	23.14	2213	9.850×10	1.15×10^{-8}	1.14×10^{-11}	1.45×10^{-15}	1.23×10^{-12}	3.81×10^{4}	1.42×10^{5}	6.56×10^{5}	2.17×10^{-2}	1.48×10^{6}	9.64×10^{-3}
724.2	450	3.907×10^{14}	788.69	22.87	2343	1.080×10^{2}	5.27×10^{-9}	5.20×10^{-12}	6.18×10^{-16}	5.25×10^{-13}	1.64×10^{4}	1.47×10^{5}	1.53×10^{6}	9.64×10^{-3}	3.44×10^{6}	4.28×10^{-3}
804.7	500	4.823×10^{14}	771.11	22.61	2471	1.178×10^{2}	2.59×10^{-9}	2.55×10^{-12}	2.85×10^{-16}	2.42×10^{-13}	7.63×10^{3}	1.52×10^{5}	3.28×10^{6}	4.64×10^{-3}	7.38×10^{6}	2.06×10^{-3}
965.6	600	6.593×10^{14}	737.68	22.10	2716	1.385×10^{2}	7.33×10^{-10}	7.23×10^{-13}	7.16×10^{-17}	6.08×10^{-14}	1.97×10^{3}	1.61×10^{5}	1.27×10^{7}	1.27×10^{-2}	2.86×10^{7}	5.63×10^{-4}
1127	700	8.288×10^{14}	706.37	21.61	2952	1.608×10^{2}	2.50×10^{-10}	2.46×10^{-13}	2.20×10^{-17}	1.87×10^{-14}	6.18×10^{2}	1.70×10^{5}	4.05×10^{7}	4.20×10^{-4}	9.11×10^{7}	1.87×10^{-4}
1287	800	9.911×10^{14}	677.02	21.14	3177	1.846×10^{2}	9.82×10^{-11}	9.69×10^{-14}	7.88×10^{-18}	6.69×10^{-15}	2.26×10^{2}	1.78×10^{5}	1.11×10^{7}	1.61×10^{-4}	2.49×10^{7}	7.16×10^{-5}
1448	900	1.147×10^{15}	649.46	20.70	3394	2.100×10^{2}	4.32×10^{-11}	4.27×10^{-14}	3.17×10^{-18}	2.69×10^{-15}	9.29×10^{1}	1.86×10^{5}	2.69×10^{7}	6.91×10^{-5}	6.06×10^{7}	3.07×10^{-5}
1609	1000	1.296×10^{15}	623.56	20.27	3601	2.370×10^{2}	2.10×10^{-11}	2.08×10^{-14}	1.42×10^{-18}	1.21×10^{-15}	4.24×10^{1}	1.94×10^{5}	5.86×10^{7}	3.31×10^{-5}	1.32×10^{8}	1.47×10^{-5}
1931	1200	1.577×10^{15}	576.19	19.46	3992	2.957×10^{2}	6.23×10^{-12}	6.15×10^{-15}	3.65×10^{-19}	3.10×10^{-16}	1.14×10^{1}	2.08×10^{5}	2.20×10^{8}	9.46×10^{-6}	4.95×10^{8}	4.20×10^{-6}
2253	1400	1.839×10^{15}	534.02	18.70	4356	3.623×10^{2}	2.33×10^{-12}	2.30×10^{-15}	1.21×10^{-19}	1.02×10^{-16}	3.92×10^{0}	2.22×10^{5}	6.38×10^{8}	3.48×10^{-6}	1.44×10^{9}	1.55×10^{-6}
2414	1500	1.961×10^{15}	514.65	18.35	4525	3.980×10^{2}	1.53×10^{-12}	1.51×10^{-15}	7.47×10^{-20}	6.34×10^{-17}	2.47×10^{0}	2.28×10^{5}	1.01×10^{9}	2.25×10^{-6}	2.28×10^{9}	1.00×10^{-6}
2816	1750	2.250×10^{15}	470.61	17.52	4926	4.963×10^{2}	6.18×10^{-13}	6.10×10^{-16}	2.64×10^{-20}	2.24×10^{-17}	9.15×10^{-1}	2.44×10^{5}	2.74×10^{9}	8.91×10^{-7}	6.15×10^{9}	3.96×10^{-7}
3219	2000	2.514×10^{15}	432.00	16.76	5294	6.074×10^{2}	2.97×10^{-13}	2.93×10^{-16}	1.13×10^{-20}	9.62×10^{-18}	4.10×10^{-1}	2.58×10^{5}	6.11×10^{9}	4.23×10^{-7}	1.37×10^{10}	1.88×10^{-7}
4023	2500	2.983×10^{15}	387.73	15.40	5946	8.273×10^{2}	9.82×10^{-14}	9.69×10^{-17}	3.06×10^{-21}	2.60×10^{-18}	1.20×10^{-1}	2.86×10^{5}	2.08×10^{10}	1.38×10^{-7}	4.68×10^{10}	6.12×10^{-8}
4828	3000	3.383×10^{15}	316.92	14.25	6502	1.196×10^{2}	4.46×10^{-14}	4.41×10^{-17}	1.17×10^{-21}	9.97×10^{-19}	5.01×10	3.11×10^{5}	4.99×10^{10}	6.23×10^{-8}	1.12×10^{11}	2.77×10^{-8}
6437	4000	4.034×10^{15}	242.42	12.38	7406	2.048×10^{3}	1.59×10^{-14}	1.57×10^{-17}	3.20×10^{-22}	2.72×10^{-19}	1.57×10	3.57×10^{5}	1.60×10^{10}	2.23×10^{-8}	3.59×10^{11}	9.93×10^{-9}
8047	5000	4.541×10^{15}	191.44	10.92	8111	3.223×10^{3}	8.52×10^{-15}	8.42×10^{-18}	1.38×10^{-22}	1.17×10^{-19}	7.66	3.96×10^{5}	3.26×10^{10}	1.21×10^{-8}	7.35×10^{11}	5.39×10^{-9}
9656	6000	4.945×10^{15}	155.02	9.75	8673	4.767×10^{3}	5.65×10^{-15}	5.58×10^{-18}	7.62×10^{-23}	6.47×10^{-20}	4.73	4.33×10^{5}	5.29×10^{10}	8.19×10^{-8}	1.19×10^{11}	3.64×10^{-8}
11,266	7000	5.276×10^{15}	128.10	8.80	9133	6.730×10^{3}	4.24×10^{-15}	4.18×10^{-18}	4.91×10^{-23}	4.17×10^{-20}	3.39	4.69×10^{5}	7.39×10^{10}	6.35×10^{-8}	1.66×10^{11}	2.82×10^{-8}
12,875	8000	5.553×10^{15}	107.63	8.00	9517	9.182×10^{3}	3.45×10^{-15}	3.41×10^{-18}	3.49×10^{-23}	2.97×10^{-20}	2.65	5.03×10^{5}	9.45×10^{10}	5.32×10^{-8}	2.13×10^{11}	2.37×10^{-8}
14,484	9000	5.786×10^{15}	91.70	7.33	9841	1.216×10^{4}	2.96×10^{-15}	2.93×10^{-18}	2.66×10^{-22}	2.26×10^{-20}	2.20	5.33×10^{5}	1.14×10^{11}	4.69×10^{-8}	2.56×10^{11}	2.08×10^{-8}
15,374	9553	5.903×10^{15}	84.38	7.00	10,000	1.407×10^{4}	2.71×10^{-15}	2.73×10^{-18}	2.28×10^{-23}	1.94×10^{-20}	2.00	5.50×10^{5}	1.25×10^{11}	4.38×10^{-8}	2.82×10^{11}	1.95×10^{-8}

1 millibar (mb) = 10^2 dynes/cm^2 = 0.750 mm of Hg

Table 3.18 ATMOSPHERIC MODEL I. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER, BASED ON $M_L = 7$
Latitude 0°. Metric Units. $p_0 = 1013$ mb, $\rho_0 = 1.178 \times 10^{-3}$ gm/cm^3. Table 24 of Ref. 3.20.

Height h mi	Height h ft	Potential ϕ ft-lb	Apparent Gravity g' ft/sec^2	Mean Mol Wt M	Temp T °R	Scale Height H ft	Pressure p lb/ft^2	Pressure Ratio p/p_0	Density ρ slug/ft^3	Density Ratio σ ρ/ρ_0	Number Density n particles/ft^3	Mean Particle Speed $\bar{v}$ ft/sec	$d = 3 \times 10^{-8}$cm: Mean Free Path λ ft	$d = 3 \times 10^{-8}$cm: Collision Freq f 1/sec	$d = 2 \times 10^{-8}$cm: Mean Free Path λ ft	$d = 2 \times 10^{-8}$cm: Collision Freq f 1/sec
186.41	9.842×10^5	0	29.308	24.35	1980	1.378×10^5	1.01×10^{-6}	4.77×10^{-10}	2.50×10^{-13}	1.05×10^{-10}	9.09×10^{10}	3.21×10^3	2.56×10^3	1.26	5.75×10^3	5.58×10^{-1}
200	1.056×10^6	2.098×10^6	29.117	24.25	2072	1.458×10^5	6.07×10^{-7}	2.87×10^{-10}	1.43×10^{-13}	6.02×10^{-11}	5.22×10^{12}	3.29×10^3	4.45×10^3	7.39×10^{-1}	1.00×10^4	3.28×10^{-1}
225	1.188×10^6	5.922×10^6	28.769	24.07	2239	1.606×10^5	2.56×10^{-7}	1.21×10^{-10}	5.54×10^{-14}	2.33×10^{-11}	2.04×10^{12}	3.43×10^3	1.14×10^4	3.01×10^{-1}	2.56×10^4	1.34×10^{-1}
250	1.320×10^6	9.700×10^6	28.427	23.89	2404	1.758×10^5	1.17×10^{-7}	5.53×10^{-11}	2.34×10^{-14}	9.85×10^{-12}	8.67×10^{12}	3.57×10^3	2.68×10^4	1.33×10^{-1}	6.03×10^4	5.92×10^{-2}
275	1.452×10^6	1.343×10^7	28.091	23.71	2567	1.915×10^5	5.68×10^{-8}	2.68×10^{-11}	1.06×10^{-14}	4.46×10^{-12}	3.96×10^{12}	3.70×10^3	5.87×10^4	6.30×10^{-3}	1.32×10^5	2.80×10^{-2}
300	1.584×10^6	1.712×10^7	27.762	23.54	2728	2.074×10^5	2.93×10^{-8}	1.38×10^{-11}	5.09×10^{-15}	2.14×10^{-12}	1.91×10^{12}	3.83×10^3	1.22×10^5	3.15×10^{-3}	2.74×10^5	1.40×10^{-2}
350	1.848×10^6	2.438×10^7	27.119	23.20	3045	2.404×10^5	8.96×10^{-9}	4.23×10^{-12}	1.37×10^{-15}	5.77×10^{-13}	5.23×10^{11}	4.07×10^3	4.44×10^5	9.16×10^{-3}	1.00×10^6	4.07×10^{-2}
400	2.112×10^6	3.146×10^7	26.499	22.86	3354	2.750×10^5	3.21×10^{-9}	1.52×10^{-12}	4.40×10^{-16}	1.85×10^{-13}	1.70×10^{11}	4.31×10^3	1.37×10^6	3.15×10^{-3}	3.08×10^6	1.40×10^{-2}
450	2.376×10^6	3.838×10^7	25.900	22.53	3656	3.112×10^5	1.30×10^{-9}	6.14×10^{-13}	1.61×10^{-16}	6.78×10^{-14}	6.32×10^{10}	4.53×10^3	1.68×10^6	1.23×10^{-3}	8.28×10^6	5.47×10^{-4}
500	2.640×10^6	4.515×10^7	25.320	22.21	3952	3.491×10^5	5.83×10^{-10}	2.75×10^{-13}	6.60×10^{-17}	2.78×10^{-14}	2.63×10^{10}	4.74×10^3	8.84×10^6	5.36×10^{-4}	1.99×10^7	2.38×10^{-4}
600	3.168×10^6	5.825×10^7	24.219	21.59	4524	4.298×10^5	1.49×10^{-10}	7.04×10^{-14}	1.43×10^{-17}	6.02×10^{-15}	5.86×10^9	5.15×10^3	3.97×10^7	1.30×10^{-4}	8.93×10^7	5.77×10^{-5}
700	3.696×10^6	7.078×10^7	23.187	21.00	5072	5.174×10^5	4.85×10^{-11}	2.29×10^{-14}	4.04×10^{-18}	1.70×10^{-15}	1.70×10^9	5.53×10^3	1.37×10^8	4.04×10^{-5}	3.08×10^8	1.80×10^{-5}
800	4.224×10^6	8.278×10^7	22.221	20.43	5596	6.123×10^5	1.90×10^{-11}	8.98×10^{-15}	1.40×10^{-18}	5.89×10^{-16}	6.06×10^8	5.89×10^3	3.84×10^8	1.54×10^{-5}	8.63×10^8	6.82×10^{-6}
900	4.752×10^6	9.430×10^7	21.313	19.89	6099	7.147×10^5	8.52×10^{-12}	4.03×10^{-15}	5.59×10^{-19}	2.35×10^{-16}	2.49×10^8	6.23×10^8	9.30×10^8	6.70×10^{-6}	2.09×10^9	2.98×10^{-6}
1000	5.280×10^6	1.053×10^8	20.460	19.37	6580	8.248×10^5	4.29×10^{-12}	2.03×10^{-15}	2.54×10^{-19}	1.07×10^{-16}	1.16×10^8	6.56×10^3	2.00×10^9	3.24×10^{-6}	4.51×10^9	1.44×10^{-6}
1200	6.336×10^6	1.262×10^8	18.901	18.38	7493	1.068×10^6	1.38×10^{-12}	6.52×10^{-16}	6.81×10^{-20}	2.87×10^{-17}	3.27×10^7	7.18×10^3	7.11×10^9	1.01×10^{-6}	1.60×10^{10}	4.49×10^{-7}
1400	7.392×10^6	1.454×10^8	17.513	17.47	8331	1.353×10^6	5.76×10^{-13}	2.72×10^{-16}	2.43×10^{-20}	1.02×10^{-17}	1.23×10^7	7.77×10^3	1.89×10^{10}	4.11×10^{-7}	4.25×10^{10}	1.83×10^{-7}
1500	7.920×10^6	1.545×10^8	16.876	17.04	8729	1.508×10^6	3.98×10^{-13}	1.88×10^{-16}	1.56×10^{-20}	6.57×10^{-18}	8.10×10^6	8.05×10^3	2.87×10^{10}	2.80×10^{-7}	6.46×10^{10}	1.25×10^{-7}
1750	9.240×10^6	1.759×10^8	15.428	16.03	9663	1.941×10^6	1.83×10^{-13}	8.65×10^{-17}	6.11×10^{-21}	2.57×10^{-18}	3.37×10^6	8.73×10^3	6.90×10^{10}	1.27×10^{-7}	1.55×10^{11}	5.62×10^{-8}
2000	1.056×10^7	1.954×10^8	14.158	15.11	10,515	2.442×10^6	9.99×10^{-14}	4.72×10^{-17}	2.89×10^{-21}	1.22×10^{-18}	1.69×10^6	9.38×10^3	1.38×10^{11}	6.82×10^{-8}	3.09×10^{11}	3.03×10^{-8}
2500	1.320×10^7	2.300×10^8	12.049	13.47	12,027	3.681×10^6	4.12×10^{-14}	1.95×10^{-17}	9.29×10^{-22}	3.91×10^{-19}	6.10×10^5	1.06×10^4	3.81×10^{11}	2.78×10^{-8}	8.57×10^{11}	1.24×10^{-8}
3000	1.584×10^7	2.597×10^8	10.381	12.06	13,324	5.287×10^6	2.25×10^{-14}	1.06×10^{-17}	4.10×10^{-22}	1.73×10^{-19}	3.01×10^5	1.18×10^4	7.72×10^{11}	1.53×10^{-8}	1.74×10^{12}	6.79×10^{-9}
3500	1.848×10^7	2.854×10^8	9.038	10.85	14,446	7.318×10^6	1.47×10^{-14}	6.95×10^{-18}	2.22×10^{-22}	9.35×10^{-20}	1.81×10^5	1.30×10^4	1.28×10^{12}	1.01×10^{-8}	2.89×10^{12}	4.50×10^{-9}
4000	2.112×10^7	3.078×10^8	7.942	9.79	15,425	9.855×10^6	1.08×10^{-14}	5.10×10^{-18}	1.38×10^{-22}	5.81×10^{-20}	1.25×10^5	1.41×10^4	1.86×10^{12}	7.58×10^{-9}	4.18×10^{12}	3.37×10^{-9}
4500	2.376×10^7	3.276×10^8	7.037	8.85	16,290	1.340×10^7	8.52×10^{-15}	4.03×10^{-18}	9.32×10^{-23}	3.92×10^{-20}	9.32×10^4	1.53×10^4	2.49×10^{13}	6.13×10^{-9}	5.61×10^{12}	2.73×10^{-9}
5000	2.640×10^7	3.452×10^8	6.280	8.02	17,059	1.683×10^7	7.12×10^{-15}	3.36×10^{-18}	6.74×10^{-23}	2.84×10^{-20}	7.44×10^4	1.64×10^4	3.12×10^{13}	5.25×10^{-9}	7.03×10^{12}	2.33×10^{-9}
5500	2.904×10^7	3.609×10^8	5.642	7.28	17,744	2.146×10^7	6.19×10^{-15}	2.92×10^{-18}	5.11×10^{-23}	2.15×10^{-20}	6.21×10^4	1.76×10^4	3.74×10^{13}	4.70×10^{-9}	8.42×10^{12}	2.09×10^{-9}
5526	2.917×10^7	3.668×10^8	5.402	7.00	18,000	2.365×10^7	5.78×10^{-15}	2.73×10^{-18}	4.52×10^{-23}	1.91×10^{-20}	5.66×10^4	1.80×10^4	4.11×10^{13}	4.38×10^{-9}	9.24×10^{12}	1.95×10^{-9}

1 lb/ft^2 = 0.3591 mm of Hg

Table 3.19 ATMOSPHERIC MODEL I. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER, BASED ON $M_L = 7$ Latitude 45°. Engineering Units. $p_0 = 2116$ lb/ft^2, $\rho_0 = 2.375 \times 10^{-3}$ slug/ft^3. Table 26 of Ref. 3.20.

Height h km	Height h mi	Potential ϕ ergs	Apparent Gravity g' cm/sec²	Mean Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm³	Density Ratio σ ρ/ρ_0	Number Density n particles/cm³	Mean Particle Speed $\bar{v}$ cm/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec
300.0	186.41	0	893.31	24.35	1100	4.201×10	4.84×10^{-7}	4.77×10^{-10}	1.29×10^{-12}	1.05×10^{-15}	3.21×10^{9}	9.78×10^{4}	7.70×10^{4}	1.26	1.754×10^{5}	5.58×10^{-1}
321.9	200	2.845×10^{13}	887.49	24.25	1151	4.443×10	2.91×10^{-7}	2.87×10^{-10}	7.36×10^{-13}	6.02×10^{-16}	1.84×10^{9}	1.00×10^{5}	1.36×10^{5}	7.39×10^{-1}	3.05×10^{5}	3.28×10^{-1}
362.1	225	8.030×10^{13}	876.88	24.07	1244	4.896×10	1.23×10^{-7}	1.21×10^{-10}	2.85×10^{-13}	2.33×10^{-16}	7.20×10^{8}	1.05×10^{5}	3.47×10^{5}	3.01×10^{-1}	7.82×10^{5}	1.34×10^{-1}
402.3	250	1.315×10^{14}	866.45	23.89	1336	5.360×10	5.60×10^{-8}	5.53×10^{-11}	1.21×10^{-13}	9.85×10^{-17}	3.06×10^{8}	1.09×10^{5}	8.17×10^{5}	1.33×10^{-1}	1.84×10^{6}	5.92×10^{-2}
442.6	275	1.821×10^{14}	856.21	23.71	1426	5.836×10	2.72×10^{-8}	2.68×10^{-11}	5.46×10^{-14}	4.46×10^{-17}	1.40×10^{8}	1.13×10^{5}	1.79×10^{6}	6.30×10^{-2}	4.03×10^{6}	2.80×10^{-2}
482.8	300	2.321×10^{14}	846.19	23.54	1516	6.321×10	1.40×10^{-8}	1.38×10^{-11}	2.62×10^{-14}	2.14×10^{-17}	6.75×10^{7}	1.17×10^{5}	3.71×10^{6}	3.15×10^{-2}	8.35×10^{6}	1.40×10^{-2}
563.3	350	3.306×10^{14}	826.59	23.20	1692	7.328×10	4.29×10^{-9}	4.23×10^{-12}	7.06×10^{-15}	5.77×10^{-18}	1.85×10^{7}	1.24×10^{5}	1.35×10^{7}	9.16×10^{-3}	3.05×10^{7}	4.07×10^{-3}
643.8	400	4.266×10^{14}	807.69	22.86	1863	8.384×10	1.54×10^{-9}	1.52×10^{-12}	2.27×10^{-15}	1.85×10^{-18}	6.00×10^{6}	1.31×10^{5}	4.17×10^{7}	3.15×10^{-2}	9.38×10^{7}	1.40×10^{-2}
724.2	450	5.204×10^{14}	789.43	22.53	2031	9.487×10	6.23×10^{-10}	6.14×10^{-13}	8.29×10^{-16}	6.78×10^{-19}	2.23×10^{6}	1.38×10^{5}	1.12×10^{8}	1.23×10^{-2}	2.52×10^{8}	5.47×10^{-3}
804.7	500	6.122×10^{14}	771.75	22.21	2196	1.064×10^{2}	2.79×10^{-10}	2.75×10^{-13}	3.40×10^{-16}	2.78×10^{-19}	9.29×10^{5}	1.44×10^{5}	2.69×10^{8}	5.36×10^{-3}	6.06×10^{8}	2.38×10^{-3}
965.6	600	7.899×10^{14}	738.20	21.59	2513	1.310×10^{2}	7.14×10^{-11}	7.04×10^{-14}	7.36×10^{-17}	6.02×10^{-20}	2.07×10^{5}	1.57×10^{5}	1.21×10^{9}	1.30×10^{-3}	2.72×10^{9}	5.77×10^{-3}
1127	700	9.598×10^{14}	706.74	21.00	2818	1.577×10^{2}	2.32×10^{-11}	2.29×10^{-14}	2.08×10^{-17}	1.70×10^{-20}	6.00×10^{4}	1.69×10^{5}	4.17×10^{9}	4.04×10^{-3}	9.38×10^{9}	1.80×10^{-3}
1288	800	1.122×10^{15}	677.30	20.43	3109	1.866×10^{2}	9.10×10^{-12}	8.98×10^{-15}	7.21×10^{-18}	5.89×10^{-21}	2.14×10^{4}	1.80×10^{5}	1.17×10^{10}	1.54×10^{-3}	2.63×10^{10}	6.82×10^{-3}
1448	900	1.279×10^{15}	649.62	19.89	3388	2.178×10^{2}	4.08×10^{-12}	4.03×10^{-15}	2.88×10^{-18}	2.35×10^{-21}	8.79×10^{3}	1.90×10^{5}	2.83×10^{10}	6.70×10^{-3}	6.38×10^{10}	2.98×10^{-3}
1609	1000	1.428×10^{15}	623.62	19.37	3656	2.514×10^{2}	2.05×10^{-12}	2.03×10^{-15}	1.31×10^{-18}	1.07×10^{-21}	4.10×10^{2}	2.00×10^{5}	6.11×10^{10}	3.24×10^{-3}	1.37×10^{11}	1.44×10^{-3}
1931	1200	1.711×10^{15}	576.10	18.38	4163	3.254×10^{2}	6.61×10^{-13}	6.52×10^{-16}	3.51×10^{-19}	2.87×10^{-22}	1.15×10^{9}	2.19×10^{5}	2.17×10^{11}	1.01×10^{-3}	4.87×10^{11}	4.49×10^{-3}
2253	1400	1.972×10^{15}	533.80	17.47	4628	4.123×10^{2}	2.76×10^{-13}	2.72×10^{-16}	1.25×10^{-19}	1.02×10^{-22}	4.34×10^{2}	2.37×10^{5}	5.76×10^{11}	4.11×10^{-3}	1.30×10^{12}	1.83×10^{-3}
2414	1500	2.095×10^{15}	514.38	17.04	4849	4.596×10^{2}	1.91×10^{-13}	1.88×10^{-16}	8.03×10^{-20}	6.57×10^{-23}	2.86×10^{2}	2.45×10^{5}	8.75×10^{11}	2.80×10^{-3}	1.97×10^{12}	1.25×10^{-3}
2816	1750	2.385×10^{15}	470.25	16.03	5368	5.916×10^{2}	8.76×10^{-14}	8.65×10^{-17}	3.15×10^{-20}	2.57×10^{-23}	1.19×10^{2}	2.66×10^{5}	2.10×10^{12}	1.27×10^{-3}	4.73×10^{12}	5.62×10^{-3}
3219	2000	2.650×10^{15}	431.54	15.11	5842	7.442×10^{2}	4.78×10^{-14}	4.72×10^{-17}	1.49×10^{-20}	1.22×10^{-23}	5.97 x 10	2.86×10^{5}	4.19×10^{12}	6.82×10^{-3}	9.43×10^{12}	3.03×10^{-3}
4023	2500	3.119×10^{15}	367.25	13.47	6682	1.122×10^{3}	1.97×10^{-14}	1.95×10^{-17}	4.78×10^{-22}	3.91×10^{-25}	2.15×10	3.23×10^{5}	1.16×10^{13}	2.78×10^{-3}	2.61×10^{13}	1.24×10^{-3}
4828	3000	3.522×10^{15}	316.41	12.06	7402	1.612×10^{3}	1.08×10^{-14}	1.06×10^{-17}	2.11×10^{-22}	1.73×10^{-25}	1.06×10	3.60×10^{5}	2.35×10^{13}	1.53×10^{-3}	5.30×10^{13}	6.79×10^{-3}
5633	3500	3.870×10^{15}	275.48	10.85	8026	2.231×10^{3}	7.04×10^{-15}	6.95×10^{-18}	1.14×10^{-22}	9.35×10^{-26}	6.39	3.96×10^{5}	3.91×10^{13}	1.01×10^{-3}	8.81×10^{13}	4.50×10^{-3}
6437	4000	4.174×10^{15}	242.07	9.79	8569	3.004×10^{3}	5.17×10^{-15}	5.10×10^{-18}	7.11×10^{-23}	5.81×10^{-26}	4.41	4.30×10^{5}	5.67×10^{13}	7.58×10^{-3}	1.28×10^{14}	3.37×10^{-3}
7242	4500	4.442×10^{15}	214.49	8.85	9050	4.085×10^{3}	4.08×10^{-15}	4.03×10^{-18}	4.80×10^{-23}	3.92×10^{-26}	3.29	4.66×10^{5}	7.60×10^{13}	6.13×10^{-3}	1.71×10^{14}	2.73×10^{-3}
8047	5000	4.681×10^{15}	191.41	8.02	9477	5.129×10^{3}	3.41×10^{-15}	3.36×10^{-18}	3.47×10^{-23}	2.84×10^{-26}	2.63	5.00×10^{5}	9.52×10^{13}	5.25×10^{-3}	2.14×10^{14}	2.33×10^{-3}
8852	5500	4.894×10^{15}	171.97	7.28	9858	6.541×10^{3}	2.96×10^{-15}	2.92×10^{-18}	2.63×10^{-23}	2.15×10^{-26}	2.19	5.36×10^{5}	1.14×10^{14}	4.70×10^{-3}	2.57×10^{14}	2.09×10^{-3}
6890	5526	4.973×10^{15}	164.65	7.00	10,000	7.208×10^{3}	2.78×10^{-15}	2.73×10^{-18}	2.34×10^{-23}	1.91×10^{-26}	2.00	5.50×10^{5}	1.25×10^{14}	4.38×10^{-3}	2.82×10^{14}	1.95×10^{-3}

1 millibar (mb) = 10^2 dynes/cm² = 0.750 mm of Hg

Table 3.20 ATMOSPHERIC MODEL I. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER, BASED ON $M_L = 7$
Latitude 45°. Metric Units. $p_0 = 1014$ mb, $\rho_0 = 1.223 \times 10^{-3}$ gm/cm³. Table 27 of Ref. 3.20.

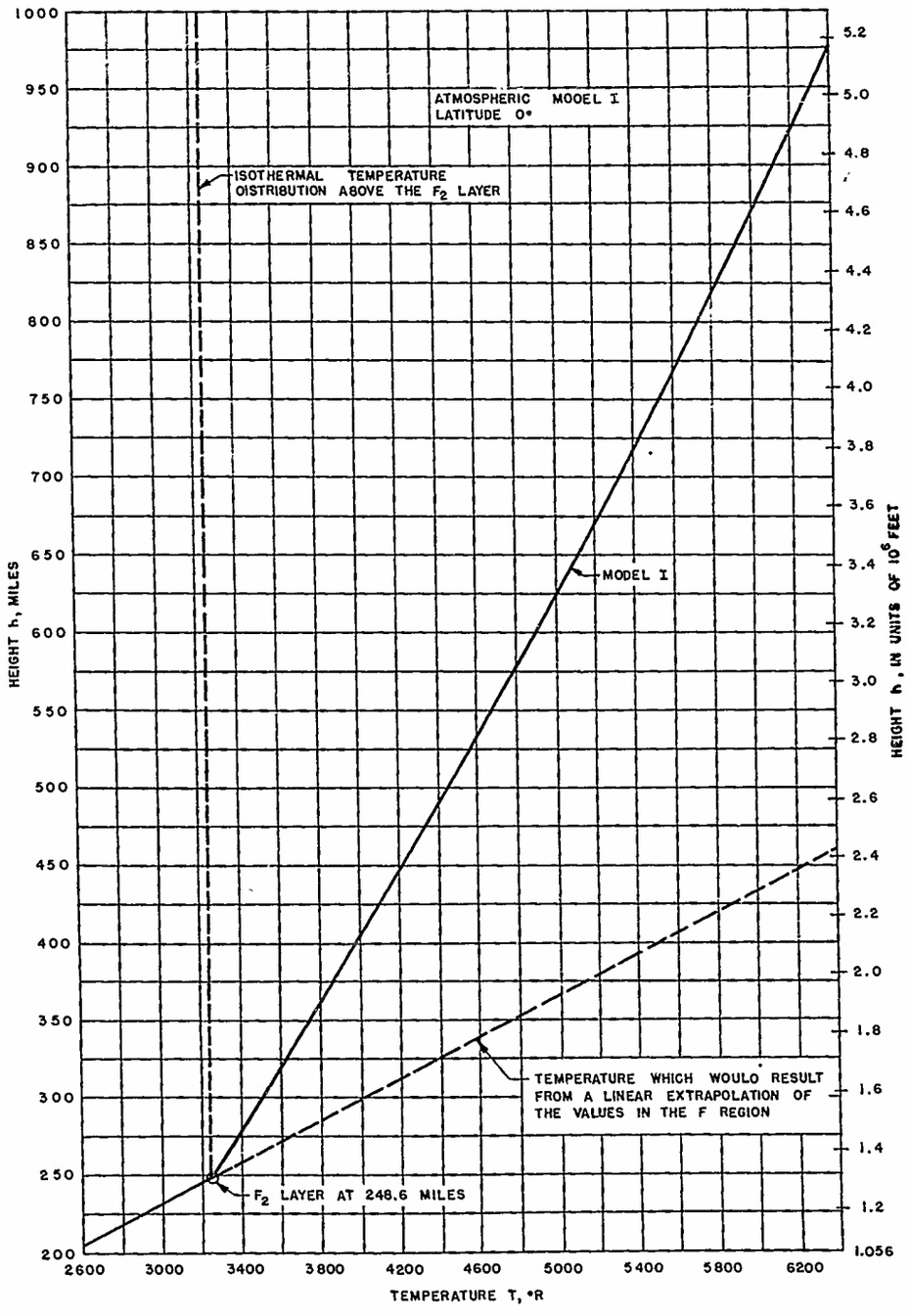


Fig. 3.39 ADOPTED VALUES OF TEMPERATURE FOR ATMOSPHERIC MODEL I FROM THE F_2-LAYER UP TO 1000 MILES
Latitude 0^0. Engineering Units. Fig. 19 of Ref. 3.20.

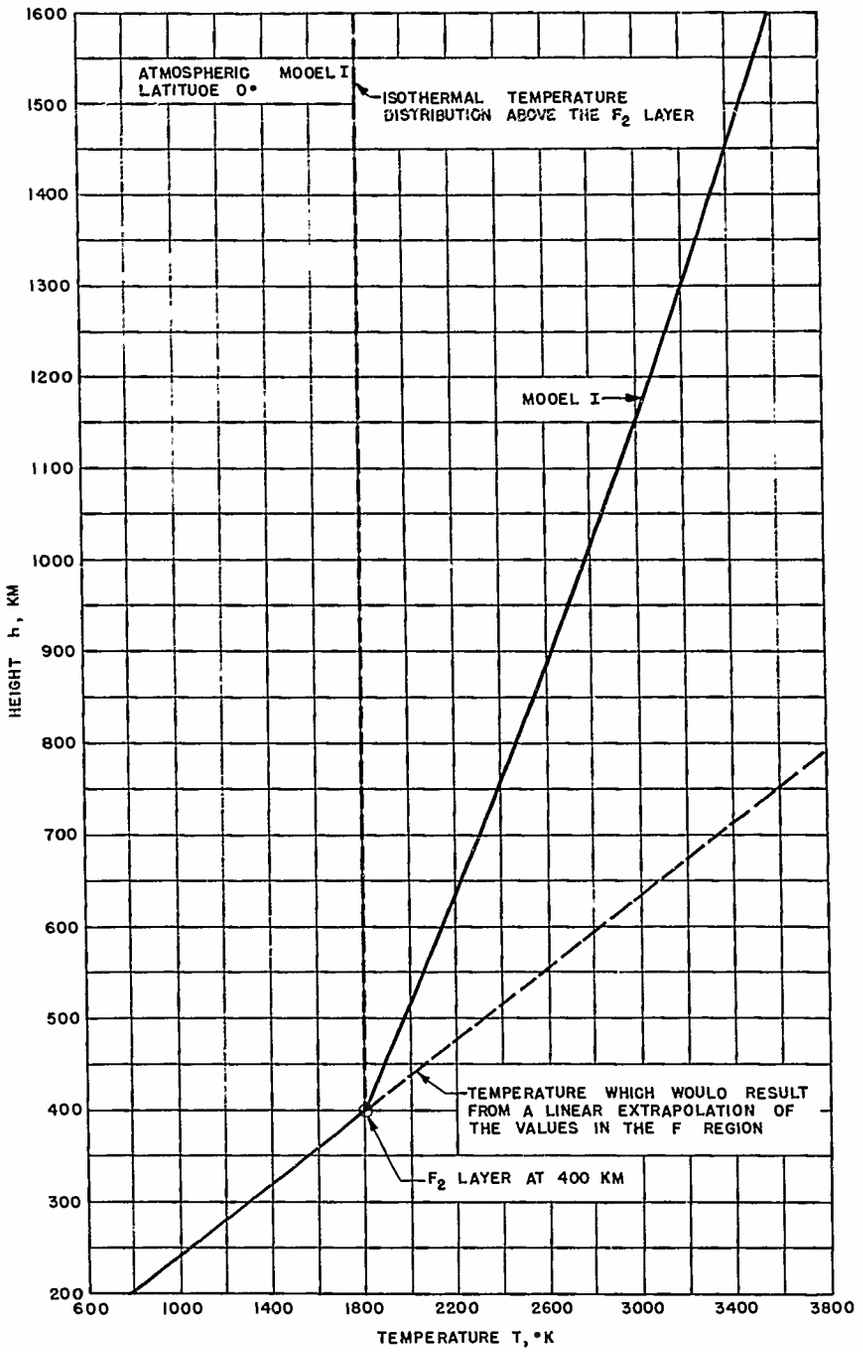


Fig. 3.40 ADOPTED VALUES OF TEMPERATURE FOR ATMOSPHERIC MODEL I FROM THE F_2-LAYER UP TO 1600 KM
Latitude 0^o. Metric Units. Fig. 20 of Ref. 3.20.

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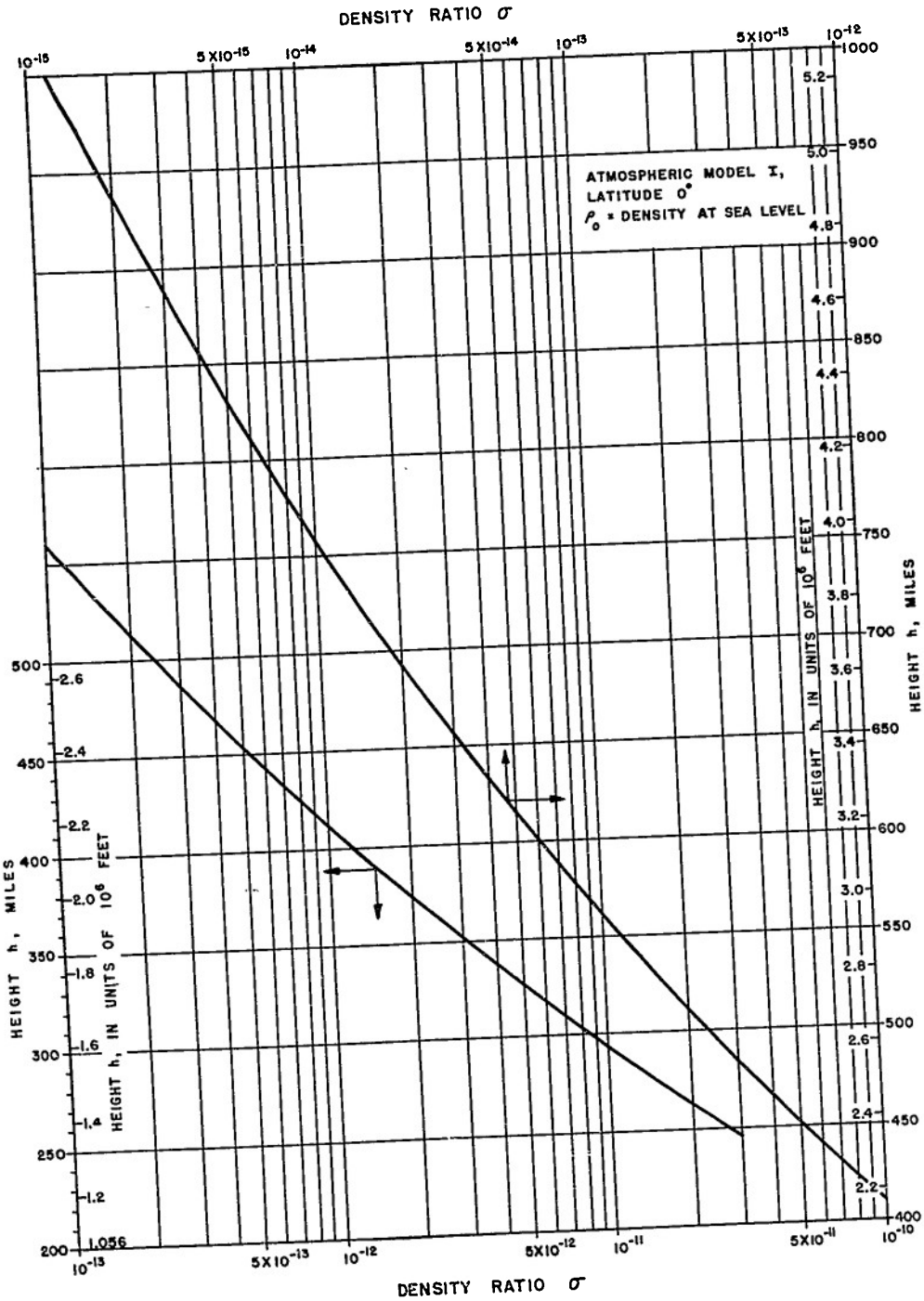


Fig. 3.41 ADOPTED VALUES OF THE DENSITY RATIO (σ) FOR ATMOSPHERIC MODEL I FROM THE F_2-LAYER UP TO 1000 MILES
Latitude 0°. Engineering Units. Fig. 21 of Ref. 3.20.

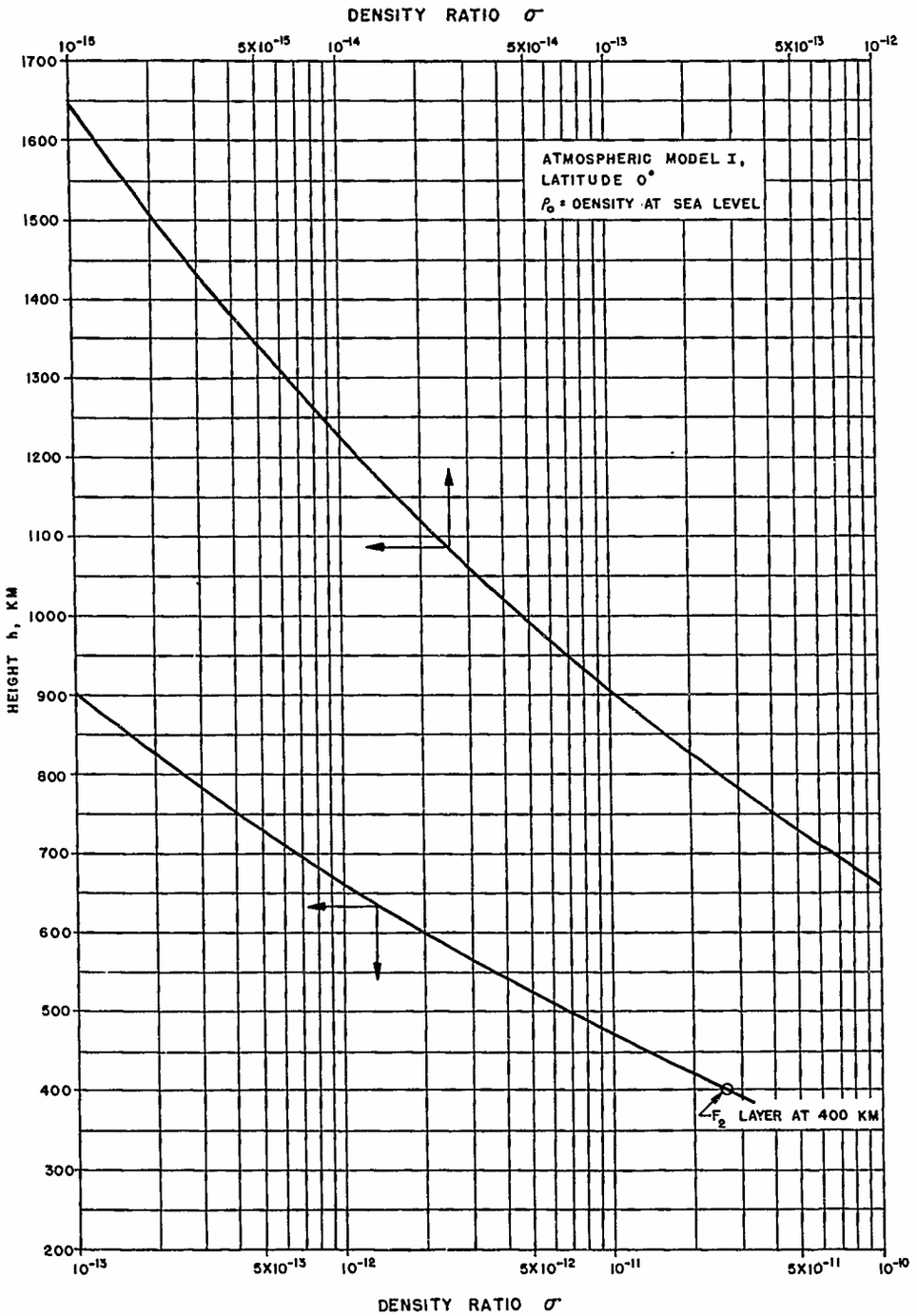


Fig. 3.42 ADOPTED VALUES OF THE DENSITY RATIO (σ) FOR ATMOSPHERIC MODEL I FROM THE F_2-LAYER UP TO 1650 KM
Latitude 0°. Metric Units. Fig. 22 of Ref. 3.20.

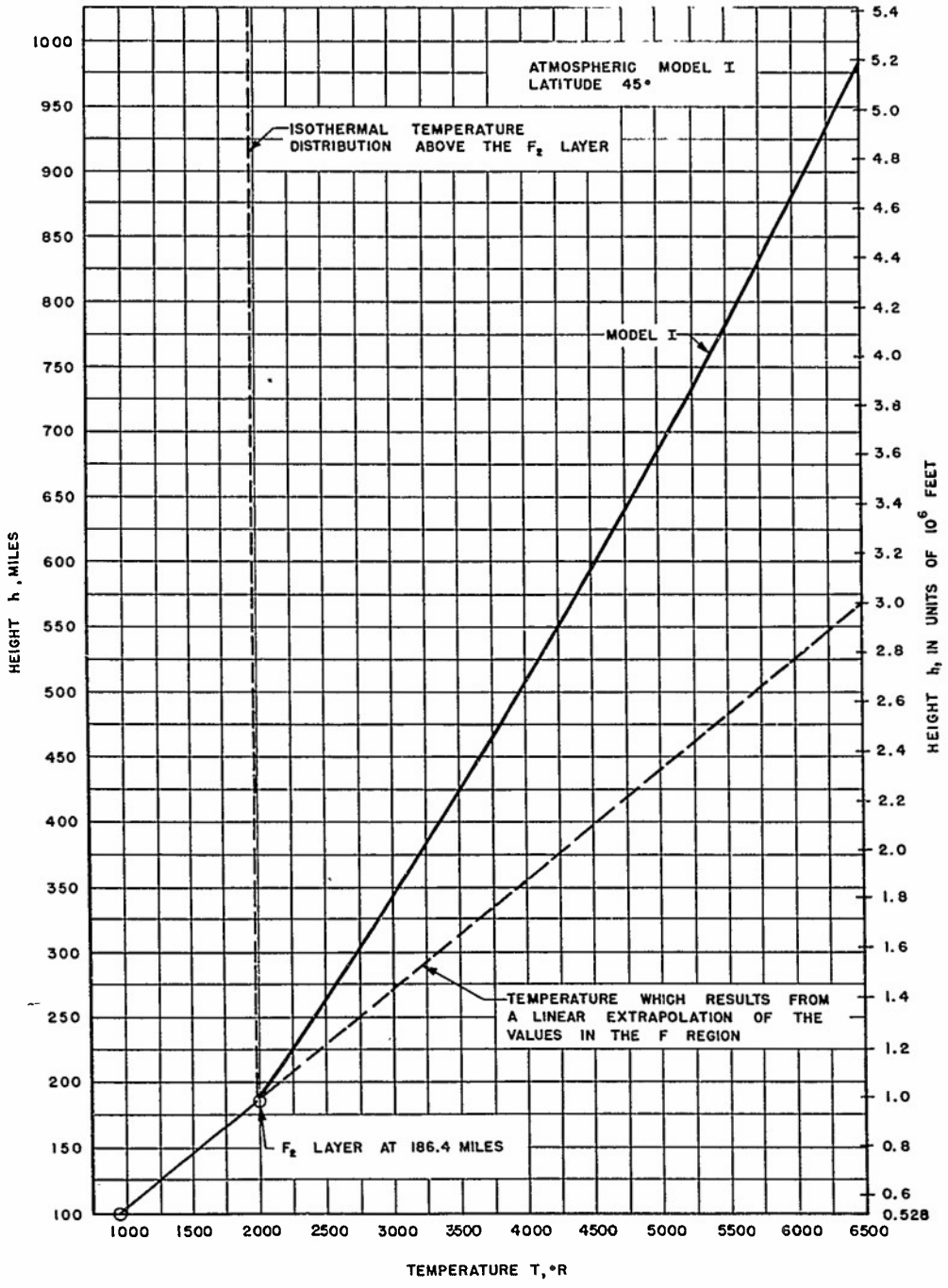


Fig. 3.43 ADOPTED VALUES OF TEMPERATURE FOR ATMOSPHERIC MODEL I FROM THE F_2-LAYER UP TO 1000 MILES
Latitude 45°. Engineering Units. Fig. 23 of Ref. 3.20.

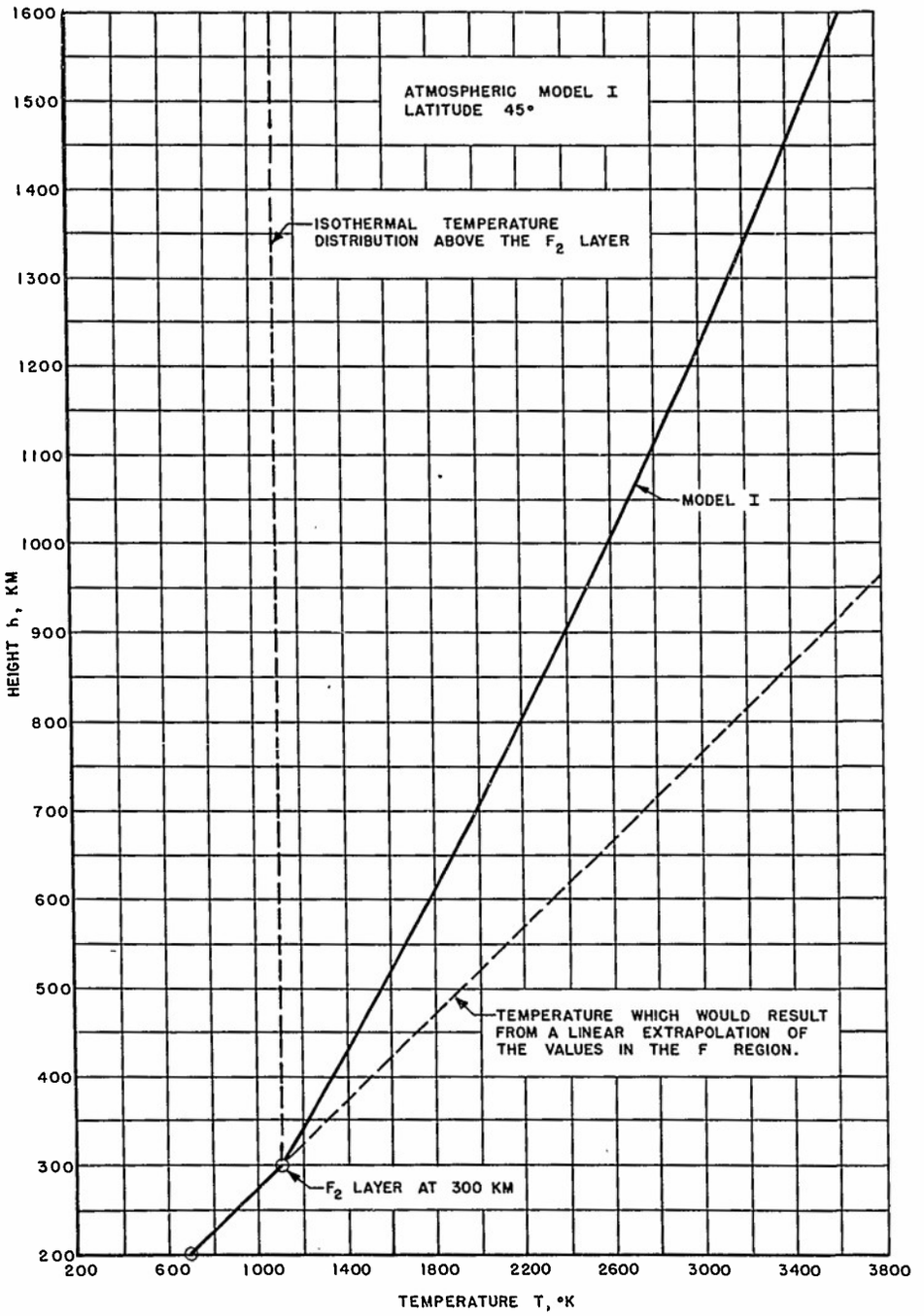


Fig. 3.44 ADOPTED VALUES OF TEMPERATURE FOR ATMOSPHERIC MODEL I FROM THE F_2-LAYER UP TO 1600 KM
Latitude 45°. Metric Units. Fig. 24 of Ref. 3.20.

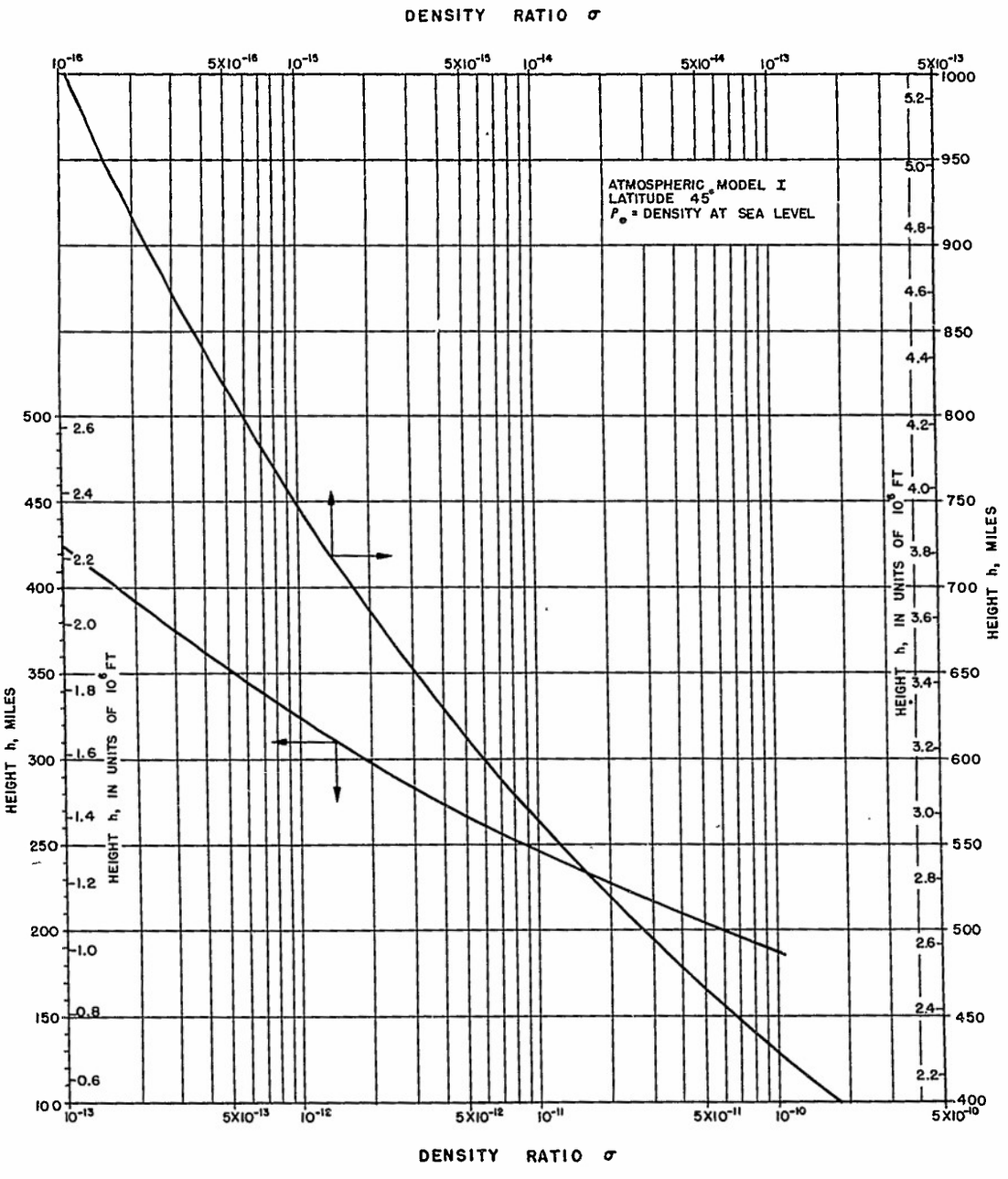


Fig. 3.45 ADOPTED VALUES OF THE DENSITY RATIO (σ) FOR ATMOSPHERIC MODEL I FROM THE F_2-LAYER UP TO 1000 MILES
Latitude 45°. Engineering Units. Fig. 25 of Ref. 3.20.

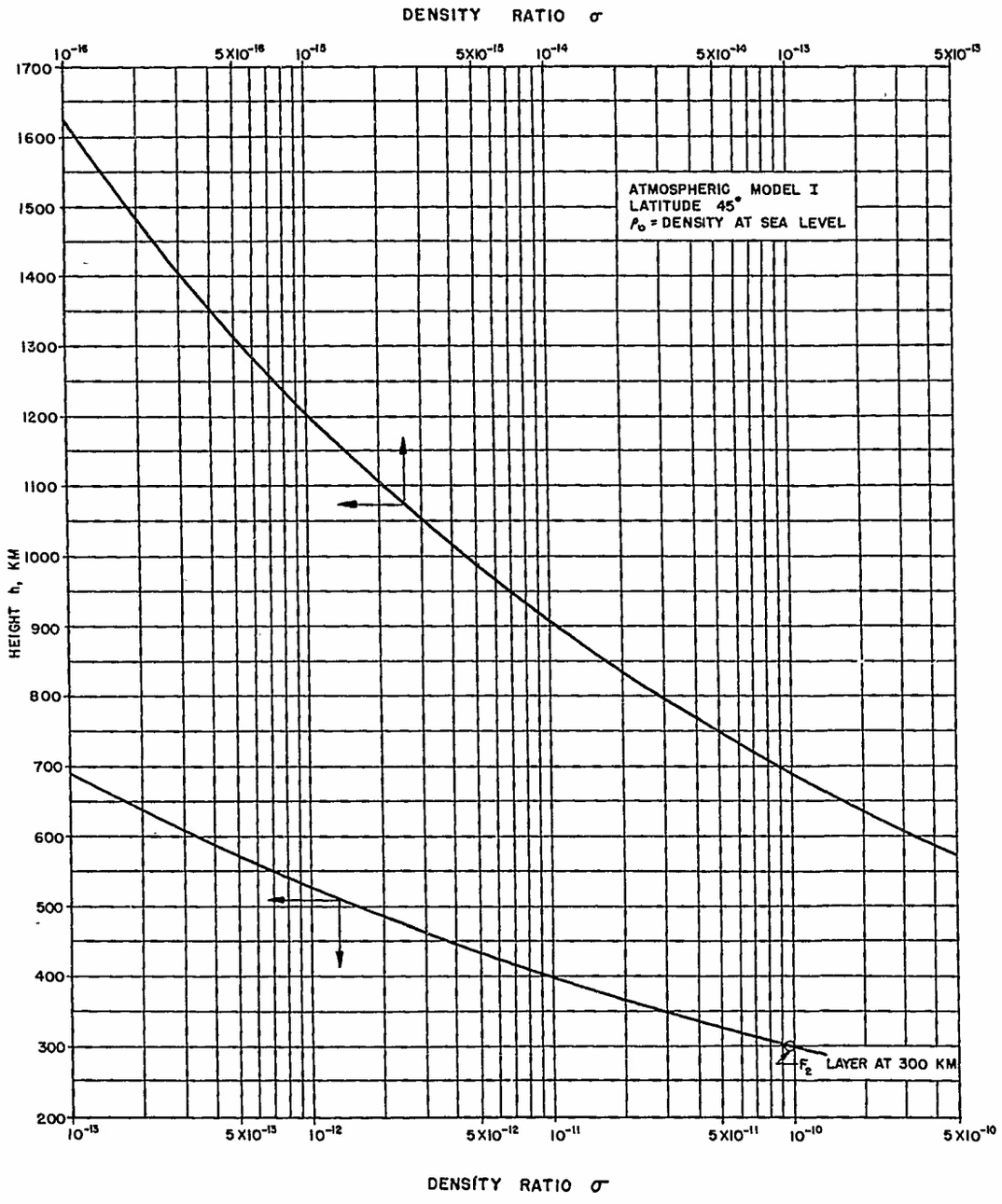


Fig. 3.46 ADOPTED VALUES OF THE DENSITY RATIO (σ) FOR ATMOSPHERIC MODEL I FROM THE F_2-LAYER UP TO 1600 KM
Latitude 45°. Metric Units. Fig. 26 of Ref. 3.20.

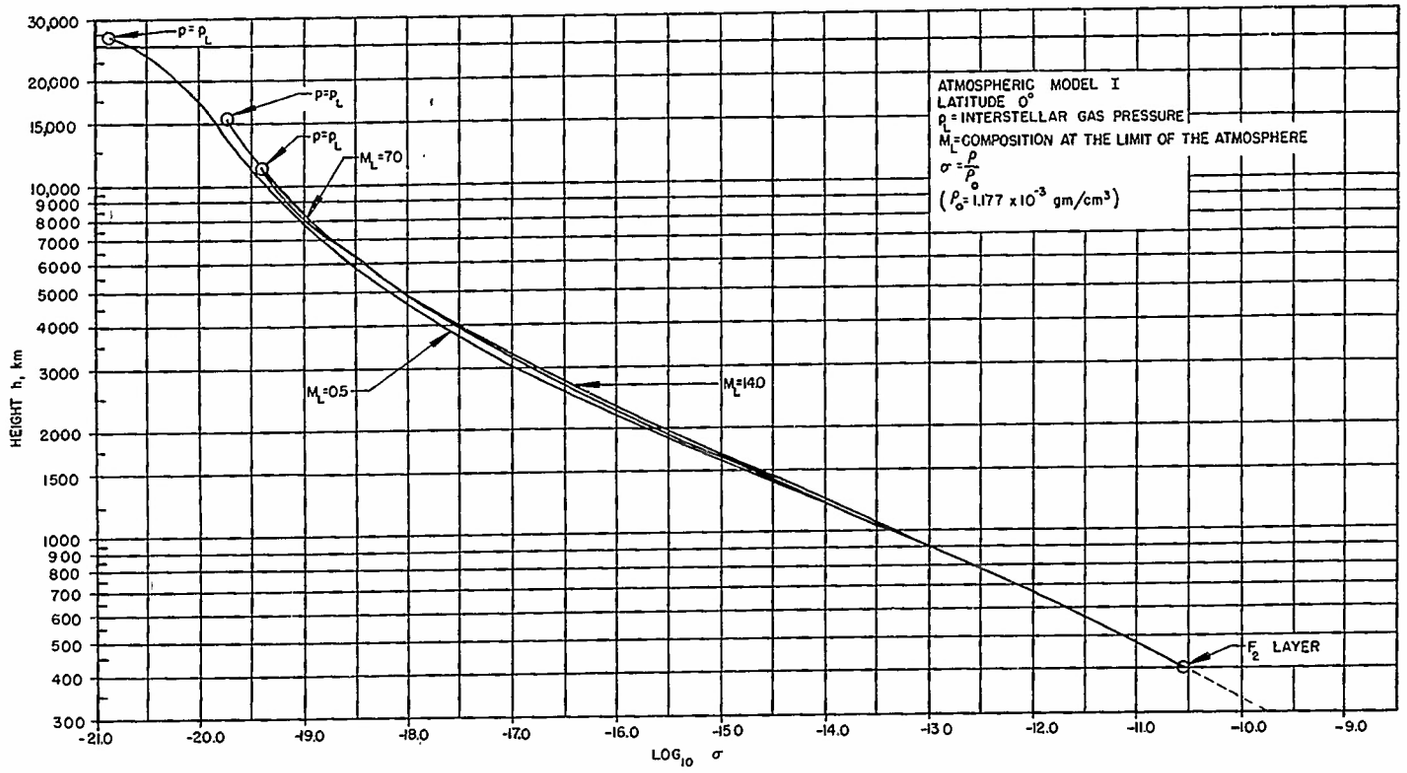


Fig. 3.47 PLOT SHOWING THE SMALL EFFECT OF THE VALUE USED FOR M_L IN DETERMINING THE VERTICAL DENSITY DISTRIBUTION FOR ATMOSPHERIC MODEL I
Latitude 0°. Fig. 44 of Ref. 3.20.

Height h		Potential ϕ	Apparent Gravity g'	Mean Mol Wt M	Temp T	Scale Height H	Pressure p	Pressure Ratio p/p_0	Density ρ	Density Ratio σ	Number Density n	Mean Particle Speed v	$d = 3 \times 10^{-8}$ cm		$d = 2 \times 10^{-8}$ cm	
													Mean Free Path λ	Mean Collision Freq f	Mean Free Path λ	Mean Collision Freq f
mi	ft	ft-lb	ft/sec²		°R	ft	lb/ft²		slug/ft³		particles/ft³	ft/sec	ft	1/sec	ft	1/sec
248.6	1.312×10^6		28.393	24.00	3240	2.362×10^6	4.33×10^{-7}	2.05×10^{-10}	6.46×10^{-13}	2.83×10^{-11}	2.38×10^{12}	4.13×10^3	9.77×10^3	4.23×10^{-1}	2.20×10^5	1.88×10^{-1}
300	1.584×10^6		27.707	23.70	3498	2.646×10^6	1.46×10^{-7}	6.90×10^{-11}	1.99×10^{-14}	8.71×10^{-13}	7.43×10^{11}	4.32×10^3	3.13×10^4	1.38×10^{-1}	7.04×10^4	6.14×10^{-2}
350	1.848×10^6		27.064	23.42	3743	2.934×10^6	5.67×10^{-8}	2.68×10^{-11}	7.14×10^{-15}	3.12×10^{-13}	2.70×10^{12}	4.50×10^3	8.61×10^4	5.03×10^{-3}	1.94×10^6	2.23×10^{-2}
400	2.112×10^6		26.444	23.14	3983	3.234×10^6	2.41×10^{-8}	1.14×10^{-11}	2.82×10^{-16}	1.23×10^{-13}	1.08×10^{12}	4.67×10^3	2.15×10^5	2.17×10^{-2}	4.84×10^5	9.64×10^{-3}
450	2.376×10^6		25.844	22.87	4217	3.544×10^6	1.10×10^{-8}	5.20×10^{-12}	1.20×10^{-16}	5.25×10^{-13}	4.64×10^{11}	4.83×10^3	5.01×10^5	9.64×10^{-3}	1.13×10^6	4.28×10^{-3}
500	2.640×10^6		25.264	22.61	4447	3.867×10^6	5.40×10^{-9}	2.55×10^{-12}	5.53×10^{-17}	2.42×10^{-13}	2.16×10^{11}	4.99×10^3	1.08×10^6	4.64×10^{-3}	2.42×10^6	2.06×10^{-3}
537	2.835×10^6	0.000	24.847	22.42	4613	4.114×10^6	3.30×10^{-9}	1.56×10^{-12}	3.23×10^{-17}	1.41×10^{-13}	1.27×10^{11}	5.10×10^3	1.83×10^6	2.79×10^{-3}	4.12×10^6	1.24×10^{-3}
550	2.904×10^6	1.61×10^6	24.704	22.42	4613	4.137×10^6	2.82×10^{-9}	1.33×10^{-12}	2.76×10^{-17}	1.21×10^{-13}	1.09×10^{11}	5.10×10^3	2.13×10^6	2.39×10^{-3}	4.80×10^6	1.06×10^{-3}
600	3.168×10^6	8.06×10^6	24.167	22.42	4613	4.229×10^6	1.50×10^{-9}	7.09×10^{-13}	1.47×10^{-17}	6.43×10^{-14}	5.80×10^{10}	5.10×10^3	4.01×10^6	1.27×10^{-3}	9.02×10^6	5.66×10^{-4}
650	3.432×10^6	1.44×10^7	23.648	22.42	4613	4.322×10^6	8.07×10^{-10}	3.82×10^{-13}	7.90×10^{-18}	3.46×10^{-14}	3.12×10^{10}	5.10×10^3	7.45×10^6	6.85×10^{-4}	1.68×10^7	3.04×10^{-4}
700	3.696×10^6	2.06×10^7	23.144	22.42	4613	4.416×10^6	4.40×10^{-10}	2.08×10^{-13}	4.30×10^{-18}	1.88×10^{-14}	1.70×10^{10}	5.10×10^3	1.37×10^7	3.73×10^{-4}	3.08×10^7	1.66×10^{-4}
750	3.960×10^6	2.66×10^7	22.657	22.42	4613	4.511×10^6	2.45×10^{-10}	1.16×10^{-13}	2.40×10^{-18}	1.05×10^{-14}	9.47×10^9	5.10×10^3	2.45×10^7	2.08×10^{-4}	5.52×10^7	9.23×10^{-5}
800	4.224×10^6	3.25×10^7	22.185	22.42	4613	4.607×10^6	1.37×10^{-10}	6.48×10^{-14}	1.34×10^{-18}	5.86×10^{-15}	5.29×10^9	5.10×10^3	4.39×10^7	1.16×10^{-4}	9.89×10^7	5.16×10^{-5}
900	4.752×10^6	4.40×10^7	21.284	22.42	4613	4.802×10^6	4.46×10^{-11}	2.11×10^{-14}	4.36×10^{-19}	1.91×10^{-15}	1.72×10^9	5.10×10^3	1.35×10^8	3.77×10^{-5}	3.04×10^8	1.68×10^{-5}
1000	5.280×10^6	5.50×10^7	20.437	22.42	4613	5.001×10^6	1.52×10^{-11}	7.19×10^{-15}	1.49×10^{-19}	6.52×10^{-16}	5.88×10^8	5.10×10^3	3.95×10^8	1.29×10^{-5}	8.90×10^8	5.73×10^{-6}
1200	6.339×10^6	7.58×10^7	18.888	22.42	4613	5.411×10^6	1.99×10^{-13}	9.41×10^{-17}	1.95×10^{-20}	8.53×10^{-17}	7.70×10^7	5.10×10^3	3.02×10^9	1.69×10^{-6}	6.79×10^9	7.51×10^{-7}
1400	7.392×10^6	9.50×10^7	17.509	22.42	4613	5.838×10^6	3.03×10^{-13}	1.43×10^{-16}	2.96×10^{-20}	1.29×10^{-17}	1.17×10^7	5.10×10^3	1.99×10^{10}	2.57×10^{-7}	4.47×10^{10}	1.14×10^{-7}
1500	7.920×10^6	1.04×10^8	17.151	22.42	4613	5.959×10^6	1.26×10^{-13}	5.96×10^{-17}	1.23×10^{-20}	5.38×10^{-18}	4.85×10^6	5.10×10^3	4.79×10^{10}	1.06×10^{-7}	1.08×10^{11}	4.73×10^{-8}
1750	9.240×10^6	1.25×10^8	15.433	22.42	4613	6.623×10^6	1.61×10^{-14}	7.61×10^{-18}	1.58×10^{-21}	6.91×10^{-19}	6.24×10^5	5.10×10^3	3.73×10^{11}	1.37×10^{-8}	8.38×10^{11}	6.08×10^{-9}
2000	1.056×10^7	1.45×10^8	14.169	22.42	4613	7.214×10^6	2.28×10^{-16}	1.08×10^{-19}	2.23×10^{-23}	9.75×10^{-20}	8.80×10^4	5.10×10^3	2.64×10^{12}	1.93×10^{-8}	5.94×10^{12}	8.58×10^{-10}
2500	1.320×10^7	1.79×10^8	12.065	22.42	4613	8.472×10^6	8.18×10^{-17}	3.87×10^{-20}	8.00×10^{-24}	3.50×10^{-21}	3.16×10^3	5.10×10^3	7.36×10^{13}	6.93×10^{-11}	1.66×10^{14}	3.08×10^{-11}
3000	1.584×10^7	2.09×10^8	10.397	22.42	4613	9.831×10^6	4.35×10^{-16}	2.06×10^{-21}	4.26×10^{-25}	1.86×10^{-22}	1.68×10^3	5.10×10^3	1.38×10^{15}	3.69×10^{-12}	3.11×10^{16}	1.64×10^{-12}
4000	2.112×10^7	2.569×10^8	7.953	22.42	4613	1.285×10^6	4.01×10^{-20}	1.90×10^{-23}	3.92×10^{-27}	1.71×10^{-24}	1.55	5.10×10^3	1.50×10^{17}	3.40×10^{-14}	3.37×10^{17}	1.51×10^{-14}
5000	2.640×10^7	2.943×10^8	6.279	22.42	4613	1.628×10^6	1.03×10^{-21}	4.87×10^{-26}	1.01×10^{-28}	4.46×10^{-26}	3.99×10^{-3}	5.10×10^3	5.83×10^{18}	8.75×10^{-16}	1.31×10^{19}	3.89×10^{-16}
6000	3.168×10^7	3.241×10^8	5.084	22.42	4613	2.011×10^6	5.59×10^{-23}	2.63×10^{-26}	5.47×10^{-30}	2.39×10^{-27}	2.16×10^{-3}	5.10×10^3	1.08×10^{20}	4.74×10^{-17}	2.42×10^{20}	2.11×10^{-17}
7000	3.696×10^7	3.485×10^8	4.199	22.42	4613	2.435×10^6	5.14×10^{-24}	2.43×10^{-27}	5.03×10^{-31}	2.20×10^{-28}	1.99×10^{-4}	5.10×10^3	1.17×10^{21}	4.37×10^{-18}	2.63×10^{21}	1.94×10^{-18}
8000	4.224×10^7	3.688×10^8	3.527	22.42	4613	2.898×10^6	7.05×10^{-26}	3.33×10^{-29}	6.90×10^{-32}	3.02×10^{-29}	2.72×10^{-5}	5.10×10^3	8.55×10^{21}	5.97×10^{-19}	1.92×10^{22}	2.65×10^{-19}
9000	4.752×10^7	3.860×10^8	3.004	22.42	4613	3.402×10^6	1.31×10^{-26}	6.19×10^{-29}	1.28×10^{-32}	5.60×10^{-30}	5.05×10^{-6}	5.10×10^3	4.60×10^{22}	1.11×10^{-19}	1.04×10^{23}	4.92×10^{-20}

1 lb/ft² = 0.3591 mm of Hg

Table 3.21 ATMOSPHERIC MODEL II. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER
Latitude 0°. Engineering Units. $p_0 = 2115$ lb/ft², $\rho_0 = 2.286 \times 10^{-3}$ slug/ft³. Table 34 of Ref. 3.20.

Height h km	Height h mi	Potential ϕ ergs	Apparent Gravity g' cm/sec	Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm³	Density Ratio σ ρ/ρ_0	Number Density n particles/cm³	Mean Particle Speed $\bar{v}$ cm/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path $\frac{\ell}{\lambda}$ cm	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path $\frac{\ell}{\lambda}$ cm	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec
	248.6		865.41	24.00	1800	7.199×10	2.07×10^{-7}	2.05×10^{-10}	3.33×10^{-14}	2.83×10^{-11}	8.40×10^{8}	1.26×10^{5}	2.98×10^{0}	4.23×10^{-1}	6.70×10^{5}	1.88×10^{-1}
483	300		844.52	23.70	1943	8.066×10	6.99×10^{-8}	6.90×10^{-11}	1.02×10^{-14}	8.71×10^{-12}	2.62×10^{8}	1.32×10^{5}	9.54×10^{5}	1.38×10^{-1}	2.15×10^{5}	6.14×10^{-2}
563	350		824.92	23.42	2079	8.941×10	2.72×10^{-8}	2.68×10^{-11}	3.68×10^{-15}	3.12×10^{-12}	9.54×10^{7}	1.37×10^{5}	2.62×10^{6}	5.03×10^{-2}	5.90×10^{6}	2.23×10^{-2}
644	400		806.00	23.14	2213	9.856×10	1.15×10^{-8}	1.14×10^{-11}	1.45×10^{-15}	1.23×10^{-12}	3.81×10^{7}	1.42×10^{5}	6.56×10^{6}	2.17×10^{-2}	1.48×10^{7}	9.64×10^{-3}
724	450		787.71	22.87	2343	1.080×10^{2}	5.27×10^{-9}	5.20×10^{-12}	6.18×10^{-16}	5.25×10^{-13}	1.64×10^{7}	1.47×10^{5}	1.53×10^{7}	9.64×10^{-3}	3.44×10^{7}	4.28×10^{-3}
805	500		770.03	22.61	2471	1.179×10^{2}	2.59×10^{-9}	2.55×10^{-12}	2.85×10^{-16}	2.42×10^{-13}	7.63×10^{6}	1.52×10^{5}	3.28×10^{7}	4.64×10^{-3}	7.38×10^{7}	2.06×10^{-3}
865	537	0.000	757.34	22.42	2563	1.254×10^{2}	1.58×10^{-9}	1.56×10^{-12}	1.66×10^{-16}	1.41×10^{-13}	4.48×10^{6}	1.55×10^{5}	5.58×10^{7}	2.79×10^{-3}	1.26×10^{8}	1.24×10^{-3}
885	550	2.18×10^{12}	752.98	22.42	2563	1.261×10^{2}	1.35×10^{-9}	1.33×10^{-12}	1.42×10^{-16}	1.21×10^{-13}	3.85×10^{6}	1.55×10^{5}	6.50×10^{7}	2.39×10^{-3}	1.46×10^{8}	1.06×10^{-3}
966	600	1.09×10^{14}	736.62	22.42	2563	1.289×10^{2}	7.18×10^{-10}	7.09×10^{-13}	7.57×10^{-17}	6.43×10^{-14}	2.05×10^{6}	1.55×10^{5}	1.22×10^{8}	1.27×10^{-3}	2.75×10^{8}	5.66×10^{-4}
1046	650	1.95×10^{14}	720.78	22.42	2563	1.317×10^{2}	3.86×10^{-10}	3.82×10^{-13}	4.07×10^{-17}	3.46×10^{-14}	1.10×10^{6}	1.55×10^{5}	2.27×10^{8}	6.85×10^{-4}	5.11×10^{8}	3.04×10^{-4}
1127	700	2.79×10^{14}	705.44	22.42	2563	1.346×10^{2}	2.11×10^{-10}	2.08×10^{-13}	2.21×10^{-17}	1.88×10^{-14}	6.00×10^{5}	1.55×10^{5}	4.17×10^{8}	3.73×10^{-4}	9.38×10^{8}	1.66×10^{-4}
1207	750	3.61×10^{14}	690.59	22.42	2563	1.375×10^{2}	1.17×10^{-10}	1.16×10^{-13}	1.24×10^{-17}	1.05×10^{-14}	3.34×10^{5}	1.55×10^{5}	7.48×10^{8}	2.08×10^{-4}	1.68×10^{9}	9.23×10^{-5}
1288	800	4.41×10^{14}	676.20	22.42	2563	1.404×10^{2}	6.56×10^{-11}	6.48×10^{-14}	6.90×10^{-18}	5.86×10^{-15}	1.87×10^{5}	1.55×10^{5}	1.34×10^{9}	1.16×10^{-4}	3.01×10^{9}	5.16×10^{-5}
1448	900	5.97×10^{14}	648.74	22.42	2563	1.464×10^{2}	2.14×10^{-11}	2.11×10^{-14}	2.25×10^{-18}	1.91×10^{-15}	6.97×10^{4}	1.55×10^{5}	4.12×10^{9}	3.77×10^{-5}	9.27×10^{9}	1.68×10^{-5}
1609	1000	7.46×10^{14}	622.92	22.42	2563	1.524×10^{2}	7.28×10^{-12}	7.19×10^{-15}	7.67×10^{-19}	6.52×10^{-16}	2.08×10^{4}	1.55×10^{5}	1.21×10^{10}	1.29×10^{-5}	2.71×10^{10}	5.73×10^{-6}
1931	1200	1.03×10^{15}	575.70	22.42	2563	1.649×10^{2}	9.53×10^{-13}	9.41×10^{-16}	1.00×10^{-19}	8.53×10^{-17}	2.72×10^{3}	1.55×10^{5}	9.20×10^{10}	1.69×10^{-6}	2.07×10^{11}	7.51×10^{-7}
2253	1400	1.29×10^{15}	533.66	22.42	2563	1.779×10^{2}	1.45×10^{-13}	1.43×10^{-16}	1.52×10^{-20}	1.29×10^{-17}	4.13×10^{2}	1.55×10^{5}	6.06×10^{11}	2.57×10^{-7}	1.36×10^{12}	1.14×10^{-7}
2414	1500	1.41×10^{15}	522.77	22.42	2563	1.816×10^{2}	6.03×10^{-14}	5.96×10^{-17}	6.33×10^{-21}	5.38×10^{-18}	1.71×10^{2}	1.55×10^{5}	1.46×10^{12}	1.06×10^{-7}	3.29×10^{12}	4.73×10^{-8}
2816	1750	1.70×10^{15}	470.39	22.42	2563	2.019×10^{2}	7.71×10^{-15}	7.61×10^{-18}	8.14×10^{-22}	6.91×10^{-19}	2.20×10	1.55×10^{5}	1.14×10^{13}	1.37×10^{-8}	2.55×10^{13}	6.08×10^{-9}
3219	2000	1.97×10^{15}	431.86	22.42	2563	2.198×10^{2}	1.09×10^{-15}	1.08×10^{-18}	1.15×10^{-22}	9.75×10^{-20}	3.11	1.55×10^{5}	8.05×10^{13}	1.93×10^{-8}	1.81×10^{14}	8.58×10^{-10}
4023	2500	2.43×10^{15}	367.73	22.42	2563	2.582×10^{2}	3.92×10^{-17}	3.87×10^{-20}	4.12×10^{-24}	3.50×10^{-21}	1.12×10^{-1}	1.55×10^{5}	2.24×10^{15}	6.93×10^{-11}	5.05×10^{15}	3.08×10^{-11}
4828	3000	2.83×10^{15}	316.90	22.42	2563	2.996×10^{2}	2.08×10^{-15}	2.06×10^{-18}	2.19×10^{-22}	1.86×10^{-19}	5.93×10^{-2}	1.55×10^{5}	4.22×10^{15}	3.69×10^{-12}	9.49×10^{15}	1.64×10^{-12}
6438	4000	3.48×10^{15}	242.41	22.42	2563	3.917×10^{2}	1.92×10^{-20}	1.90×10^{-22}	2.02×10^{-27}	1.71×10^{-24}	5.47×10^{-5}	1.55×10^{5}	4.57×10^{18}	3.40×10^{-14}	1.03×10^{18}	1.51×10^{-14}
8047	5000	3.99×10^{15}	191.40	22.42	2563	4.961×10^{2}	4.93×10^{-22}	4.87×10^{-25}	5.20×10^{-29}	4.46×10^{-26}	1.41×10^{-5}	1.55×10^{5}	1.78×10^{20}	8.75×10^{-16}	4.00×10^{20}	3.89×10^{-16}
9656	6000	4.39×10^{15}	154.95	22.42	2563	6.129×10^{2}	2.68×10^{-23}	2.63×10^{-26}	2.82×10^{-30}	2.39×10^{-27}	7.63×10^{-8}	1.55×10^{5}	3.28×10^{21}	4.74×10^{-17}	7.38×10^{21}	2.11×10^{-17}
11,266	7000	4.72×10^{15}	127.99	22.42	2563	7.422×10^{2}	2.46×10^{-24}	2.43×10^{-27}	2.59×10^{-31}	2.20×10^{-28}	7.03×10^{-9}	1.55×10^{5}	3.56×10^{22}	4.37×10^{-18}	8.01×10^{22}	1.94×10^{-18}
12,875	8000	5.00×10^{15}	107.51	22.42	2563	8.833×10^{2}	3.38×10^{-25}	3.33×10^{-28}	3.55×10^{-32}	3.02×10^{-29}	9.61×10^{-10}	1.55×10^{5}	2.60×10^{23}	5.97×10^{-19}	5.86×10^{23}	2.65×10^{-19}
14,484	9000	5.23×10^{15}	91.57	22.42	2563	1.037×10^{3}	6.27×10^{-26}	6.19×10^{-29}	6.59×10^{-33}	5.60×10^{-30}	1.78×10^{-10}	1.55×10^{5}	1.40×10^{24}	1.11×10^{-19}	3.16×10^{24}	4.92×10^{-20}

1 millibar (mb) = 10^3 dynes/cm² = 0.750 mm of Hg

Table 3.22 ATMOSPHERIC MODEL II. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER
Latitude 0°. Metric Units. $p_0 = 1013$ mb, $\rho_0 = 1.178 \times 10^{-3}$ gm/cm³. Table 35 of Ref. 3.20.

Height h mi	Height h ft	Potential ϕ ft-lb	Apparent Gravity g' ft/sec^2	Mean Mol Wt M	Temp T °R	Scale Height H ft	Pressure p lb/ft^2	Pressure Ratio p/p_0	Density ρ slug/ft^3	Density Ratio σ ρ/ρ_0	Number Density n particles/ft^2	Mean Particle Speed $\bar{v}$ ft/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ ft	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ ft	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec
186.41	9.842×10^5		29.334	24.35	1980	1.377×10^5	1.01×10^{-6}	4.77×10^{-10}	2.50×10^{-12}	1.05×10^{-10}	9.09×10^{13}	3.21×10^3	2.56×10^2	1.26	5.75×10^3	5.58×10^{-1}
200	1.056×10^5		29.141	24.25	2072	1.457×10^5	6.07×10^{-7}	2.87×10^{-10}	1.43×10^{-12}	6.02×10^{-11}	5.22×10^{13}	3.29×10^3	4.45×10^2	7.39×10^{-1}	1.00×10^4	3.28×10^{-1}
225	1.188×10^5		28.793	24.08	2239	1.604×10^5	2.56×10^{-7}	1.21×10^{-10}	5.54×10^{-13}	2.33×10^{-11}	2.04×10^{13}	3.43×10^3	1.14×10^4	3.01×10^{-1}	2.56×10^4	1.34×10^{-1}
250	1.320×10^5		28.450	23.90	2404	1.756×10^5	1.17×10^{-7}	5.53×10^{-11}	2.34×10^{-13}	9.85×10^{-12}	8.67×10^{13}	3.56×10^3	2.68×10^4	1.33×10^{-1}	6.03×10^4	5.90×10^{-2}
275	1.452×10^5		28.113	23.73	2567	1.888×10^5	5.68×10^{-8}	2.68×10^{-11}	1.06×10^{-13}	4.46×10^{-12}	3.96×10^{12}	3.70×10^3	5.87×10^4	6.30×10^{-2}	1.32×10^5	2.80×10^{-2}
300	1.584×10^5		27.782	23.56	2728	2.070×10^5	2.93×10^{-8}	1.38×10^{-11}	5.09×10^{-14}	2.14×10^{-12}	1.91×10^{13}	3.83×10^3	1.22×10^5	3.15×10^{-2}	2.74×10^5	1.40×10^{-2}
325	1.716×10^5		27.457	23.40	2887	2.226×10^5	1.46×10^{-8}	6.90×10^{-12}	2.04×10^{-14}	8.58×10^{-13}	7.87×10^{11}	3.95×10^3	2.95×10^5	1.34×10^{-2}	6.65×10^5	5.94×10^{-3}
350	1.848×10^5		27.138	23.23	3045	2.399×10^5	8.96×10^{-9}	4.23×10^{-12}	1.37×10^{-14}	5.77×10^{-12}	5.23×10^{11}	4.07×10^3	4.44×10^5	9.16×10^{-3}	1.00×10^6	4.07×10^{-3}
375	1.980×10^5		26.824	23.07	3201	2.570×10^5	5.46×10^{-9}	2.58×10^{-12}	7.64×10^{-15}	3.21×10^{-12}	2.95×10^{11}	4.19×10^3	7.88×10^5	5.32×10^{-3}	1.77×10^6	2.36×10^{-3}
391	2.064×10^5	0.000	26.626	22.92	3299	2.685×10^5	3.82×10^{-9}	1.81×10^{-12}	5.34×10^{-15}	2.25×10^{-13}	2.06×10^{11}	4.27×10^3	1.13×10^6	3.78×10^{-3}	2.54×10^6	1.68×10^{-3}
400	2.112×10^5	1.204×10^6	26.517	22.92	3299	2.697×10^5	3.23×10^{-9}	1.53×10^{-13}	4.52×10^{-16}	1.90×10^{-13}	1.75×10^{11}	4.27×10^3	1.33×10^6	3.21×10^{-3}	2.99×10^6	1.43×10^{-3}
450	2.376×10^5	8.129×10^6	25.919	22.92	3299	2.759×10^5	1.23×10^{-9}	5.81×10^{-13}	1.72×10^{-16}	7.24×10^{-14}	6.64×10^{10}	4.27×10^3	3.21×10^6	1.33×10^{-3}	7.22×10^6	5.91×10^{-4}
475	2.508×10^5	1.153×10^7	25.628	22.92	3299	2.790×10^5	7.62×10^{-10}	3.60×10^{-13}	1.07×10^{-16}	4.51×10^{-14}	4.13×10^{10}	4.27×10^3	5.63×10^6	7.59×10^{-4}	1.27×10^7	3.37×10^{-4}
500	2.640×10^5	1.489×10^7	25.342	22.92	3299	2.822×10^5	4.76×10^{-10}	2.25×10^{-13}	6.66×10^{-17}	2.80×10^{-14}	2.57×10^{10}	4.27×10^3	9.05×10^6	4.72×10^{-4}	2.04×10^7	2.10×10^{-4}
550	2.904×10^5	2.151×10^7	24.783	22.92	3299	2.885×10^5	1.89×10^{-10}	8.93×10^{-14}	2.64×10^{-17}	1.11×10^{-14}	1.02×10^{10}	4.27×10^3	2.28×10^7	2.87×10^{-4}	5.13×10^7	1.28×10^{-4}
600	3.168×10^5	2.798×10^7	24.243	22.92	3299	2.945×10^5	7.63×10^{-11}	3.61×10^{-14}	1.07×10^{-17}	4.51×10^{-15}	4.13×10^9	4.27×10^3	5.63×10^7	7.59×10^{-5}	1.27×10^8	3.37×10^{-5}
700	3.696×10^5	4.051×10^7	23.215	22.92	3299	3.076×10^5	1.32×10^{-11}	6.24×10^{-15}	1.85×10^{-18}	7.79×10^{-16}	7.14×10^8	4.27×10^3	3.26×10^8	1.31×10^{-5}	7.33×10^8	5.83×10^{-6}
800	4.224×10^5	5.251×10^7	22.250	22.92	3299	3.214×10^5	2.47×10^{-12}	1.17×10^{-15}	3.45×10^{-19}	1.45×10^{-16}	1.33×10^8	4.27×10^3	1.75×10^9	2.44×10^{-6}	3.93×10^9	1.09×10^{-6}
900	4.752×10^5	6.401×10^7	21.345	22.92	3299	3.350×10^5	4.95×10^{-12}	2.34×10^{-15}	6.92×10^{-20}	2.91×10^{-17}	2.67×10^7	4.27×10^3	8.71×10^9	4.90×10^{-7}	1.96×10^{10}	2.18×10^{-7}
1000	5.280×10^5	7.505×10^7	20.493	22.92	3299	3.489×10^5	1.05×10^{-13}	4.96×10^{-17}	1.47×10^{-20}	6.19×10^{-18}	5.68×10^6	4.27×10^3	4.09×10^{10}	1.04×10^{-7}	9.21×10^{10}	4.64×10^{-8}
1200	6.336×10^5	9.586×10^7	18.223	22.92	3299	3.924×10^5	5.75×10^{-16}	2.72×10^{-19}	8.04×10^{-23}	3.39×10^{-20}	3.10×10^5	4.27×10^3	7.50×10^{11}	5.69×10^{-9}	1.69×10^{13}	2.53×10^{-9}
1400	7.392×10^5	1.151×10^8	17.551	22.92	3299	4.074×10^5	3.90×10^{-16}	1.84×10^{-19}	5.45×10^{-23}	2.29×10^{-20}	2.10×10^4	4.27×10^3	1.11×10^{13}	3.86×10^{-10}	2.49×10^{13}	1.71×10^{-10}
1500	7.920×10^5	1.242×10^8	16.914	22.92	3299	4.227×10^5	1.09×10^{-16}	5.15×10^{-20}	1.52×10^{-23}	6.40×10^{-21}	5.87×10^3	4.27×10^3	3.96×10^{13}	1.08×10^{-10}	8.91×10^{13}	4.79×10^{-11}
1750	9.240×10^5	1.456×10^8	15.466	22.92	3299	4.623×10^5	5.48×10^{-17}	2.59×10^{-20}	7.66×10^{-24}	3.23×10^{-21}	2.96×10^3	4.27×10^2	7.85×10^{14}	5.44×10^{-12}	1.77×10^{15}	2.42×10^{-12}
2000	1.056×10^6	1.651×10^8	14.197	22.92	3299	5.037×10^5	3.58×10^{-18}	1.69×10^{-21}	5.01×10^{-25}	2.11×10^{-22}	1.93×10	4.27×10^2	1.20×10^{16}	3.55×10^{-13}	2.71×10^{16}	1.58×10^{-13}
2500	1.320×10^6	1.997×10^8	12.085	22.92	3299	5.917×10^5	2.84×10^{-21}	1.34×10^{-24}	3.97×10^{-28}	1.67×10^{-25}	1.53×10^{-1}	4.27×10^3	1.52×10^{18}	2.81×10^{-16}	3.42×10^{18}	1.25×10^{-16}
3000	1.584×10^6	2.293×10^8	10.412	22.92	3299	6.867×10^5	4.52×10^{-23}	2.14×10^{-26}	6.32×10^{-30}	2.66×10^{-27}	2.44×10^{-3}	4.27×10^3	9.53×10^{19}	4.48×10^{-17}	2.14×10^{20}	1.99×10^{-17}
3500	1.848×10^6	2.550×10^8	9.064	22.92	3299	7.889×10^5	1.24×10^{-24}	5.86×10^{-28}	1.73×10^{-31}	7.28×10^{-29}	6.68×10^{-6}	4.27×10^3	3.48×10^{21}	1.23×10^{-18}	7.83×10^{21}	5.45×10^{-19}
4000	2.112×10^6	2.774×10^8	7.961	22.92	3299	8.981×10^5	5.41×10^{-26}	2.56×10^{-29}	7.57×10^{-32}	3.19×10^{-29}	2.92×10^{-8}	4.27×10^3	7.96×10^{22}	5.36×10^{-19}	1.79×10^{23}	2.38×10^{-19}
4500	2.376×10^6	2.972×10^8	7.049	22.92	3299	1.014×10^6	3.39×10^{-27}	1.60×10^{-30}	4.74×10^{-34}	2.00×10^{-31}	1.83×10^{-7}	4.27×10^3	1.27×10^{24}	3.36×10^{-21}	2.86×10^{24}	1.49×10^{-21}
5000	2.640×10^6	3.147×10^8	6.284	22.92	3299	1.138×10^6	2.94×10^{-28}	1.39×10^{-31}	4.11×10^{-35}	1.73×10^{-32}	1.59×10^{-8}	4.27×10^3	1.46×10^{25}	2.92×10^{-22}	3.29×10^{25}	1.30×10^{-22}
5500	2.904×10^6	3.304×10^8	5.638	22.92	3299	1.268×10^6	3.27×10^{-29}	1.55×10^{-32}	4.57×10^{-36}	1.92×10^{-33}	1.76×10^{-9}	4.27×10^3	1.32×10^{26}	3.23×10^{-23}	2.97×10^{26}	1.44×10^{-23}

1 lb/ft^2 = 0.3591 mm of Hg

Table 3.23 ATMOSPHERIC MODEL II. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER
Latitude 45°. Engineering Units. $p_0 = 2116$ lb/ft^2, $\rho_0 = 2.375 \times 10^{-3}$ slug/ft^3. Table 36 of Ref. 3.20.

Height h km	Height h mi	Potential ϕ ergs	Apparent Gravity g'	Mol Wt M	Temp T °K	Scale Height H km	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gm/cm²	Density Ratio σ ρ/ρ_0	Number Density n particles/cm²	Mean Particle Speed v cm/sec	$d = 3 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec	$d = 2 \times 10^{-8}$ cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$ cm: Mean Collision Freq f 1/sec
300	186.41		894.09	24.35	1100	4.197×10	4.84×10^{-7}	4.77×10^{-10}	1.29×10^{-12}	1.05×10^{-15}	3.21×10^{8}	9.78×10^{4}	7.79×10^{4}	1.26	1.75×10^{5}	5.58×10^{-1}
322	200		888.23	24.25	1151	4.439×10	2.91×10^{-7}	2.87×10^{-10}	7.36×10^{-14}	6.02×10^{-11}	1.84×10^{9}	1.00×10^{5}	1.36×10^{5}	7.39×10^{-1}	3.05×10^{5}	3.28×10^{-1}
362	225		877.60	24.07	1244	4.890×10	1.23×10^{-7}	1.21×10^{-10}	2.85×10^{-14}	2.33×10^{-11}	7.20×10^{8}	1.05×10^{5}	3.47×10^{5}	3.01×10^{-1}	7.81×10^{5}	1.34×10^{-1}
402	250		867.15	23.89	1336	5.353×10	5.60×10^{-8}	5.53×10^{-11}	1.21×10^{-14}	9.85×10^{-12}	3.06×10^{8}	1.09×10^{5}	8.17×10^{5}	1.33×10^{-1}	1.84×10^{6}	5.90×10^{-2}
443	275		856.89	23.71	1426	5.755×10	2.72×10^{-8}	2.68×10^{-11}	5.46×10^{-15}	4.46×10^{-12}	1.40×10^{8}	1.13×10^{5}	1.79×10^{6}	6.30×10^{-2}	4.03×10^{6}	2.80×10^{-2}
483	300		846.81	23.54	1516	6.311×10	1.40×10^{-8}	1.38×10^{-11}	2.62×10^{-15}	2.14×10^{-12}	6.75×10^{7}	1.17×10^{5}	3.71×10^{6}	3.15×10^{-2}	8.35×10^{6}	1.40×10^{-2}
523	325		836.90	23.38	1604	6.786×10	7.00×10^{-9}	6.90×10^{-12}	1.05×10^{-15}	8.58×10^{-13}	2.78×10^{7}	1.21×10^{5}	9.00×10^{6}	1.34×10^{-2}	2.03×10^{7}	5.94×10^{-3}
563	350		827.17	23.20	1692	7.313×10	4.29×10^{-9}	4.23×10^{-12}	7.06×10^{-16}	5.77×10^{-13}	1.85×10^{7}	1.24×10^{5}	1.35×10^{7}	9.16×10^{-3}	3.05×10^{7}	4.07×10^{-3}
604	375		817.60	23.04	1779	7.832×10	2.61×10^{-9}	2.58×10^{-12}	3.93×10^{-16}	3.21×10^{-13}	1.04×10^{7}	1.28×10^{5}	2.40×10^{7}	5.32×10^{-3}	5.40×10^{7}	2.36×10^{-3}
630	391	0.000	811.57	22.92	1833	8.185×10	1.83×10^{-9}	1.81×10^{-12}	2.75×10^{-16}	2.25×10^{-13}	7.27×10^{6}	1.30×10^{5}	3.44×10^{7}	3.78×10^{-3}	7.74×10^{7}	1.68×10^{-3}
644	400	1.633×10^{12}	808.22	22.92	1833	8.219×10	1.55×10^{-9}	1.53×10^{-12}	2.33×10^{-16}	1.90×10^{-13}	6.18×10^{6}	1.30×10^{5}	4.05×10^{7}	3.21×10^{-3}	9.11×10^{7}	1.43×10^{-3}
724	450	1.102×10^{14}	790.01	22.92	1833	8.409×10	5.89×10^{-10}	5.81×10^{-13}	8.86×10^{-17}	7.24×10^{-14}	2.34×10^{6}	1.30×10^{5}	9.79×10^{7}	1.33×10^{-3}	2.20×10^{8}	5.91×10^{-4}
765	475	1.563×10^{14}	781.14	22.92	1833	8.504×10	3.65×10^{-10}	3.60×10^{-13}	5.51×10^{-17}	4.51×10^{-14}	1.46×10^{6}	1.30×10^{5}	1.72×10^{8}	7.59×10^{-4}	3.86×10^{8}	3.37×10^{-4}
805	500	2.019×10^{14}	772.42	22.92	1833	8.600×10	2.28×10^{-10}	2.25×10^{-13}	3.43×10^{-17}	2.80×10^{-14}	9.08×10^{5}	1.30×10^{5}	2.76×10^{8}	4.72×10^{-4}	6.20×10^{8}	2.10×10^{-4}
885	550	2.917×10^{14}	755.40	22.92	1833	8.794×10	9.05×10^{-11}	8.93×10^{-14}	1.36×10^{-17}	1.11×10^{-14}	3.60×10^{5}	1.30×10^{5}	6.95×10^{8}	2.87×10^{-4}	1.56×10^{9}	1.28×10^{-4}
966	600	3.794×10^{14}	738.94	22.92	1833	8.975×10	3.65×10^{-11}	3.61×10^{-14}	5.51×10^{-18}	4.51×10^{-15}	1.46×10^{5}	1.30×10^{5}	1.72×10^{9}	7.59×10^{-5}	3.86×10^{9}	3.37×10^{-5}
1127	700	5.493×10^{14}	707.59	22.92	1833	9.375×10	6.32×10^{-12}	6.24×10^{-15}	9.53×10^{-19}	7.79×10^{-16}	2.52×10^{4}	1.30×10^{5}	9.92×10^{9}	1.31×10^{-5}	2.23×10^{10}	5.83×10^{-6}
1288	800	7.120×10^{14}	678.19	22.92	1833	9.795×10	1.18×10^{-12}	1.17×10^{-15}	1.78×10^{-19}	1.45×10^{-16}	4.70×10^{3}	1.30×10^{5}	5.33×10^{10}	2.44×10^{-6}	1.19×10^{11}	1.09×10^{-6}
1448	900	8.680×10^{14}	650.59	22.92	1833	1.021×10^{2}	2.37×10^{-12}	2.34×10^{-15}	3.56×10^{-20}	2.91×10^{-17}	9.43×10^{2}	1.30×10^{5}	2.65×10^{11}	4.90×10^{-7}	5.93×10^{11}	2.18×10^{-7}
1609	1000	1.018×10^{15}	624.64	22.92	1833	1.063×10^{2}	5.03×10^{-14}	4.96×10^{-17}	7.57×10^{-21}	6.19×10^{-18}	2.01×10^{2}	1.30×10^{5}	1.25×10^{12}	1.04×10^{-7}	2.79×10^{12}	4.64×10^{-8}
1931	1200	1.300×10^{15}	555.43	22.92	1833	1.196×10^{2}	2.75×10^{-16}	2.72×10^{-18}	4.14×10^{-22}	3.39×10^{-19}	1.09 x 10	1.30×10^{5}	2.29×10^{12}	5.69×10^{-9}	5.11×10^{12}	2.53×10^{-9}
2253	1400	1.561×10^{15}	534.95	22.92	1833	1.242×10^{2}	1.87×10^{-15}	1.84×10^{-18}	2.81×10^{-22}	2.29×10^{-25}	7.42×10^{-1}	1.30×10^{5}	3.37×10^{14}	3.86×10^{-10}	7.54×10^{14}	1.71×10^{-10}
2414	1500	1.684×10^{15}	515.54	22.92	1833	1.289×10^{2}	5.22×10^{-17}	5.15×10^{-20}	7.83×10^{-24}	6.40×10^{-21}	2.07×10^{-1}	1.30×10^{5}	1.21×10^{15}	1.08×10^{-10}	2.70×10^{15}	4.79×10^{-11}
2816	1750	1.974×10^{15}	471.41	22.92	1833	1.409×10^{2}	2.62×10^{-18}	2.59×10^{-21}	3.94×10^{-25}	3.23×10^{-22}	1.05×10^{-2}	1.30×10^{5}	2.39×10^{15}	5.44×10^{-13}	5.35×10^{15}	2.42×10^{-12}
3219	2000	2.239×10^{15}	432.72	22.92	1833	1.535×10^{2}	1.71×10^{-19}	1.69×10^{-22}	2.58×10^{-25}	2.11×10^{-23}	6.82×10^{-4}	1.30×10^{5}	3.67×10^{17}	3.55×10^{-13}	8.20×10^{17}	1.58×10^{-12}
4023	2500	2.708×10^{15}	368.36	22.92	1833	1.803×10^{2}	1.36×10^{-21}	1.34×10^{-24}	2.04×10^{-28}	1.67×10^{-26}	5.40×10^{-6}	1.30×10^{5}	4.63×10^{19}	2.81×10^{-15}	1.03×10^{20}	1.25×10^{-15}
4828	3000	3.109×10^{15}	317.36	22.92	1833	2.053×10^{2}	2.16×10^{-22}	2.14×10^{-25}	3.25×10^{-29}	2.66×10^{-27}	8.62×10^{-8}	1.30×10^{5}	2.90×10^{21}	4.48×10^{-17}	6.49×10^{21}	1.99×10^{-17}
5633	3500	3.458×10^{15}	276.27	22.92	1833	2.404×10^{2}	5.94×10^{-25}	5.86×10^{-28}	8.91×10^{-32}	7.28×10^{-29}	2.36×10^{-8}	1.30×10^{5}	1.06×10^{23}	1.23×10^{-18}	2.37×10^{23}	5.45×10^{-19}
6438	4000	3.762×10^{15}	242.66	22.92	1833	2.737×10^{2}	2.59×10^{-26}	2.56×10^{-29}	3.90×10^{-33}	3.19×10^{-30}	1.03×10^{-10}	1.30×10^{5}	2.43×10^{24}	5.36×10^{-19}	5.42×10^{24}	2.38×10^{-19}
7242	4500	4.030×10^{15}	214.84	22.92	1833	3.092×10^{2}	1.62×10^{-27}	1.60×10^{-30}	2.44×10^{-34}	2.00×10^{-31}	6.46×10^{-12}	1.30×10^{5}	3.87×10^{25}	3.36×10^{-21}	8.65×10^{25}	1.49×10^{-21}
8047	5000	4.267×10^{15}	191.54	22.92	1833	3.468×10^{2}	1.41×10^{-28}	1.39×10^{-31}	2.12×10^{-35}	1.73×10^{-32}	5.62×10^{-13}	1.30×10^{5}	4.46×10^{26}	2.92×10^{-22}	9.95×10^{26}	1.30×10^{-22}
8851	5500	4.480×10^{15}	171.83	22.92	1833	3.866×10^{2}	1.57×10^{-29}	1.55×10^{-32}	2.35×10^{-36}	1.92×10^{-33}	6.22×10^{-14}	1.30×10^{5}	4.03×10^{27}	3.23×10^{-23}	8.99×10^{27}	1.44×10^{-23}

1 millibar (mb) = 10^2 dynes/cm² = 0.750 mm of Hg

Table 3.24 ATMOSPHERIC MODEL II. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER
Latitude 45°. Metric Units. $p_0 = 1014$ mb, $\rho_0 = 1.223 \times 10^{-3}$ gm/cm3. Table 37 of Ref. 3.20.

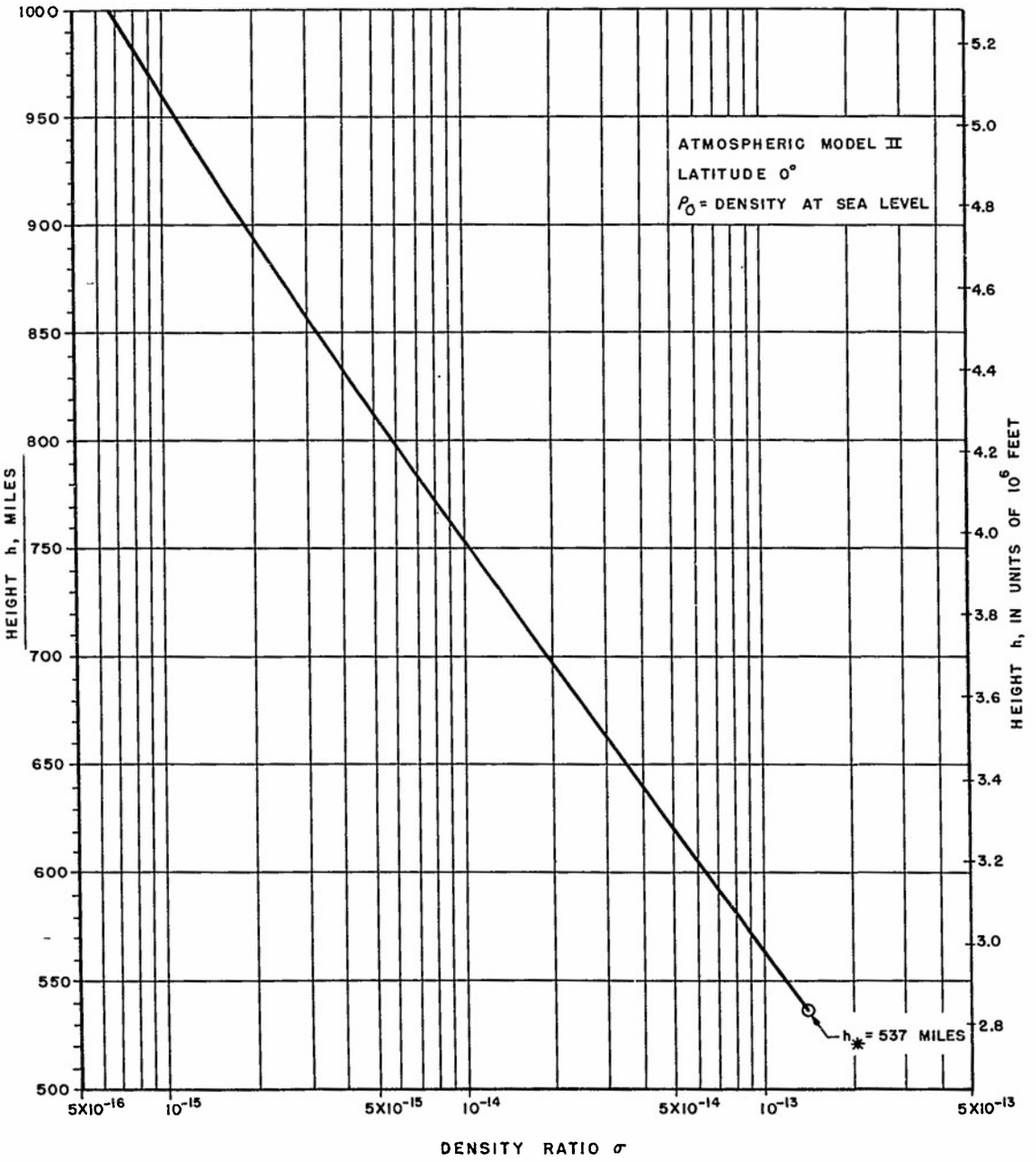


Fig. 3.48 ADOPTED VALUES OF THE DENSITY RATIO (σ) FOR ATMOSPHERIC MODEL II FROM h_* UP TO 1000 MILES

Latitude 0°. Engineering Units. Fig. 29 of Ref. 3.20.

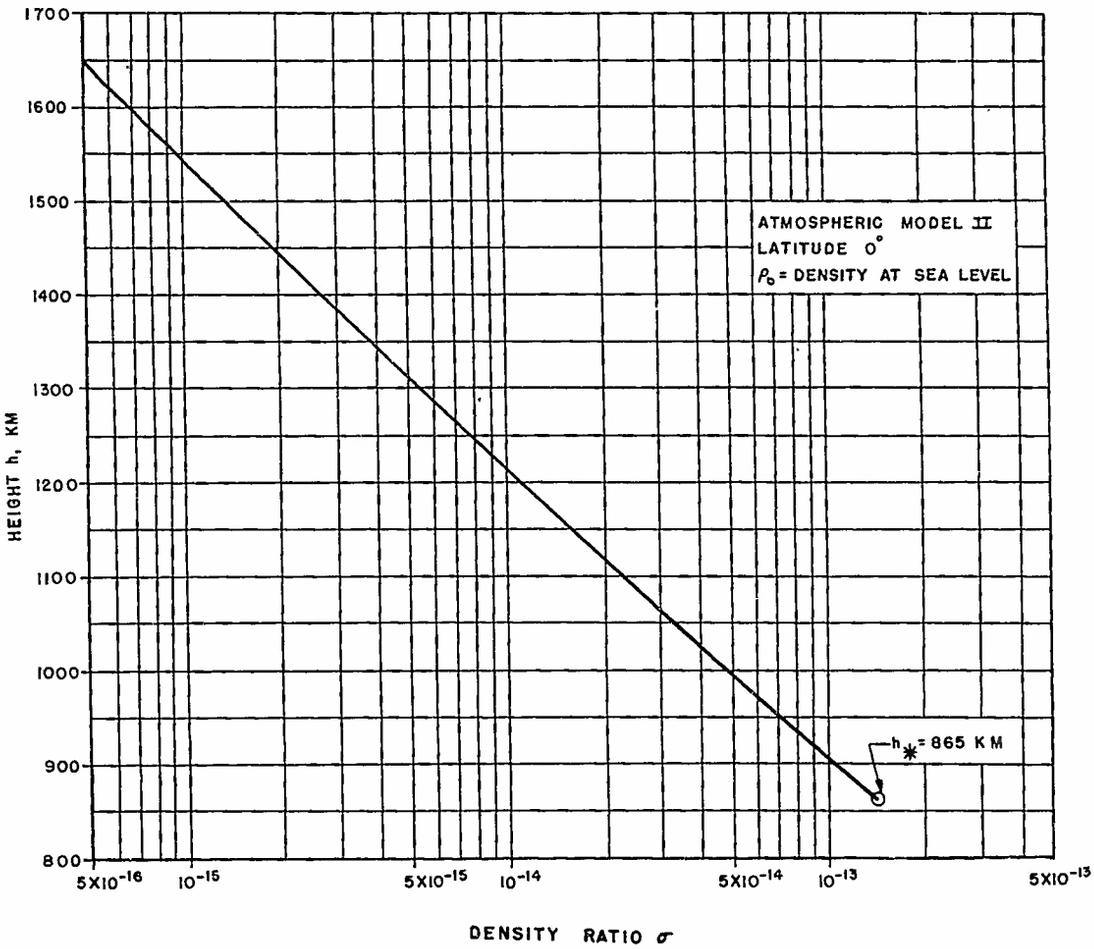


Fig. 3.49 ADOPTED VALUES OF THE DENSITY RATIO (σ) FOR ATMOSPHERIC MODEL II FROM h_* UP TO 1650 KM
Latitude 0°. Metric Units. Fig. 30 of Ref. 20.

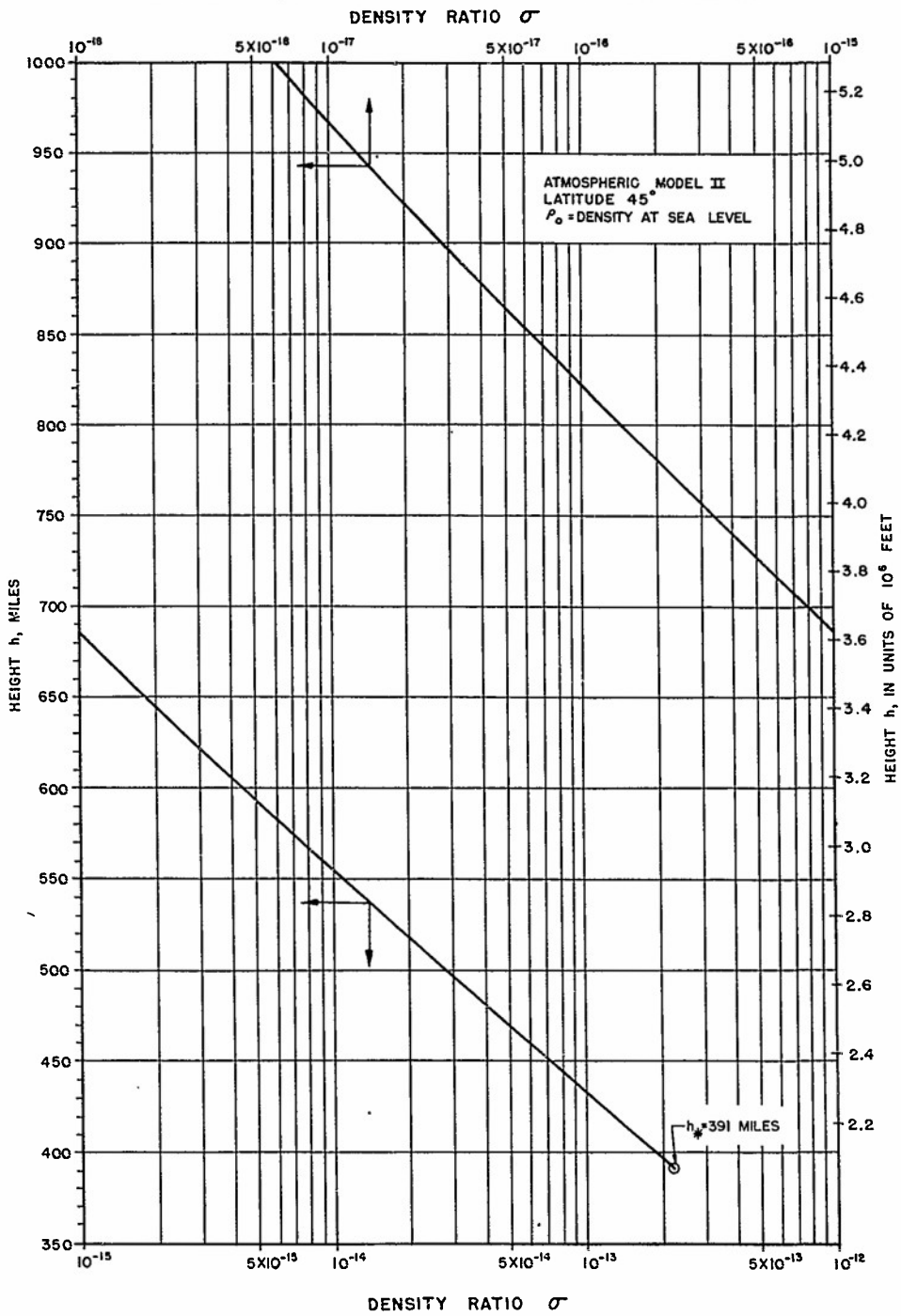


Fig. 3.50 ADOPTED VALUES OF THE DENSITY RATIO (σ) FOR ATMOSPHERIC MODEL II FROM h_* UP TO 1000 MILES
Latitude 45°. Engineering Units. Fig. 31 of Ref. 3.20.

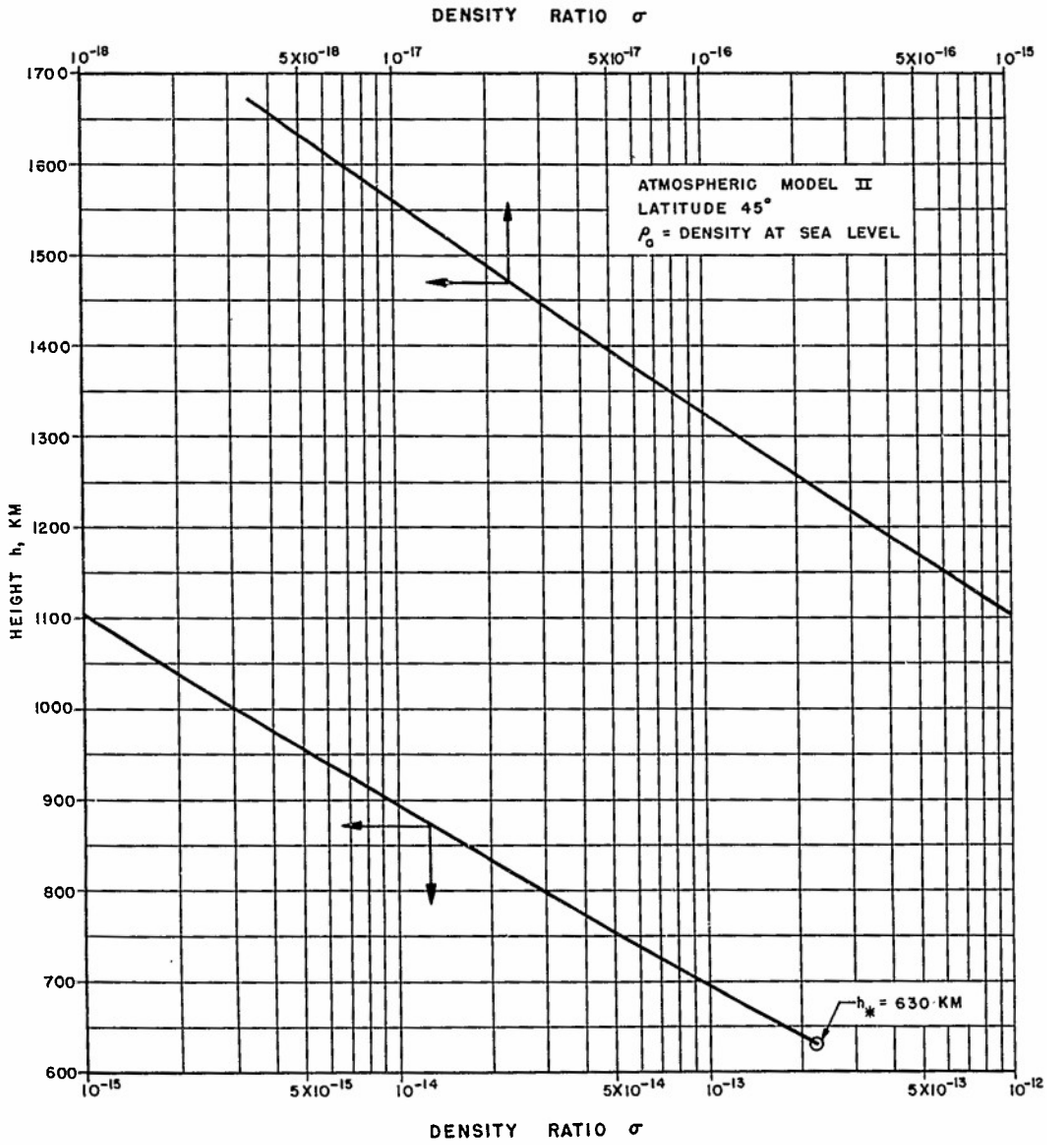


Fig. 3.51 ADOPTED VALUES OF THE DENSITY RATIO (σ) FOR ATMOSPHERIC MODEL II FROM h_* UP TO 1650 KM

Latitude 45°. Metric Units. Fig. 32 of Ref. 3.20.

Height h		Apparent Gravity g'	Temp T	Percentage Composition by Mass C_x				Mean Mol Wt	Scale Height H	Pressure p	Pressure Ratio	Density ρ	Density Ratio σ	Number Density n	Mean Particle Speed	$d = 2 \times 10^{-8}$ cm		$d = 3 \times 10^{-8}$ cm	
				Atomic Oxygen	Atomic Nitrogen	Atomic Helium	Atomic Hydrogen									Mean Free Path	Mean Collision Freq	Mean Free Path	Mean Collision Freq
mi	ft	ft/sec²	°R					M	ft	lb/ft²	p/p₀	slugs/ft³	ρ/ρ₀	particles/ft³	v ft/sec	λ ft	f 1/sec	λ ft	f 1/sec
248.5	1.312×10^6	28.393	3240	33% O	67% N_2	--	--	24.00	2.364×10^3	4.33×10^{-7}	2.04×10^{-10}	6.43×10^{-14}	2.82×10^{-11}	2.37×10^{13}	4.13×10^3	2.21×10^4	1.87×10^{-1}	9.81×10^3	4.22×10^{-1}
264.1	1.394×10^6	28.183	3330	--	--	--	--	21.60	2.720×10^3	3.12×10^{-7}	1.47×10^{-10}	4.08×10^{-14}	1.79×10^{-11}	1.67×10^{13}	4.43×10^3	3.14×10^4	1.41×10^{-1}	1.39×10^4	3.17×10^{-1}
279.6	1.476×10^6	27.976	3420	--	--	--	--	19.20	3.166×10^3	2.36×10^{-7}	1.11×10^{-10}	2.66×10^{-14}	1.17×10^{-11}	1.23×10^{13}	4.76×10^3	4.26×10^4	1.11×10^{-1}	1.89×10^4	2.51×10^{-1}
295.1	1.558×10^6	27.771	3510	--	--	--	--	16.80	3.740×10^3	1.86×10^{-7}	8.77×10^{-11}	1.79×10^{-14}	7.85×10^{-12}	9.43×10^{12}	5.15×10^3	5.58×10^4	9.24×10^{-2}	2.47×10^4	2.08×10^{-1}
310.7	1.640×10^6	27.568	3600	22.21	77.78	1.39×10^{-4}	6.00×10^{-6}	14.40	4.509×10^3	1.57×10^{-7}	7.41×10^{-11}	1.26×10^{-14}	5.54×10^{-12}	7.76×10^{12}	5.64×10^3	6.76×10^4	8.32×10^{-2}	3.00×10^4	1.88×10^{-1}
326.2	1.722×10^6	27.367	3690	21.79	78.21	1.58×10^{-4}	7.09×10^{-6}	14.39	4.659×10^3	1.31×10^{-7}	6.20×10^{-11}	1.03×10^{-14}	4.51×10^{-12}	6.31×10^{12}	5.71×10^3	8.30×10^4	6.87×10^{-2}	3.67×10^4	1.55×10^{-1}
341.8	1.804×10^6	27.169	3780	21.41	78.59	1.80×10^{-4}	8.34×10^{-6}	14.38	4.810×10^3	1.10×10^{-7}	5.20×10^{-11}	8.43×10^{-15}	3.69×10^{-12}	5.18×10^{12}	5.77×10^3	1.01×10^5	5.70×10^{-2}	4.49×10^4	1.29×10^{-1}
357.3	1.886×10^6	26.972	3870	20.99	79.01	2.03×10^{-4}	9.75×10^{-6}	14.38	4.961×10^3	9.32×10^{-8}	4.40×10^{-11}	6.97×10^{-15}	3.05×10^{-12}	4.28×10^{12}	5.84×10^3	1.22×10^5	4.77×10^{-2}	5.41×10^4	1.08×10^{-1}
372.8	1.968×10^6	26.778	3960	20.62	79.38	2.28×10^{-4}	1.13×10^{-5}	14.37	5.118×10^3	7.92×10^{-8}	3.74×10^{-11}	5.79×10^{-15}	2.53×10^{-12}	3.57×10^{12}	5.91×10^3	1.47×10^5	4.01×10^{-2}	6.53×10^4	9.44×10^{-2}
388.4	2.050×10^6	26.590	4050	20.26	79.74	2.56×10^{-4}	1.21×10^{-5}	14.36	5.272×10^3	6.76×10^{-8}	3.20×10^{-11}	4.83×10^{-15}	2.11×10^{-12}	2.97×10^{12}	5.97×10^3	1.77×10^5	3.39×10^{-2}	7.81×10^4	7.64×10^{-2}
403.9	2.133×10^6	26.396	4140	19.92	80.08	2.86×10^{-4}	1.53×10^{-5}	14.36	5.433×10^3	5.80×10^{-8}	2.74×10^{-11}	4.06×10^{-15}	1.77×10^{-12}	2.49×10^{12}	6.04×10^3	2.10×10^5	2.88×10^{-2}	9.32×10^4	6.49×10^{-2}
419.4	2.215×10^6	26.208	4230	19.59	80.41	3.18×10^{-4}	1.74×10^{-5}	14.35	5.590×10^3	5.00×10^{-8}	2.36×10^{-11}	3.42×10^{-15}	1.50×10^{-12}	2.10×10^{12}	6.10×10^3	2.49×10^5	2.45×10^{-2}	1.11×10^5	5.53×10^{-2}
435.0	2.297×10^6	26.012	4320	19.27	80.73	3.53×10^{-4}	1.99×10^{-5}	14.35	5.758×10^3	4.33×10^{-8}	2.04×10^{-11}	2.89×10^{-15}	1.27×10^{-12}	1.78×10^{12}	6.17×10^3	2.94×10^5	2.10×10^{-2}	1.30×10^5	4.74×10^{-2}
450.5	2.379×10^6	25.838	4410	18.95	81.05	3.94×10^{-4}	2.29×10^{-5}	14.34	5.919×10^3	3.72×10^{-8}	1.76×10^{-11}	2.45×10^{-15}	1.07×10^{-12}	1.50×10^{12}	6.23×10^3	3.48×10^5	1.79×10^{-2}	1.54×10^5	4.04×10^{-2}
466.0	2.461×10^6	25.656	4500	18.68	81.32	4.32×10^{-4}	2.58×10^{-5}	14.33	6.083×10^3	3.28×10^{-8}	1.55×10^{-11}	2.10×10^{-15}	9.21×10^{-13}	1.30×10^{12}	6.30×10^3	4.04×10^5	1.56×10^{-2}	1.79×10^5	3.52×10^{-2}
497.1	2.625×10^6	25.300	4500	18.12	81.88	5.24×10^{-4}	3.31×10^{-5}	14.32	6.174×10^3	2.51×10^{-8}	1.18×10^{-11}	1.61×10^{-15}	7.04×10^{-13}	9.91×10^{11}	6.30×10^3	5.28×10^5	1.20×10^{-2}	2.34×10^5	2.69×10^{-2}
528.2	2.789×10^6	24.952	4500	17.58	82.42	6.34×10^{-4}	4.24×10^{-5}	14.31	6.265×10^3	1.93×10^{-8}	9.11×10^{-12}	1.23×10^{-15}	5.40×10^{-13}	7.62×10^{11}	6.30×10^3	6.86×10^5	9.20×10^{-2}	3.05×10^5	2.07×10^{-2}
559.2	2.953×10^6	24.612	4500	17.06	82.94	7.65×10^{-4}	5.40×10^{-5}	14.30	6.355×10^3	1.49×10^{-8}	7.02×10^{-12}	9.51×10^{-16}	4.16×10^{-13}	5.89×10^{11}	6.31×10^3	8.89×10^5	7.10×10^{-2}	3.94×10^5	1.60×10^{-2}
590.3	3.117×10^6	24.278	4500	16.56	83.44	9.21×10^{-4}	6.86×10^{-5}	14.30	6.447×10^3	1.15×10^{-8}	5.44×10^{-12}	7.36×10^{-16}	3.22×10^{-13}	4.56×10^{11}	6.31×10^3	1.15×10^5	5.49×10^{-2}	5.12×10^5	1.24×10^{-2}
621.4	3.281×10^6	23.950	4500	16.07	83.92	1.11×10^{-3}	8.68×10^{-5}	14.29	6.539×10^3	8.94×10^{-9}	4.22×10^{-12}	5.71×10^{-16}	2.50×10^{-13}	3.54×10^{11}	6.32×10^3	1.48×10^5	4.27×10^{-2}	6.56×10^5	9.61×10^{-2}
683.5	3.609×10^6	23.316	4500	15.16	84.84	1.58×10^{-3}	1.38×10^{-4}	14.27	6.725×10^3	5.45×10^{-9}	2.57×10^{-12}	3.48×10^{-16}	1.52×10^{-13}	2.15×10^{11}	6.33×10^3	2.42×10^5	2.60×10^{-2}	1.08×10^6	5.86×10^{-2}
745.6	3.937×10^6	22.706	4500	14.31	85.68	2.24×10^{-3}	2.15×10^{-4}	14.25	6.913×10^3	3.36×10^{-9}	1.59×10^{-12}	2.16×10^{-16}	9.40×10^{-14}	1.33×10^{11}	6.33×10^3	3.94×10^5	1.61×10^{-2}	1.75×10^6	3.62×10^{-2}
807.8	4.265×10^6	22.119	4500	13.53	86.47	3.14×10^{-3}	3.33×10^{-4}	14.24	7.104×10^3	2.11×10^{-9}	9.96×10^{-13}	1.34×10^{-16}	5.88×10^{-14}	8.35×10^{10}	6.33×10^3	6.27×10^5	1.01×10^{-2}	2.79×10^6	2.23×10^{-2}
869.9	4.593×10^6	21.556	4500	12.79	87.20	4.36×10^{-3}	5.09×10^{-4}	14.22	7.297×10^3	1.34×10^{-9}	6.31×10^{-13}	8.50×10^{-17}	3.72×10^{-14}	5.30×10^{10}	6.33×10^3	9.88×10^5	6.40×10^{-2}	4.40×10^6	1.44×10^{-2}
932.0	4.921×10^6	21.013	4500	12.11	87.88	6.00×10^{-3}	7.70×10^{-4}	14.21	7.492×10^3	8.58×10^{-10}	4.05×10^{-13}	5.46×10^{-17}	2.39×10^{-14}	3.40×10^{10}	6.33×10^3	1.54×10^6	4.11×10^{-2}	6.86×10^6	9.25×10^{-2}
994.2	5.249×10^6	20.491	4500	11.48	88.51	8.19×10^{-3}	1.15×10^{-3}	14.20	7.690×10^3	5.58×10^{-10}	2.63×10^{-13}	3.53×10^{-17}	1.55×10^{-14}	2.20×10^{10}	6.33×10^3	2.38×10^6	2.67×10^{-2}	1.06×10^7	6.00×10^{-2}
1056	5.577×10^6	19.988	4500	10.89	89.09	1.11×10^{-2}	1.70×10^{-3}	14.18	7.892×10^3	3.65×10^{-10}	1.73×10^{-13}	2.31×10^{-17}	1.02×10^{-14}	1.44×10^{10}	6.34×10^3	3.61×10^6	1.75×10^{-2}	1.61×10^7	3.94×10^{-2}
1118	5.905×10^6	19.503	4500	10.34	89.64	1.49×10^{-2}	2.50×10^{-3}	14.17	8.095×10^3	2.42×10^{-10}	1.14×10^{-13}	1.54×10^{-17}	6.73×10^{-15}	9.60×10^9	6.34×10^3	5.45×10^6	1.16×10^{-2}	2.42×10^7	2.62×10^{-2}
1181	6.234×10^6	19.035	4500	9.814	90.16	1.97×10^{-2}	3.62×10^{-3}	14.16	8.301×10^3	1.63×10^{-10}	7.69×10^{-14}	1.03×10^{-17}	4.51×10^{-15}	6.43×10^9	6.34×10^3	8.14×10^6	7.80×10^{-2}	3.61×10^7	1.76×10^{-2}
1243	6.562×10^6	18.584	4500	9.350	90.62	2.63×10^{-2}	5.21×10^{-3}	14.15	8.511×10^3	1.10×10^{-10}	5.19×10^{-14}	6.95×10^{-18}	3.05×10^{-15}	4.36×10^9	6.35×10^3	1.20×10^7	5.28×10^{-2}	5.35×10^7	1.19×10^{-2}
1553	8.202×10^6	16.554	4500	7.379	92.50	9.72×10^{-2}	2.83×10^{-3}	14.04	9.624×10^3	1.79×10^{-11}	8.46×10^{-15}	1.13×10^{-18}	4.93×10^{-16}	7.08×10^8	6.36×10^3	7.38×10^6	8.64×10^{-2}	3.28×10^7	1.94×10^{-2}
1864	9.842×10^6	14.839	4500	5.936	93.62	.3105	.1274	13.77	1.095×10^3	3.61×10^{-12}	1.71×10^{-15}	2.23×10^{-19}	9.75×10^{-17}	1.43×10^8	6.43×10^3	3.64×10^6	1.76×10^{-2}	1.62×10^8	3.96×10^{-2}
2175	1.148×10^7	13.377	4500	4.836	93.80	.8740	.4885	12.98	1.289×10^3	9.02×10^{-13}	4.26×10^{-16}	5.24×10^{-20}	2.29×10^{-17}	3.57×10^7	6.63×10^3	1.47×10^6	4.52×10^{-2}	6.53×10^8	1.02×10^{-2}
2485	1.312×10^7	12.122	4500	3.947	92.25	2.186	1.616	11.13	1.659×10^3	2.90×10^{-13}	1.37×10^{-16}	1.44×10^{-20}	6.31×10^{-18}	1.14×10^7	7.15×10^3	4.56×10^6	1.57×10^{-2}	2.03×10^9	3.52×10^{-2}
2796	1.476×10^7	11.035	4500	3.156	87.30	4.836	4.606	8.18	2.478×10^3	1.27×10^{-13}	5.99×10^{-17}	4.64×10^{-21}	2.03×10^{-18}	5.01×10^6	8.33×10^3	1.04×10^6	8.00×10^{-2}	4.63×10^9	1.80×10^{-2}
3107	1.640×10^7	10.087	4500	2.389	77.22	9.272	11.12	5.26	4.217×10^3	7.56×10^{-14}	3.57×10^{-17}	1.78×10^{-21}	7.78×10^{-19}	3.00×10^6	1.04×10^6	1.75×10^{11}	5.95×10^{-2}	7.78×10^{10}	1.34×10^{-2}
3728	1.968×10^7	8.525	4500	1.010	42.86	20.02	36.10	2.28	1.153×10^3	4.70×10^{-14}	2.22×10^{-17}	4.78×10^{-22}	2.09×10^{-19}	1.85×10^6	1.58×10^4	2.82×10^{11}	5.61×10^{-2}	1.25×10^{11}	1.26×10^{-2}
4350	2.297×10^7	7.300	4500	.2973	15.90	23.62	60.19	1.50	2.046×10^3	3.80×10^{-14}	1.80×10^{-17}	2.54×10^{-22}	1.12×10^{-19}	1.50×10^6	1.95×10^4	3.48×10^{11}	5.61×10^{-2}	1.55×10^{11}	1.26×10^{-2}
4971	2.625×10^7	6.321	4500	8.13×10^{-2}	5.306	21.34	72.69	1.28	2.775×10^3	3.32×10^{-14}	1.57×10^{-17}	1.89×10^{-22}	8.29×10^{-20}	1.31×10^6	2.11×10^4	3.97×10^{11}	5.31×10^{-2}	1.77×10^{11}	1.19×10^{-2}
5592	2.953×10^7	5.527	4500	2.42×10^{-2}	1.881	18.00	80.10	1.19	3.405×10^3	2.99×10^{-14}	1.41×10^{-17}	1.59×10^{-22}	6.95×10^{-20}	1.18×10^6	2.19×10^4	4.43×10^{11}	4.94×10^{-2}	1.97×10^{11}	1.11×10^{-2}
6214	3.281×10^7	4.873	4500	8.14×10^{-3}	.7357	15.07	84.19	1.14	4.010×10^3	2.74×10^{-14}	1.29×10^{-17}	1.40×10^{-22}	6.12×10^{-20}	1.08×10^6	2.23×10^4	4.86×10^{11}	4.61×10^{-2}	2.15×10^{11}	1.04×10^{-2}
9320	4.921×10^7	2.862	4500	1.48×10^{-3}	2.31×10^{-2}	7.310	92.67	1.06	7.331×10^3	2.02×10^{-14}	9.54×10^{-18}	9.63×10^{-23}	4.22×10^{-20}	7.99×10^5	2.31×10^4	6.53×10^{11}	3.53×10^{-2}	2.91×10^{11}	7.95×10^{-3}
12427	6.562×10^7	1.880	4500	1.19×10^{-3}	2.61×10^{-2}	4.528	95.47	1.04	1.141×10^3	1.69×10^{-14}	7.98×10^{-18}	7.88×10^{-23}	3.45×10^{-20}	6.68×10^8	2.34×10^4	7.84×10^{11}	2.99×10^{-2}	3.48×10^{11}	6.72×10^{-3}
15534	8.202×10^7	1.329	4500	2.12×10^{-3}	5.87×10^{-2}	3.244	96.76	1.03	1.630×10^3	1.50×10^{-14}	7.07×10^{-18}	6.91×10^{-23}	3.03×10^{-20}	5.92×10^5	2.35×10^4	8.83×10^{11}	2.66×10^{-2}	3.94×10^{11}	5.99×10^{-3}
18641	9.842×10^7	0.989	4500	6.06×10^{-3}	1.99×10^{-2}	2.541	97.46	1.03	2.202×10^3	1.37×10^{-14}	6.49×10^{-18}	6.31×10^{-23}	2.76×10^{-20}	5.44×10^5	2.36×10^4	9.61×10^{11}	2.45×10^{-2}	4.26×10^{11}	5.51×10^{-3}
21748	1.148×10^8	0.764	4500	2.34×10^{-3}	8.71×10^{-2}	2.109	97.89	1.02	2.858×10^3	1.29×10^{-14}	6.08×10^{-18}	5.88×10^{-23}	2.58×10^{-20}	5.10×10^5	2.36×10^4	1.03×10^{12}	2.30×10^{-2}	4.56×10^{11}	5.17×10^{-3}
24855	1.312×10^8	0.609	4500	1.11×10^{-3}	4.56×10^{-2}	1.822	98.18	1.02	3.598×10^3	1.22×10^{-14}	5.77×10^{-18}	5.59×10^{-23}	2.45×10^{-20}	4.84×10^5	2.36×10^4	1.08×10^{12}	2.18×10^{-2}	4.79×10^{11}	4.91×10^{-3}
27961	1.476×10^8	0.496	4500	6.08×10^{-3}	2.71×10^{-2}	1.618	98.38	1.02	4.422×10^3	1.17×10^{-14}	5.54×10^{-18}	5.36×10^{-23}	2.34×10^{-20}	4.64×10^5	2.36×10^4	1.13×10^{12}	2.10×10^{-2}	5.02×10^{11}	4.72×10^{-3}
31068	1.640×10^8	0.412	4500	3.71×10^{-3}	1.76×10^{-2}	1.468	98.53	1.02	5.330×10^3	1.13×10^{-14}	5.36×10^{-18}	5.16×10^{-23}	2.26×10^{-20}	4.47×10^5	2.37×10^4	1.16×10^{12}	2.03×10^{-2}	5.18×10^{11}	4.56×10^{-3}
34175	1.804×10^8	0.347	4500	2.45×10^{-3}	1.23×10^{-2}	1.352	98.65	1.02	6.322×10^3	1.10×10^{-14}	5.21×10^{-18}	5.03×10^{-23}	2.20×10^{-20}	4.36×10^5	2.37×10^4	1.20×10^{12}	1.97×10^{-2}	5.31×10^{11}	4.43×10^{-3}
37282	1.968×10^8	0.297	4500	1.72×10^{-3}	9.08×10^{-3}	1.261	98.74	1.02	7.400×10^3	1.08×10^{-14}	5.08×10^{-18}	4.89×10^{-23}	2.15×10^{-20}	4.25×10^5	2.37×10^4	1.23×10^{12}	1.93×10^{-2}	5.45×10^{11}	4.34×10^{-3}

Table 3.25 ATMOSPHERIC MODEL III. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER
Latitude 0°. Engineering Units. $p_0 = 2115$ lb/ft², $\rho_0 = 2.286 \times 10^{-3}$ slug/ft³. Table 42 of Ref. 3.20.

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Height h		Apparent Gravity g'	Temp T	Percentage Composition by Mass C_x				Mean Mol Wt M	Scale Height H	Pressure p	Pressure Ratio p/p_0	Density ρ	Density Ratio σ	Number Density n	Mean Particle Speed v	$d = 2 \times 10^{-8}$ cm		$d = 3 \times 10^{-8}$ cm	
				Atomic Oxygen	Atomic Nitrogen	Atomic Helium	Atomic Hydrogen									Mean Free Path λ	Mean Collision Freq f	Mean Free Path λ	Mean Collision Freq f
km	mi	cm/sec²	°K						km	millibars		gram/cm³	ρ/ρ_0	particles/cm³	cm/sec	cm	1/sec	cm	1/sec
400	248.5	865.42	1800	33%O	67%N_2			24.00	7.21×10	2.07×10^{-7}	2.04×10^{-10}	3.31×10^{-14}	2.82×10^{-11}	8.37×10^{8}	1.26×10^{5}	6.74×10^{6}	1.87×10^{-1}	2.99×10^{6}	4.22×10^{-1}
425	264.1	859.02	1850					21.60	8.29×10	1.49×10^{-7}	1.47×10^{-10}	2.10×10^{-14}	1.79×10^{-11}	5.89×10^{8}	1.35×10^{5}	9.58×10^{6}	1.41×10^{-1}	4.24×10^{6}	3.17×10^{-1}
450	279.6	852.70	1900					19.20	9.65×10	1.13×10^{-7}	1.11×10^{-10}	1.37×10^{-14}	1.17×10^{-11}	4.33×10^{8}	1.45×10^{5}	1.30×10^{7}	1.11×10^{-1}	5.77×10^{6}	2.51×10^{-1}
475	295.1	846.45	1950					16.80	1.14×10^{3}	8.89×10^{-8}	8.77×10^{-11}	9.21×10^{-15}	7.85×10^{-12}	3.33×10^{8}	1.57×10^{5}	1.70×10^{7}	9.24×10^{-2}	7.52×10^{6}	2.08×10^{-1}
500	310.7	840.27	2000	22.21	77.78	1.39×10^{-4}	6.00×10^{-5}	14.40	1.37×10^{3}	7.51×10^{-8}	7.41×10^{-11}	6.50×10^{-15}	5.54×10^{-12}	2.74×10^{8}	1.72×10^{5}	2.06×10^{7}	8.32×10^{-2}	9.13×10^{6}	1.88×10^{-1}
525	326.2	834.16	2050	21.79	78.21	1.58×10^{-4}	7.09×10^{-5}	14.39	1.42×10^{3}	6.28×10^{-8}	6.20×10^{-11}	5.30×10^{-15}	4.51×10^{-12}	2.23×10^{8}	1.74×10^{5}	2.53×10^{7}	6.87×10^{-2}	1.12×10^{7}	1.55×10^{-1}
550	341.8	828.11	2100	21.41	78.59	1.80×10^{-4}	8.34×10^{-5}	14.38	1.47×10^{3}	5.27×10^{-8}	5.20×10^{-11}	4.34×10^{-15}	3.69×10^{-12}	1.83×10^{8}	1.76×10^{5}	3.08×10^{7}	5.70×10^{-2}	1.37×10^{7}	1.29×10^{-1}
575	357.3	822.12	2150	20.99	79.01	2.03×10^{-4}	9.75×10^{-5}	14.38	1.51×10^{3}	4.46×10^{-8}	4.40×10^{-11}	3.59×10^{-15}	3.05×10^{-12}	1.51×10^{8}	1.78×10^{5}	3.73×10^{7}	4.77×10^{-2}	1.65×10^{7}	1.08×10^{-1}
600	372.8	816.20	2200	20.62	79.38	2.28×10^{-4}	1.13×10^{-5}	14.37	1.56×10^{3}	3.79×10^{-8}	3.74×10^{-11}	2.98×10^{-15}	2.53×10^{-12}	1.26×10^{8}	1.80×10^{5}	4.49×10^{7}	4.01×10^{-2}	1.99×10^{7}	9.04×10^{-2}
625	388.4	810.45	2250	20.26	79.74	2.56×10^{-4}	1.21×10^{-5}	14.36	1.61×10^{3}	3.24×10^{-8}	3.20×10^{-11}	2.49×10^{-15}	2.11×10^{-12}	1.05×10^{8}	1.82×10^{5}	5.38×10^{7}	3.39×10^{-2}	2.38×10^{7}	7.64×10^{-2}
650	403.9	804.56	2300	19.92	80.08	2.86×10^{-4}	1.53×10^{-5}	14.36	1.66×10^{3}	2.78×10^{-8}	2.74×10^{-11}	2.09×10^{-15}	1.77×10^{-12}	8.81×10^{7}	1.84×10^{5}	6.41×10^{7}	2.84×10^{-2}	2.84×10^{7}	6.49×10^{-2}
675	419.4	798.82	2350	19.59	80.41	3.18×10^{-4}	1.74×10^{-5}	14.35	1.70×10^{3}	2.39×10^{-8}	2.36×10^{-11}	1.76×10^{-15}	1.50×10^{-12}	7.43×10^{7}	1.86×10^{5}	7.60×10^{7}	2.45×10^{-2}	3.37×10^{7}	5.53×10^{-2}
700	435.0	792.85	2400	19.27	80.73	3.53×10^{-4}	1.99×10^{-5}	14.35	1.75×10^{3}	2.07×10^{-8}	2.04×10^{-11}	1.49×10^{-15}	1.27×10^{-12}	6.30×10^{7}	1.88×10^{5}	8.97×10^{7}	2.10×10^{-2}	3.97×10^{7}	4.74×10^{-2}
725	450.5	787.54	2450	18.95	81.05	3.94×10^{-4}	2.29×10^{-5}	14.34	1.80×10^{3}	1.78×10^{-8}	1.76×10^{-11}	1.26×10^{-15}	1.07×10^{-12}	5.31×10^{7}	1.90×10^{5}	1.06×10^{7}	1.79×10^{-2}	4.71×10^{7}	4.04×10^{-2}
750	466.0	781.98	2500	18.68	81.32	4.32×10^{-4}	2.58×10^{-5}	14.33	1.85×10^{3}	1.57×10^{-8}	1.55×10^{-11}	1.08×10^{-15}	9.21×10^{-13}	4.58×10^{7}	1.92×10^{5}	1.23×10^{7}	1.56×10^{-2}	5.46×10^{7}	3.52×10^{-2}
800	497.1	771.15	2500	18.12	81.88	5.24×10^{-4}	3.31×10^{-5}	14.32	1.88×10^{3}	1.20×10^{-8}	1.18×10^{-11}	8.28×10^{-16}	7.04×10^{-13}	3.50×10^{7}	1.92×10^{5}	1.61×10^{7}	1.20×10^{-2}	7.14×10^{7}	2.69×10^{-2}
850	528.2	760.55	2500	17.58	82.42	6.34×10^{-4}	4.24×10^{-5}	14.31	1.91×10^{3}	9.23×10^{-9}	9.11×10^{-12}	6.36×10^{-16}	5.40×10^{-13}	2.69×10^{7}	1.92×10^{5}	2.09×10^{7}	9.20×10^{-2}	9.29×10^{7}	2.07×10^{-2}
900	559.2	750.16	2500	17.06	82.94	7.65×10^{-4}	5.40×10^{-5}	14.30	1.94×10^{3}	7.12×10^{-9}	7.02×10^{-12}	4.90×10^{-16}	4.16×10^{-13}	2.08×10^{7}	1.92×10^{5}	2.71×10^{7}	7.10×10^{-2}	1.20×10^{7}	1.60×10^{-1}
950	590.3	739.98	2500	16.56	83.44	9.21×10^{-4}	6.86×10^{-5}	14.30	1.97×10^{3}	5.51×10^{-9}	5.44×10^{-12}	3.79×10^{-16}	3.22×10^{-13}	1.61×10^{7}	1.92×10^{5}	3.50×10^{7}	5.49×10^{-2}	1.56×10^{7}	1.24×10^{-1}
1000	621.4	730.01	2500	16.07	83.92	1.11×10^{-3}	8.68×10^{-5}	14.29	1.99×10^{3}	4.28×10^{-9}	4.22×10^{-12}	2.94×10^{-16}	2.50×10^{-13}	1.25×10^{7}	1.92×10^{5}	4.51×10^{7}	4.27×10^{-2}	2.00×10^{7}	9.61×10^{-2}
1100	683.5	710.66	2500	15.16	84.84	1.58×10^{-3}	1.38×10^{-4}	14.27	2.05×10^{3}	2.61×10^{-9}	2.57×10^{-12}	1.79×10^{-16}	1.52×10^{-13}	7.61×10^{6}	1.93×10^{5}	7.39×10^{7}	2.60×10^{-2}	3.29×10^{7}	5.86×10^{-2}
1200	745.6	692.07	2500	14.31	85.68	2.24×10^{-3}	2.15×10^{-4}	14.25	2.11×10^{3}	1.61×10^{-9}	1.59×10^{-12}	1.11×10^{-16}	9.40×10^{-14}	4.70×10^{6}	1.93×10^{5}	1.20×10^{8}	1.61×10^{-2}	5.32×10^{7}	3.62×10^{-2}
1300	807.8	674.20	2500	13.53	86.47	3.14×10^{-3}	3.33×10^{-4}	14.24	2.17×10^{3}	1.01×10^{-9}	9.96×10^{-13}	6.91×10^{-17}	5.88×10^{-14}	2.95×10^{6}	1.93×10^{5}	1.91×10^{8}	1.01×10^{-2}	8.49×10^{7}	2.23×10^{-2}
1400	869.9	657.02	2500	12.79	87.20	4.26×10^{-3}	5.09×10^{-4}	14.22	2.22×10^{3}	6.40×10^{-10}	6.31×10^{-13}	4.38×10^{-17}	3.72×10^{-14}	1.87×10^{6}	1.93×10^{5}	3.01×10^{8}	6.40×10^{-3}	1.34×10^{8}	1.44×10^{-2}
1500	932.0	640.48	2500	12.11	87.88	6.00×10^{-3}	7.70×10^{-4}	14.21	2.28×10^{3}	4.11×10^{-10}	4.05×10^{-13}	2.81×10^{-17}	2.39×10^{-14}	1.20×10^{6}	1.93×10^{5}	4.70×10^{8}	4.11×10^{-3}	2.09×10^{8}	9.25×10^{-3}
1600	994.2	624.56	2500	11.48	88.51	8.19×10^{-3}	1.15×10^{-3}	14.20	2.34×10^{3}	2.67×10^{-10}	2.63×10^{-13}	1.82×10^{-17}	1.55×10^{-14}	7.78×10^{5}	1.93×10^{5}	7.24×10^{8}	2.67×10^{-3}	3.22×10^{8}	6.00×10^{-3}
1700	1056	609.23	2500	10.89	89.09	1.11×10^{-2}	1.70×10^{-3}	14.18	2.41×10^{3}	1.75×10^{-10}	1.73×10^{-13}	1.19×10^{-17}	1.02×10^{-14}	5.10×10^{5}	1.93×10^{5}	1.10×10^{9}	1.75×10^{-3}	4.90×10^{8}	3.91×10^{-3}
1800	1118	594.45	2500	10.34	89.64	1.49×10^{-2}	2.50×10^{-3}	14.17	2.47×10^{3}	1.16×10^{-10}	1.14×10^{-13}	7.91×10^{-18}	6.73×10^{-15}	3.39×10^{5}	1.93×10^{5}	1.66×10^{9}	1.15×10^{-3}	7.39×10^{8}	2.62×10^{-3}
1900	1181	580.20	2500	9.814	90.16	1.97×10^{-2}	3.62×10^{-3}	14.16	2.53×10^{3}	7.79×10^{-11}	7.69×10^{-14}	5.30×10^{-18}	4.51×10^{-15}	2.27×10^{5}	1.93×10^{5}	2.48×10^{9}	7.80×10^{-4}	1.10×10^{9}	1.76×10^{-3}
2000	1243	566.46	2500	9.350	90.62	2.63×10^{-2}	5.21×10^{-3}	14.15	2.59×10^{3}	5.26×10^{-11}	5.19×10^{-14}	3.58×10^{-18}	3.05×10^{-15}	1.54×10^{5}	1.93×10^{5}	3.66×10^{9}	5.28×10^{-4}	1.63×10^{9}	1.19×10^{-3}
2500	1553	504.58	2500	7.379	92.50	9.72×10^{-2}	2.83×10^{-3}	14.04	2.93×10^{3}	8.58×10^{-12}	8.46×10^{-15}	5.80×10^{-19}	4.93×10^{-16}	2.50×10^{4}	1.94×10^{5}	2.25×10^{10}	8.64×10^{-5}	9.99×10^{9}	1.94×10^{-4}
3000	1854	452.30	2500	5.936	93.62	.3105	.1274	13.77	3.34×10^{3}	1.73×10^{-12}	1.71×10^{-15}	1.15×10^{-19}	9.75×10^{-17}	5.05×10^{3}	1.96×10^{5}	1.11×10^{11}	1.76×10^{-5}	1.95×10^{10}	3.9×10^{-5}
3500	2175	407.75	2500	4.836	93.80	.8740	.4885	12.98	3.93×10^{3}	4.32×10^{-13}	4.26×10^{-16}	2.70×10^{-20}	2.29×10^{-17}	1.26×10^{3}	2.02×10^{5}	4.47×10^{11}	4.52×10^{-7}	1.99×10^{11}	1.02×10^{-6}
4000	2485	369.47	2500	3.947	92.25	2.186	1.616	11.13	5.06×10^{3}	1.39×10^{-12}	1.37×10^{-15}	7.42×10^{-21}	6.31×10^{-18}	4.04×10^{2}	2.18×10^{5}	1.39×10^{12}	1.57×10^{-7}	6.19×10^{11}	3.52×10^{-7}
4500	2796	336.34	2500	3.156	87.40	4.836	4.606	8.18	7.55×10^{3}	6.07×10^{-14}	5.99×10^{-17}	2.39×10^{-21}	2.03×10^{-18}	1.77×10^{2}	2.54×10^{5}	3.18×10^{12}	8.00×10^{-8}	1.41×10^{12}	1.80×10^{-7}
5000	3107	307.47	2500	2.389	77.22	9.272	11.12	5.26	1.29×10^{3}	3.62×10^{-14}	3.57×10^{-17}	9.15×10^{-22}	7.78×10^{-19}	1.06×10^{2}	3.17×10^{5}	5.33×10^{12}	5.95×10^{-8}	2.37×10^{12}	1.34×10^{-7}
6000	3728	259.86	2500	1.010	42.86	20.02	36.10	2.28	3.52×10^{3}	2.25×10^{-14}	2.22×10^{-17}	2.46×10^{-22}	2.09×10^{-19}	6.55×10	4.82×10^{5}	8.59×10^{12}	5.61×10^{-8}	3.82×10^{12}	1.26×10^{-7}
7000	4350	222.51	2500	.2273	15.90	23.62	60.19	1.50	6.24×10^{3}	1.82×10^{-14}	1.80×10^{-17}	1.31×10^{-22}	1.12×10^{-19}	5.31×10	5.94×10^{5}	1.06×10^{13}	5.61×10^{-8}	4.71×10^{12}	1.26×10^{-7}
8000	4971	192.67	2500	8.13×10^{-3}	5.306	21.34	72.69	1.28	8.46×10^{3}	1.59×10^{-14}	1.57×10^{-17}	9.75×10^{-23}	8.29×10^{-20}	4.64×10	6.44×10^{5}	1.21×10^{13}	5.31×10^{-8}	5.40×10^{12}	1.19×10^{-7}
9000	5592	168.46	2500	2.42×10^{-3}	1.881	18.00	80.10	1.19	1.04×10^{4}	1.43×10^{-14}	1.41×10^{-17}	8.17×10^{-23}	6.95×10^{-20}	4.17×10	6.67×10^{5}	1.35×10^{13}	4.94×10^{-8}	6.00×10^{12}	1.11×10^{-7}
10,000	6214	148.53	2500	8.14×10^{-3}	.7357	15.07	84.19	1.14	1.22×10^{4}	1.31×10^{-14}	1.29×10^{-17}	7.20×10^{-23}	6.12×10^{-20}	3.81×10	6.80×10^{5}	1.48×10^{13}	4.61×10^{-8}	6.56×10^{12}	1.04×10^{-7}
15,000	9320	87.22	2500	1.48×10^{-4}	2.31×10^{-3}	7.310	92.67	1.06	2.23×10^{4}	9.67×10^{-15}	9.54×10^{-18}	4.96×10^{-22}	4.22×10^{-19}	2.82×10	7.04×10^{5}	1.99×10^{13}	3.53×10^{-8}	8.86×10^{12}	7.95×10^{-8}
20,000	12,427	57.31	2500	1.19×10^{-6}	2.61×10^{-3}	4.528	95.47	1.04	3.48×10^{4}	8.09×10^{-16}	7.98×10^{-19}	4.06×10^{-23}	3.45×10^{-20}	2.36×10	7.12×10^{5}	2.39×10^{13}	2.99×10^{-8}	1.06×10^{13}	6.72×10^{-8}
25,000	15,534	40.51	2500	2.12×10^{-6}	5.87×10^{-4}	3.244	96.76	1.03	4.97×10^{4}	7.17×10^{-17}	7.07×10^{-19}	3.56×10^{-23}	3.03×10^{-20}	2.09×10	7.16×10^{5}	2.69×10^{13}	2.66×10^{-8}	1.20×10^{13}	5.99×10^{-8}
30,000	18,641	30.14	2500	6.06×10^{-7}	1.99×10^{-4}	2.541	97.46	1.03	6.71×10^{4}	6.58×10^{-18}	6.49×10^{-19}	3.25×10^{-23}	2.76×10^{-20}	1.92×10	7.18×10^{5}	2.93×10^{13}	2.45×10^{-8}	1.30×10^{13}	5.51×10^{-8}
35,000	21,748	23.30	2500	2.34×10^{-7}	8.71×10^{-5}	2.109	97.89	1.02	8.71×10^{4}	6.16×10^{-18}	6.08×10^{-19}	3.03×10^{-23}	2.58×10^{-20}	1.80×10	7.19×10^{5}	3.13×10^{13}	2.30×10^{-8}	1.39×10^{13}	5.17×10^{-8}
40,000	24,855	18.55	2500	1.11×10^{-7}	4.56×10^{-5}	1.822	98.18	1.02	1.10×10^{5}	5.85×10^{-18}	5.77×10^{-19}	2.88×10^{-23}	2.45×10^{-20}	1.71×10	7.20×10^{5}	3.30×10^{13}	2.18×10^{-8}	1.46×10^{13}	4.91×10^{-8}
45,000	27,961	15.12	2500	6.08×10^{-8}	2.71×10^{-5}	1.618	98.38	1.02	1.35×10^{5}	5.62×10^{-18}	5.54×10^{-19}	2.76×10^{-23}	2.34×10^{-20}	1.64×10	7.20×10^{5}	3.43×10^{13}	2.10×10^{-8}	1.53×10^{13}	4.72×10^{-8}
50,000	31,068	12.55	2500	3.71×10^{-8}	1.76×10^{-5}	1.468	98.53	1.02	1.62×10^{5}	5.43×10^{-18}	5.36×10^{-19}	2.66×10^{-23}	2.26×10^{-20}	1.58×10	7.21×10^{5}	3.55×10^{13}	2.03×10^{-8}	1.58×10^{13}	4.56×10^{-8}
55,000	34,175	10.59	2500	2.45×10^{-8}	1.23×10^{-5}	1.352	98.65	1.02	1.93×10^{5}	5.28×10^{-18}	5.21×10^{-19}	2.59×10^{-23}	2.20×10^{-20}	1.54×10	7.21×10^{5}	3.65×10^{13}	1.97×10^{-8}	1.62×10^{13}	4.44×10^{-8}
60,000	37,282	9.06	2500	1.72×10^{-8}	9.08×10^{-5}	1.261	98.74	1.02	2.25×10^{5}	5.15×10^{-18}	5.08×10^{-19}	2.52×10^{-23}	2.15×10^{-20}	1.50×10	7.21×10^{5}	3.74×10^{13}	1.93×10^{-8}	1.66×10^{13}	4.34×10^{-8}

1 millibar = 10^2 dynes/cm² = 0.750 mm of Hg

Table 3.26 ATMOSPHERIC MODEL III. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER
Latitude 0°. Metric Units. $p_0 = 1013$ mb, $\rho_0 = 1.178 \times 10^{-3}$ gm/cm³. Table 43 of Ref. 3.20.

Height h mi	Height h ft	Apparent Gravity g' ft/sec^2	Temp T °K	Percentage Composition by Mass C_s Atomic Oxygen	Atomic Nitrogen	Atomic Helium	Atomic Hydrogen	Mean Mol Wt M	Scale Height H ft	Pressure p lb/ft^2	Pressure Ratio p/p_0	Density ρ slug/ft^3	Density Ratio σ ρ/ρ_0	Number Density n particles/ft^3	Mean Particle Speed $\bar{v}$ ft/sec	$d = 2 \times 10^{-8}$ cm Mean Free Path λ ft	$d = 2 \times 10^{-8}$ cm Mean Collision Freq f 1/sec	$d = 3 \times 10^{-8}$ cm Mean Free Path λ ft	$d = 3 \times 10^{-8}$ cm Mean Collision Freq f 1/sec
186.4	9.842×10^5	29.334	1980	30.5% O	69.5% N_2	--	--	24.35	1.370×10^5	1.01×10^{-5}	4.78×10^{-10}	2.50×10^{-13}	1.05×10^{-10}	9.09×10^{12}	3.21×10^3	5.77×10^2	5.56×10^{-1}	2.56×10^3	1.26
201.9	1.066×10^6	29.114	2160	--	--	--	--	21.86	1.687×10^5	5.94×10^{-7}	2.81×10^{-10}	1.21×10^{-13}	5.09×10^{-11}	4.90×10^{12}	3.54×10^3	1.07×10^4	3.30×10^{-1}	4.76×10^3	7.46×10^{-1}
217.5	1.148×10^6	28.897	2340	--	--	--	--	19.38	2.078×10^5	3.83×10^{-7}	1.82×10^{-10}	6.39×10^{-14}	2.68×10^{-11}	2.92×10^{12}	3.90×10^3	1.80×10^4	2.18×10^{-1}	7.97×10^3	4.91×10^{-1}
233.0	1.230×10^6	28.682	2520	--	--	--	--	16.89	2.586×10^5	2.69×10^{-7}	1.27×10^{-10}	3.63×10^{-14}	1.52×10^{-11}	1.90×10^{12}	4.33×10^3	2.76×10^4	1.57×10^{-1}	1.22×10^4	3.55×10^{-1}
248.5	1.312×10^6	28.469	2700	22.22	77.78	1.39×10^{-4}	6.00×10^{-8}	14.40	3.275×10^5	2.03×10^{-7}	8.57×10^{-11}	2.17×10^{-14}	9.14×10^{-12}	1.34×10^{12}	4.86×10^3	3.94×10^4	1.24×10^{-1}	1.74×10^3	2.80×10^{-1}
264.1	1.394×10^6	28.260	2880	21.64	78.36	1.66×10^{-4}	7.51×10^{-9}	14.39	3.520×10^5	1.59×10^{-7}	7.52×10^{-11}	1.60×10^{-14}	6.74×10^{-12}	9.85×10^{11}	5.02×10^3	5.31×10^4	9.45×10^{-2}	2.36×10^3	2.13×10^{-1}
279.6	1.476×10^6	28.052	3060	21.13	78.87	1.95×10^{-4}	9.26×10^{-9}	14.38	3.786×10^5	1.27×10^{-7}	6.01×10^{-11}	1.20×10^{-14}	5.07×10^{-12}	7.39×10^{11}	5.10×10^3	7.09×10^4	7.32×10^{-2}	3.14×10^4	1.65×10^{-1}
295.1	1.558×10^6	27.846	3240	20.64	79.36	2.27×10^{-4}	1.13×10^{-8}	14.37	4.026×10^5	1.03×10^{-7}	4.87×10^{-11}	9.20×10^{-15}	3.88×10^{-12}	5.66×10^{11}	5.35×10^3	9.25×10^4	5.78×10^{-2}	4.10×10^4	1.30×10^{-1}
310.7	1.640×10^6	27.649	3420	20.20	79.80	2.62×10^{-4}	1.35×10^{-8}	14.36	4.281×10^5	8.47×10^{-8}	4.01×10^{-11}	7.16×10^{-15}	3.01×10^{-12}	4.42×10^{11}	5.48×10^3	1.19×10^5	4.62×10^{-2}	5.28×10^4	1.04×10^{-1}
326.2	1.722×10^6	27.442	3600	19.78	80.22	2.99×10^{-4}	1.61×10^{-8}	14.35	4.544×10^5	7.03×10^{-8}	3.32×10^{-11}	5.65×10^{-15}	2.38×10^{-12}	3.48×10^{11}	5.64×10^3	1.51×10^5	3.74×10^{-2}	6.69×10^4	8.43×10^{-2}
341.8	1.804×10^6	27.242	3780	19.40	80.60	3.40×10^{-4}	1.89×10^{-8}	14.35	4.810×10^5	5.90×10^{-8}	2.79×10^{-11}	4.50×10^{-15}	1.90×10^{-12}	2.78×10^{11}	5.77×10^3	1.89×10^5	3.06×10^{-2}	8.37×10^4	6.91×10^{-2}
357.3	1.886×10^6	27.046	3960	19.04	80.96	3.83×10^{-4}	2.21×10^{-8}	14.34	5.075×10^5	5.00×10^{-8}	2.37×10^{-11}	3.65×10^{-15}	1.53×10^{-12}	2.25×10^{11}	5.91×10^3	2.33×10^5	2.54×10^{-2}	1.03×10^5	5.72×10^{-2}
372.8	1.968×10^6	26.884	4140	18.70	81.30	4.29×10^{-4}	2.56×10^{-8}	14.33	5.341×10^5	4.28×10^{-8}	2.02×10^{-11}	2.99×10^{-15}	1.26×10^{-12}	1.84×10^{11}	6.04×10^3	2.85×10^5	2.12×10^{-2}	1.26×10^5	4.79×10^{-2}
388.4	2.050×10^6	26.659	4320	18.39	81.61	4.78×10^{-4}	2.94×10^{-8}	14.33	5.623×10^5	3.68×10^{-8}	1.74×10^{-11}	2.47×10^{-15}	1.04×10^{-12}	1.52×10^{11}	6.17×10^3	3.44×10^5	1.79×10^{-2}	1.53×10^5	4.04×10^{-2}
403.9	2.133×10^6	26.468	4500	18.10	81.90	5.35×10^{-4}	3.36×10^{-8}	14.32	5.902×10^5	3.20×10^{-8}	1.51×10^{-11}	2.04×10^{-15}	8.62×10^{-13}	1.26×10^{11}	6.30×10^3	4.13×10^5	1.52×10^{-2}	1.84×10^5	3.43×10^{-2}
435.0	2.297×10^6	26.096	4500	17.53	82.47	6.53×10^{-4}	4.34×10^{-8}	14.31	5.991×10^5	2.42×10^{-8}	1.14×10^{-11}	1.55×10^{-15}	6.54×10^{-13}	9.60×10^{10}	6.30×10^3	5.45×10^5	1.16×10^{-2}	2.42×10^5	2.60×10^{-2}
466.0	2.461×10^6	25.731	4500	16.99	83.01	7.95×10^{-4}	5.60×10^{-8}	14.30	6.079×10^5	1.85×10^{-8}	8.73×10^{-12}	1.18×10^{-15}	4.98×10^{-13}	7.31×10^{10}	6.30×10^3	7.15×10^5	8.83×10^{-3}	3.18×10^5	1.99×10^{-2}
497.1	2.625×10^6	25.374	4500	16.47	83.53	9.64×10^{-4}	7.18×10^{-8}	14.29	6.168×10^5	1.41×10^{-8}	6.68×10^{-12}	9.05×10^{-16}	3.81×10^{-13}	5.61×10^{10}	6.31×10^3	9.35×10^5	6.75×10^{-3}	4.17×10^5	1.52×10^{-2}
528.2	2.789×10^6	25.024	4500	15.96	84.03	1.17×10^{-3}	9.19×10^{-8}	14.28	6.260×10^5	1.09×10^{-8}	5.13×10^{-12}	6.93×10^{-16}	2.92×10^{-13}	4.30×10^{10}	6.32×10^3	1.22×10^5	5.19×10^{-3}	5.41×10^5	1.17×10^{-2}
559.2	2.953×10^6	24.681	4500	15.48	84.52	1.41×10^{-3}	1.17×10^{-7}	14.28	6.352×10^5	8.37×10^{-8}	3.96×10^{-12}	5.34×10^{-16}	2.25×10^{-13}	3.31×10^{10}	6.33×10^3	1.58×10^5	4.00×10^{-3}	7.02×10^5	9.01×10^{-3}
590.3	3.117×10^6	24.346	4500	15.02	84.98	1.69×10^{-3}	1.49×10^{-7}	14.27	6.440×10^5	6.47×10^{-8}	3.06×10^{-12}	4.14×10^{-16}	1.74×10^{-13}	2.56×10^{10}	6.33×10^3	2.04×10^5	3.10×10^{-3}	9.06×10^5	6.97×10^{-3}
621.4	3.281×10^6	24.017	4500	14.57	85.43	2.03×10^{-3}	1.88×10^{-7}	14.26	6.535×10^5	5.03×10^{-8}	2.38×10^{-12}	3.20×10^{-16}	1.35×10^{-13}	1.99×10^{10}	6.33×10^3	2.63×10^5	2.41×10^{-3}	1.17×10^6	5.42×10^{-3}
683.5	3.609×10^6	23.379	4500	13.73	86.27	2.91×10^{-3}	2.98×10^{-7}	14.24	6.719×10^5	3.07×10^{-8}	1.45×10^{-12}	1.96×10^{-16}	8.22×10^{-14}	1.21×10^{10}	6.33×10^3	4.30×10^5	1.47×10^{-3}	1.92×10^6	3.30×10^{-3}
745.6	3.937×10^6	22.766	4500	12.94	87.05	4.11×10^{-3}	4.67×10^{-7}	14.23	6.906×10^5	1.89×10^{-8}	8.95×10^{-13}	1.21×10^{-16}	5.08×10^{-14}	7.50×10^9	6.33×10^3	6.99×10^5	9.07×10^{-4}	3.10×10^6	2.04×10^{-3}
807.8	4.265×10^6	22.308	4500	12.22	87.78	5.77×10^{-3}	7.23×10^{-7}	14.21	7.100×10^5	1.19×10^{-8}	5.60×10^{-13}	7.53×10^{-17}	3.17×10^{-14}	4.70×10^9	6.33×10^3	1.12×10^5	5.68×10^{-4}	4.95×10^6	1.28×10^{-3}
869.9	4.593×10^6	21.611	4500	11.55	88.44	8.01×10^{-3}	1.11×10^{-6}	14.20	7.290×10^5	7.52×10^{-9}	3.55×10^{-13}	4.78×10^{-17}	2.01×10^{-14}	2.97×10^9	6.33×10^3	1.76×10^5	3.60×10^{-4}	7.81×10^6	8.11×10^{-4}
932.0	4.921×10^6	21.065	4500	10.92	89.06	1.10×10^{-2}	1.67×10^{-6}	14.19	7.487×10^5	4.82×10^{-9}	2.28×10^{-13}	3.07×10^{-17}	1.29×10^{-14}	1.91×10^9	6.34×10^3	2.74×10^5	2.31×10^{-4}	1.22×10^7	5.20×10^{-4}
994.2	5.249×10^6	20.541	4500	10.34	89.64	1.51×10^{-2}	2.50×10^{-6}	14.17	7.687×10^5	3.13×10^{-9}	1.48×10^{-13}	1.98×10^{-17}	8.35×10^{-15}	1.24×10^9	6.34×10^3	4.23×10^5	1.50×10^{-4}	1.88×10^7	3.38×10^{-4}
1056	5.577×10^6	20.034	4500	9.804	90.17	2.04×10^{-2}	3.70×10^{-6}	14.16	7.887×10^5	2.05×10^{-9}	9.70×10^{-14}	1.30×10^{-17}	5.47×10^{-15}	8.13×10^8	6.35×10^3	6.43×10^5	9.85×10^{-5}	2.86×10^7	2.22×10^{-4}
1243	6.562×10^6	18.626	4500	8.397	91.54	4.84×10^{-2}	1.13×10^{-5}	14.11	8.514×10^5	6.18×10^{-10}	2.92×10^{-14}	3.90×10^{-18}	1.64×10^{-15}	2.44×10^8	6.36×10^3	2.14×10^5	2.97×10^{-5}	9.51×10^7	6.68×10^{-4}
1553	8.202×10^6	16.588	4500	6.604	93.16	.1788	6.15×10^{-5}	13.94	9.675×10^5	1.01×10^{-10}	4.78×10^{-15}	6.31×10^{-19}	2.65×10^{-16}	3.99×10^8	6.40×10^3	1.31×10^5	4.89×10^{-5}	5.81×10^7	1.10×10^{-4}
1864	9.842×10^6	14.866	4500	5.286	93.87	.5699	.2767	13.42	1.122×10^6	2.08×10^{-10}	9.83×10^{-15}	1.25×10^{-18}	5.26×10^{-17}	8.21×10^7	6.53×10^3	6.36×10^5	1.02×10^{-5}	2.82×10^8	2.31×10^{-5}
2175	1.148×10^7	13.399	4500	4.262	93.10	1.591	1.052	11.96	1.396×10^6	5.51×10^{-11}	2.60×10^{-15}	2.95×10^{-20}	1.24×10^{-17}	2.19×10^7	6.89×10^3	2.39×10^5	2.88×10^{-6}	1.06×10^9	6.49×10^{-5}
2485	1.312×10^7	12.139	4500	3.392	89.32	3.887	3.402	9.14	2.016×10^6	2.04×10^{-11}	9.62×10^{-16}	8.33×10^{-21}	3.50×10^{-18}	8.04×10^6	7.91×10^3	6.50×10^5	1.22×10^{-7}	2.89×10^{10}	2.74×10^{-7}
2796	1.476×10^7	11.049	4500	2.566	80.10	8.148	9.194	5.87	3.451×10^6	1.08×10^{-12}	5.09×10^{-17}	2.83×10^{-21}	1.19×10^{-18}	4.25×10^6	9.84×10^3	1.23×10^{11}	8.03×10^{-8}	5.45×10^{10}	1.81×10^{-7}
3107	1.640×10^7	10.100	4500	1.757	64.02	14.13	20.10	3.55	6.237×10^6	7.52×10^{-13}	3.55×10^{-17}	1.20×10^{-21}	5.04×10^{-19}	2.97×10^5	1.27×10^4	1.76×10^{11}	7.21×10^{-8}	7.81×10^{10}	1.62×10^{-7}
728	1.968×10^7	8.534	4500	.5616	26.86	23.13	49.44	1.76	1.489×10^7	5.39×10^{-14}	2.55×10^{-17}	4.23×10^{-22}	1.78×10^{-19}	2.13×10^6	1.80×10^4	2.46×10^{11}	7.32×10^{-8}	1.09×10^{11}	1.65×10^{-7}
4350	2.297×10^7	7.306	4500	.1378	8.306	22.76	68.80	1.35	2.267×10^7	4.49×10^{-14}	2.12×10^{-17}	2.72×10^{-22}	1.14×10^{-19}	1.78×10^6	2.05×10^4	2.95×10^{11}	6.97×10^{-8}	1.31×10^{11}	1.57×10^{-7}
4971	2.625×10^7	6.322	4500	3.51×10^{-2}	2.584	19.18	78.20	1.21	2.922×10^7	3.99×10^{-14}	1.88×10^{-17}	2.16×10^{-22}	9.09×10^{-20}	1.58×10^6	2.17×10^4	3.31×10^{11}	6.54×10^{-8}	1.47×10^{11}	1.47×10^{-7}
5592	2.953×10^7	5.529	4500	1.02×10^{-2}	.8932	15.78	83.32	1.15	3.507×10^7	3.59×10^{-14}	1.70×10^{-17}	1.85×10^{-22}	7.81×10^{-20}	1.42×10^6	2.22×10^4	3.67×10^{11}	6.04×10^{-8}	1.63×10^{11}	1.36×10^{-7}
6215	3.281×10^7	4.875	4500	3.38×10^{-2}	.3451	13.12	86.53	1.12	4.091×10^7	3.30×10^{-14}	1.56×10^{-17}	1.65×10^{-22}	6.96×10^{-20}	1.31×10^6	2.25×10^4	4.00×10^{11}	5.62×10^{-8}	1.78×10^{11}	1.26×10^{-7}
9120	4.921×10^7	2.861	4500	6.05×10^{-2}	1.07×10^{-5}	6.234	93.76	1.06	7.395×10^7	2.44×10^{-14}	1.15×10^{-17}	1.16×10^{-22}	4.88×10^{-20}	9.68×10^5	2.32×10^4	5.38×10^{11}	4.30×10^{-8}	2.40×10^{11}	9.68×10^{-8}
12427	6.562×10^7	1.879	4500	4.85×10^{-2}	1.20×10^{-5}	3.847	96.23	1.04	1.148×10^8	2.05×10^{-14}	9.69×10^{-18}	9.51×10^{-23}	4.00×10^{-20}	8.10×10^5	2.34×10^4	6.43×10^{11}	3.64×10^{-8}	2.86×10^{11}	8.18×10^{-8}
15534	8.202×10^7	1.328	4500	8.64×10^{-2}	2.70×10^{-4}	2.749	97.25	1.03	1.637×10^8	1.82×10^{-14}	8.59×10^{-18}	8.37×10^{-23}	3.53×10^{-20}	7.19×10^5	2.35×10^4	7.25×10^{11}	3.24×10^{-8}	3.23×10^{11}	7.29×10^{-8}
18641	9.842×10^7	.988	4500	2.47×10^{-1}	9.12×10^{-4}	2.152	97.85	1.02	2.210×10^8	1.65×10^{-14}	7.79×10^{-18}	7.65×10^{-23}	3.22×10^{-20}	6.60×10^5	2.36×10^4	7.91×10^{11}	2.98×10^{-8}	3.51×10^{11}	6.70×10^{-8}
21748	1.148×10^8	.764	4500	9.54×10^{-2}	4.00×10^{-3}	1.785	98.21	1.02	2.867×10^8	1.56×10^{-14}	7.39×10^{-18}	7.15×10^{-23}	3.01×10^{-20}	6.17×10^5	2.36×10^4	8.46×10^{11}	2.79×10^{-8}	3.77×10^{11}	6.28×10^{-8}
24855	1.312×10^8	.608	4500	4.52×10^{-2}	2.10×10^{-3}	1.541	98.46	1.02	3.609×10^8	1.48×10^{-14}	7.01×10^{-18}	6.78×10^{-23}	2.85×10^{-20}	5.89×10^5	2.36×10^4	8.89×10^{11}	2.66×10^{-8}	3.97×10^{11}	5.98×10^{-8}
27961	1.476×10^8	.495	4500	2.48×10^{-2}	1.24×10^{-3}	1.369	98.63	1.02	4.436×10^8	1.43×10^{-14}	6.74×10^{-18}	6.49×10^{-23}	2.73×10^{-20}	5.64×10^5	2.37×10^4	9.25×10^{11}	2.55×10^{-8}	4.13×10^{11}	5.74×10^{-8}
31068	1.640×10^8	.411	4500	1.51×10^{-2}	8.11×10^{-4}	1.241	98.76	1.02	5.344×10^8	1.38×10^{-14}	6.51×10^{-18}	6.27×10^{-23}	2.64×10^{-20}	5.47×10^5	2.37×10^4	9.58×10^{11}	2.47×10^{-8}	4.26×10^{11}	5.56×10^{-8}
34175	1.804×10^8	.347	4500	9.98×10^{-3}	5.66×10^{-4}	1.144	98.86	1.02	6.338×10^8	1.34×10^{-14}	6.33×10^{-18}	6.10×10^{-23}	2.57×10^{-20}	5.30×10^5	2.37×10^4	9.88×10^{11}	2.40×10^{-8}	4.40×10^{11}	5.40×10^{-8}
37282	1.968×10^8	.297	4500	7.02×10^{-3}	3.92×10^{-4}	1.067	98.93	1.02	7.421×10^8	1.31×10^{-14}	6.19×10^{-18}	5.94×10^{-23}	2.50×10^{-20}	5.18×10^5	2.37×10^4	1.01×10^{12}	2.34×10^{-8}	4.49×10^{11}	5.28×10^{-8}
43496	2.297×10^8	.224	4500	3.99×10^{-3}	2.56×10^{-4}	.9536	99.05	1.02	9.833×10^8	1.26×10^{-14}	5.95×10^{-18}	5.71×10^{-23}	2.41×10^{-20}	4.98×10^5	2.37×10^4	1.05×10^{12}	2.26×10^{-8}	4.66×10^{11}	5.08×10^{-8}

Table 3.27 ATMOSPHERIC MODEL III. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER
Latitude 45°. Engineering Units. $p_0 = 2116$ lb/ft^2, $\rho_0 = 2.375 \times 10^{-3}$ slug/ft^3. Table 44 of Ref. 3.20.

Height h km	Height h mi	Apparent Gravity g' cm/sec^2	Temp T °K	Percentage Composition by Mass C_x: Atomic Oxygen	Atomic Nitrogen	Atomic Helium	Atomic Hydrogen	Mean Mol Wt M	Scale Height H	Pressure p millibars	Pressure Ratio p/p_0	Density ρ gram/cm^3	Density Ratio σ ρ/ρ_0	Number Density n particles/cm^3	Mean Particle Speed $\bar{v}$ cm/sec	$d = 2 \times 10^{-8}$cm: Mean Free Path λ cm	$d = 2 \times 10^{-8}$cm: Mean Collision Freq f 1/sec	$d = 3 \times 10^{-8}$cm: Mean Free Path λ cm	$d = 3 \times 10^{-8}$cm: Mean Collision Freq f 1/sec
300	186.4	894.09	1100	30.5%O	69.5%N_2			24.35	4.20 × 10	4.84 × 10^{-7}	4.78 × 10^{-10}	1.29 × 10^{-10}	1.05 × 10^{-10}	3.21 × 10^{8}	9.78 × 10^{4}	1.76 × 10^{8}	5.56 × 10^{-1}	7.79 × 10^{8}	1.26
325	201.9	887.39	1200					21.86	5.14 × 10	2.85 × 10^{-7}	2.81 × 10^{-10}	6.24 × 10^{-11}	5.09 × 10^{-11}	1.73 × 10^{8}	1.08 × 10^{5}	3.26 × 10^{8}	3.30 × 10^{-1}	1.45 × 10^{9}	7.46 × 10^{-1}
350	217.5	880.77	1300					19.38	6 33 × 10	1.84 × 10^{-7}	1.82 × 10^{-10}	3.29 × 10^{-11}	2.68 × 10^{-11}	1.03 × 10^{8}	1.19 × 10^{5}	5.48 × 10^{8}	2.18 × 10^{-1}	2.43 × 10^{9}	4.91 × 10^{-1}
375	233.0	874.22	1400					16.89	7.88 × 10	1.29 × 10^{-7}	1.27 × 10^{-10}	1.87 × 10^{-11}	1.52 × 10^{-11}	6.70 × 10^{7}	1.32 × 10^{5}	8.42 × 10^{8}	1.57 × 10^{-1}	3.73 × 10^{9}	3.55 × 10^{-1}
400	248.5	867.75	1500	22.22	77.78	1.39 × 10^{-4}	6.00 × 10^{-5}	14.40	9.98 × 10	9.70 × 10^{-8}	8.57 × 10^{-11}	1.12 × 10^{-11}	9.14 × 10^{-12}	4.72 × 10^{7}	1.48 × 10^{5}	1.20 × 10^{9}	1.24 × 10^{-2}	5.30 × 10^{9}	2.80 × 10^{-1}
425	264.1	861.35	1600	21.64	78.36	1.66 × 10^{-4}	7.51 × 10^{-5}	14.39	1.07 × 10^{2}	7.62 × 10^{-8}	7.52 × 10^{-11}	8.24 × 10^{-12}	6.74 × 10^{-12}	3.48 × 10^{7}	1.53 × 10^{5}	1.62 × 10^{9}	9.45 × 10^{-2}	7.20 × 10^{9}	2.13 × 10^{-1}
450	279.6	855.01	1700	21.13	78.87	1.95 × 10^{-4}	9.26 × 10^{-5}	14.38	1.15 × 10^{2}	6.99 × 10^{-8}	6.01 × 10^{-11}	6.20 × 10^{-12}	5.07 × 10^{-12}	2.61 × 10^{7}	1.58 × 10^{5}	2.16 × 10^{9}	7.32 × 10^{-2}	9.57 × 10^{9}	1.65 × 10^{-1}
475	295.1	848.75	1800	20.64	79.36	2.27 × 10^{-4}	1.13 × 10^{-4}	14.37	1.23 × 10^{2}	4.94 × 10^{-8}	4.87 × 10^{-11}	4.74 × 10^{-12}	3.88 × 10^{-12}	2.00 × 10^{7}	1.63 × 10^{5}	2.82 × 10^{9}	5.78 × 10^{-2}	1.25 × 10^{10}	1.30 × 10^{-1}
500	310.7	842.75	1900	20.20	79.80	2.62 × 10^{-4}	1.35 × 10^{-4}	14.36	1.30 × 10^{2}	4.06 × 10^{-8}	4.01 × 10^{-11}	3.69 × 10^{-12}	3.01 × 10^{-12}	1.56 × 10^{7}	1.67 × 10^{5}	3.63 × 10^{9}	4.62 × 10^{-2}	1.61 × 10^{10}	1.04 × 10^{-1}
525	326.2	836.42	2000	19.78	80.22	2.99 × 10^{-4}	1.61 × 10^{-4}	14.35	1.38 × 10^{2}	3.37 × 10^{-8}	3.32 × 10^{-11}	2.91 × 10^{-12}	2.38 × 10^{-12}	1.23 × 10^{7}	1.72 × 10^{5}	4.60 × 10^{9}	3.74 × 10^{-2}	2.04 × 10^{10}	8.43 × 10^{-2}
550	341.8	830.36	2100	19.40	80.60	3.40 × 10^{-4}	1.89 × 10^{-4}	14.35	1.47 × 10^{2}	2.83 × 10^{-8}	2.79 × 10^{-11}	2.32 × 10^{-12}	1.90 × 10^{-12}	9.82 × 10^{6}	1.76 × 10^{5}	5.75 × 10^{9}	3.06 × 10^{-2}	2.55 × 10^{10}	6.91 × 10^{-2}
575	357.3	824.36	2200	19.04	80.96	3.83 × 10^{-4}	2.21 × 10^{-4}	14.34	1.55 × 10^{2}	2.40 × 10^{-8}	2.37 × 10^{-11}	1.88 × 10^{-12}	1.54 × 10^{-12}	7.94 × 10^{6}	1.80 × 10^{5}	7.11 × 10^{9}	2.54 × 10^{-2}	3.15 × 10^{10}	5.72 × 10^{-2}
600	372.8	819.43	2300	18.70	81.30	4.29 × 10^{-4}	2.56 × 10^{-4}	14.33	1.63 × 10^{2}	2.05 × 10^{-8}	2.02 × 10^{-11}	1.54 × 10^{-12}	1.26 × 10^{-12}	6.49 × 10^{6}	1.84 × 10^{5}	8.69 × 10^{9}	2.12 × 10^{-2}	3.85 × 10^{10}	4.79 × 10^{-2}
625	388.4	812.56	2400	18.39	81.61	4.78 × 10^{-4}	2.94 × 10^{-4}	14.33	1.71 × 10^{2}	1.76 × 10^{-8}	1.74 × 10^{-11}	1.27 × 10^{-12}	1.04 × 10^{-12}	5.36 × 10^{6}	1.88 × 10^{5}	1.05 × 10^{10}	1.79 × 10^{-2}	4.66 × 10^{10}	4.04 × 10^{-2}
650	403.9	806.75	2500	18.10	81.90	5.35 × 10^{-4}	3.36 × 10^{-4}	14.32	1.80 × 10^{2}	1.53 × 10^{-8}	1.51 × 10^{-11}	1.05 × 10^{-12}	8.62 × 10^{-13}	4.46 × 10^{6}	1.92 × 10^{5}	1.26 × 10^{10}	1.52 × 10^{-2}	5.60 × 10^{10}	3.43 × 10^{-2}
700	435.0	795.40	2500	17.53	82.47	6.53 × 10^{-4}	4.34 × 10^{-4}	14.31	1.83 × 10^{2}	1.16 × 10^{-8}	1.14 × 10^{-11}	8.00 × 10^{-13}	6.54 × 10^{-13}	3.39 × 10^{6}	1.92 × 10^{5}	1.66 × 10^{10}	1.16 × 10^{-2}	7.38 × 10^{10}	2.60 × 10^{-2}
750	466.0	784.28	2500	16.99	83.01	7.95 × 10^{-4}	5.60 × 10^{-4}	14.30	1.85 × 10^{2}	8.85 × 10^{-9}	8.73 × 10^{-12}	6.09 × 10^{-13}	4.98 × 10^{-13}	2.58 × 10^{6}	1.92 × 10^{5}	2.18 × 10^{10}	8.83 × 10^{-3}	9.69 × 10^{10}	1.99 × 10^{-2}
800	497.1	773.39	2500	16.47	83.53	9.64 × 10^{-4}	7.18 × 10^{-4}	14.29	1.88 × 10^{2}	6.77 × 10^{-9}	6.68 × 10^{-12}	4.66 × 10^{-13}	3.81 × 10^{-13}	1.98 × 10^{6}	1.92 × 10^{5}	2.85 × 10^{10}	6.75 × 10^{-3}	1.27 × 10^{11}	1.52 × 10^{-2}
850	528.2	762.73	2500	15.96	84.03	1.17 × 10^{-3}	9.19 × 10^{-5}	14.28	1.91 × 10^{2}	5.20 × 10^{-9}	5 13 × 10^{-12}	3.57 × 10^{-13}	2.92 × 10^{-13}	1.52 × 10^{6}	1.92 × 10^{5}	3.71 × 10^{10}	5.19 × 10^{-3}	1.65 × 10^{11}	1.17 × 10^{-2}
900	559.2	752.29	2500	15.48	84.52	1.41 × 10^{-3}	1.17 × 10^{-4}	14.28	1.94 × 10^{2}	4.01 × 10^{-9}	3.96 × 10^{-12}	2.75 × 10^{-13}	2.25 × 10^{-13}	1.17 × 10^{6}	1.93 × 10^{5}	4.81 × 10^{10}	4.00 × 10^{-3}	2.14 × 10^{11}	9.01 × 10^{-3}
950	590.3	742.06	2500	15.02	84.98	1.69 × 10^{-3}	1.49 × 10^{-4}	14.27	1.96 × 10^{2}	3.10 × 10^{-9}	3.06 × 10^{-12}	2.13 × 10^{-13}	1.74 × 10^{-13}	9.05 × 10^{5}	1.93 × 10^{5}	6.22 × 10^{10}	3.10 × 10^{-3}	2.76 × 10^{11}	6.97 × 10^{-3}
1000	621.4	732.04	2500	14.57	85.43	2.03 × 10^{-3}	1.88 × 10^{-4}	14.26	1.99 × 10^{2}	2.41 × 10^{-9}	2.38 × 10^{-12}	1.65 × 10^{-13}	1.35 × 10^{-13}	7.03 × 10^{5}	1.93 × 10^{5}	8.01 × 10^{10}	2.41 × 10^{-3}	3.56 × 10^{11}	5.42 × 10^{-3}
1100	683.5	712.59	2500	13.73	86.27	2.91 × 10^{-3}	2.98 × 10^{-4}	14.24	2.05 × 10^{2}	1.47 × 10^{-9}	1.45 × 10^{-12}	1.01 × 10^{-13}	8.22 × 10^{-14}	4.28 × 10^{5}	1.93 × 10^{5}	1.31 × 10^{11}	1.47 × 10^{-3}	5.84 × 10^{11}	3.30 × 10^{-3}
1200	745.6	693.91	2500	12.94	87.05	4.11 × 10^{-3}	4.67 × 10^{-4}	14.23	2.10 × 10^{2}	9.07 × 10^{-10}	8.95 × 10^{-13}	6.21 × 10^{-14}	5.08 × 10^{-14}	2.65 × 10^{5}	1.93 × 10^{5}	2.13 × 10^{11}	9.07 × 10^{-4}	9.45 × 10^{11}	2.04 × 10^{-3}
1300	807.8	679.96	2500	12.22	87.78	5.77 × 10^{-3}	7.23 × 10^{-4}	14.21	2.16 × 10^{2}	5.68 × 10^{-10}	5.60 × 10^{-13}	3.88 × 10^{-14}	3.17 × 10^{-14}	1.66 × 10^{5}	1.93 × 10^{5}	3.40 × 10^{11}	5.68 × 10^{-4}	1.51 × 10^{12}	1.28 × 10^{-3}
1400	869.9	658.69	2500	11.55	88.44	8.01 × 10^{-3}	1.11 × 10^{-3}	14.20	2.22 × 10^{2}	3.60 × 10^{-10}	3.55 × 10^{-13}	2.46 × 10^{-14}	2.01 × 10^{-14}	1.05 × 10^{5}	1.93 × 10^{5}	5.36 × 10^{11}	3.60 × 10^{-4}	2.38 × 10^{12}	8.11 × 10^{-4}
1500	932.0	642.07	2500	10.92	89.06	1.10 × 10^{-2}	1.67 × 10^{-3}	14.19	2.28 × 10^{2}	2.31 × 10^{-10}	2.28 × 10^{-13}	1.58 × 10^{-14}	1.29 × 10^{-14}	6.73 × 10^{6}	1.93 × 10^{5}	8.36 × 10^{11}	2.31 × 10^{-4}	3.71 × 10^{12}	5.20 × 10^{-4}
1600	994.2	626.08	2500	10.34	89.64	1.51 × 10^{-2}	2.50 × 10^{-3}	14.17	2.34 × 10^{2}	1.50 × 10^{-10}	1.48 × 10^{-13}	1.02 × 10^{-14}	8.35 × 10^{-15}	4.37 × 10^{5}	1.93 × 10^{5}	1.29 × 10^{12}	1.50 × 10^{-4}	5.72 × 10^{12}	3.38 × 10^{-4}
1700	1056	610.64	2500	9.804	90.17	2.04 × 10^{-2}	3.70 × 10^{-3}	14.16	2.40 × 10^{2}	9.83 × 10^{-11}	9.70 × 10^{-14}	6.69 × 10^{-15}	5.47 × 10^{-15}	2.87 × 10^{5}	1.93 × 10^{5}	1.96 × 10^{12}	9.85 × 10^{-5}	8.72 × 10^{12}	2.22 × 10^{-4}
1800	1243	567.73	2500	8.397	91.54	4.84 × 10^{-2}	1.13 × 10^{-2}	14.11	2.60 × 10^{2}	2.96 × 10^{-11}	2.92 × 10^{-14}	2.01 × 10^{-15}	1.64 × 10^{-15}	8.62 × 10^{4}	1.94 × 10^{5}	6.52 × 10^{12}	2.97 × 10^{-5}	2.90 × 10^{13}	6.68 × 10^{-5}
2000	1553	505.59	2500	6.604	93.16	.1788	6.15 × 10^{-2}	13.94	2.95 × 10^{2}	4.84 × 10^{-13}	4.78 × 10^{-15}	3.25 × 10^{-15}	2.65 × 10^{-15}	1.41 × 10^{5}	1.95 × 10^{5}	3.99 × 10^{12}	4.89 × 10^{-5}	1.77 × 10^{13}	1.10 × 10^{-4}
2500	1864	453.12	2500	5.286	93.87	.5699	.2767	13.42	3.42 × 10^{2}	9.96 × 10^{-13}	9.83 × 10^{-15}	6.43 × 10^{-16}	5.26 × 10^{-17}	2.90 × 10^{4}	1.99 × 10^{5}	1.94 × 10^{11}	1.02 × 10^{-5}	8.61 × 10^{13}	2.31 × 10^{-5}
3000	2175	408.41	2500	4.262	93.10	1.591	1.052	11.96	4.25 × 10^{2}	2.64 × 10^{-13}	2.60 × 10^{-15}	1.52 × 10^{-16}	1.24 × 10^{-17}	7.72 × 10^{3}	2.10 × 10^{5}	7.29 × 10^{11}	2.88 × 10^{-7}	3.24 × 10^{14}	6.49 × 10^{-7}
3500	2485	370.01	2500	3.392	89.32	3.887	3.402	9.14	6.14 × 10^{2}	9.75 × 10^{-14}	9.62 × 10^{-17}	4.29 × 10^{-21}	3.50 × 10^{-18}	2.84 × 10^{2}	2.41 × 10^{5}	1.98 × 10^{13}	1.22 × 10^{-7}	8.80 × 10^{13}	2.74 × 10^{-7}
4000	2796	336.78	2500	2.566	80.10	8.148	9.194	5.87	1.05 × 10^{2}	5.16 × 10^{-14}	5.09 × 10^{-17}	1.45 × 10^{-21}	1.19 × 10^{-18}	1.50 × 10^{3}	3.00 × 10^{5}	3.74 × 10^{13}	8.03 × 10^{-8}	1.66 × 10^{14}	1.81 × 10^{-7}
4500	3107	307 84	2500	1.757	64.02	14.13	20.10	3.55	1.90 × 10^{2}	3.60 × 10^{-14}	3.55 × 10^{-17}	6.16 × 10^{-22}	5.04 × 10^{-19}	1.05 × 10^{3}	3.86 × 10^{5}	5.35 × 10^{13}	7.21 × 10^{-8}	2.38 × 10^{14}	1.62 × 10^{-7}
5000	3728	260.11	2500	.5616	26.86	23.13	49.44	1.76	4.54 × 10^{2}	2.58 × 10^{-14}	2.55 × 10^{-17}	2.18 × 10^{-22}	1.78 × 10^{-19}	7.52 × 10	5.48 × 10^{5}	7.49 × 10^{13}	7.32 × 10^{-8}	3.33 × 10^{14}	1.65 × 10^{-7}
6000	4350	222.68	2500	.1378	8.306	22.76	68.80	1.35	6.91 × 10^{2}	2.15 × 10^{-14}	2.12 × 10^{-17}	1.40 × 10^{-22}	1.14 × 10^{-19}	6.27 × 10	6.26 × 10^{5}	8.98 × 10^{13}	6.97 × 10^{-8}	3.99 × 10^{14}	1.57 × 10^{-7}
7000	4971	192.68	2500	3.51 × 10^{-2}	2.584	19.18	78.20	1.21	8.91 × 10^{2}	1.91 × 10^{-14}	1.88 × 10^{-17}	1.11 × 10^{-22}	9.09 × 10^{-20}	5.57 × 10	6.61 × 10^{5}	1.01 × 10^{14}	6.54 × 10^{-8}	4.49 × 10^{14}	1.47 × 10^{-7}
8000	5592	168.53	2500	1.02 × 10^{-2}	.8932	15.78	83.32	1.15	1.07 × 10^{3}	1.72 × 10^{-14}	1.70 × 10^{-17}	9.55 × 10^{-23}	7.81 × 10^{-20}	5.02 × 10	6.77 × 10^{5}	1.12 × 10^{14}	6.04 × 10^{-8}	4.98 × 10^{14}	1.36 × 10^{-7}
9000	6214	148.58	2500	3.38 × 10^{-3}	.3451	13.12	86.53	1.12	1.25 × 10^{3}	1.58 × 10^{-14}	1.56 × 10^{-17}	8.52 × 10^{-23}	6.96 × 10^{-20}	4.61 × 10	6.87 × 10^{5}	1.22 × 10^{14}	5.62 × 10^{-8}	5.43 × 10^{14}	1.26 × 10^{-7}
10,000	6214	148.58	2500	6.05 × 10^{-3}	1.07 × 10^{-3}	6.234	93.76	1.06	2.25 × 10^{3}	1.17 × 10^{-14}	1.15 × 10^{-17}	5.97 × 10^{-23}	4.88 × 10^{-20}	3.42 × 10	7.08 × 10^{5}	1.64 × 10^{14}	4.30 × 10^{-8}	7.31 × 10^{14}	9.68 × 10^{-8}
15,000	9320	87.21	2500	4.85 × 10^{-3}	1.20 × 10^{-3}	3.847	96.23	1.04	3.50 × 10^{3}	9.82 × 10^{-15}	9.69 × 10^{-18}	4.90 × 10^{-23}	4.00 × 10^{-20}	2.86 × 10	7.14 × 10^{5}	1.96 × 10^{14}	3.64 × 10^{-8}	8.73 × 10^{14}	8.18 × 10^{-8}
20,000	12,427	57.28	2500	8.64 × 10^{-3}	2.70 × 10^{-4}	2.749	97.25	1.03	4.99 × 10^{3}	8.71 × 10^{-15}	8.59 × 10^{-18}	4.31 × 10^{-23}	3.53 × 10^{-20}	2.54 × 10	7.17 × 10^{5}	2.21 × 10^{14}	3.24 × 10^{-8}	9.84 × 10^{14}	7.29 × 10^{-8}
25,000	15,534	40.48	2500	1.23 × 10^{-2}	9.12 × 10^{-5}	2.152	97.85	1.02	6.74 × 10^{3}	7.90 × 10^{-15}	7.79 × 10^{-18}	3.94 × 10^{-23}	3.22 × 10^{-20}	2.33 × 10	7.19 × 10^{5}	2.41 × 10^{14}	2.98 × 10^{-8}	1.07 × 10^{15}	6.70 × 10^{-8}
30,000	18,641	30.12	2500	2.47 × 10^{-2}	1.47 × 10^{-5}	1.785	98.21	1.02	8.74 × 10^{3}	7.49 × 10^{-15}	7.39 × 10^{-18}	3.68 × 10^{-23}	3.01 × 10^{-20}	2.18 × 10	7.20 × 10^{5}	2.58 × 10^{14}	2.79 × 10^{-8}	1.15 × 10^{15}	6.28 × 10^{-8}
35,000	21,748	23.28	2500	9.54 × 10^{-3}	4.00 × 10^{-5}	1.541	98.46	1.02	1.10 × 10^{4}	7.11 × 10^{-15}	7.01 × 10^{-18}	3.49 × 10^{-23}	2.85 × 10^{-20}	2.08 × 10	7.20 × 10^{5}	2.71 × 10^{14}	2.66 × 10^{-8}	1.21 × 10^{15}	5.98 × 10^{-8}
40,000	24,855	18.53	2500	4.52 × 10^{-3}	2.10 × 10^{-5}	1.369	98.63	1.02	1.35 × 10^{4}	6.83 × 10^{-15}	6.74 × 10^{-18}	3.34 × 10^{-23}	2.73 × 10^{-20}	1.99 × 10	7.21 × 10^{5}	2.82 × 10^{14}	2.55 × 10^{-8}	1.26 × 10^{15}	5.74 × 10^{-8}
45,000	27,961	15.10	2500	2.48 × 10^{-3}	1.24 × 10^{-5}	1.241	98.76	1.02	1.63 × 10^{4}	6.60 × 10^{-15}	6.51 × 10^{-18}	3.23 × 10^{-23}	2.64 × 10^{-20}	1.93 × 10	7.21 × 10^{5}	2.92 × 10^{14}	2.47 × 10^{-8}	1.30 × 10^{15}	5.56 × 10^{-8}
50,000	31,068	12.54	2500	1.51 × 10^{-3}	8.11 × 10^{-6}	1.144	98.86	1.02	1.93 × 10^{4}	6.42 × 10^{-15}	6.33 × 10^{-18}	3.14 × 10^{-23}	2.57 × 10^{-20}	1.87 × 10	7.22 × 10^{5}	3.01 × 10^{14}	2.40 × 10^{-8}	1.34 × 10^{15}	5.40 × 10^{-8}
55,000	34,175	10.58	2500	9.98 × 10^{-4}	5.66 × 10^{-6}	1.067	98.93	1.02	2.26 × 10^{4}	6.27 × 10^{-15}	6.19 × 10^{-18}	3.06 × 10^{-23}	2.50 × 10^{-20}	1.83 × 10	7.22 × 10^{5}	3.08 × 10^{14}	2.34 × 10^{-8}	1.37 × 10^{15}	5.28 × 10^{-8}
60,000	37,282	9.05	2500	7.02 × 10^{-4}	3.92 × 10^{-6}	.9536	99.05	1.02	3.00 × 10^{4}	6.03 × 10^{-15}	5.95 × 10^{-18}	2.94 × 10^{-23}	2.41 × 10^{-20}	1.76 × 10	7.22 × 10^{5}	3.20 × 10^{14}	2.26 × 10^{-8}	1.42 × 10^{15}	5.08 × 10^{-8}
70,000	43,496	6.83	2500	3.99 × 10^{-4}	2.56 × 10^{-6}														

Table 3.28 ATMOSPHERIC MODEL III. VALUES OF TEMPERATURE, PRESSURE AND DENSITY ABOVE THE F_2-LAYER
Latitude 45°. Metric Units. p_0 = 1014 mb, $\rho_0 = 1.223 \times 10^{-3}$ gm/cm^3. Table 45 of Ref. 3.20.

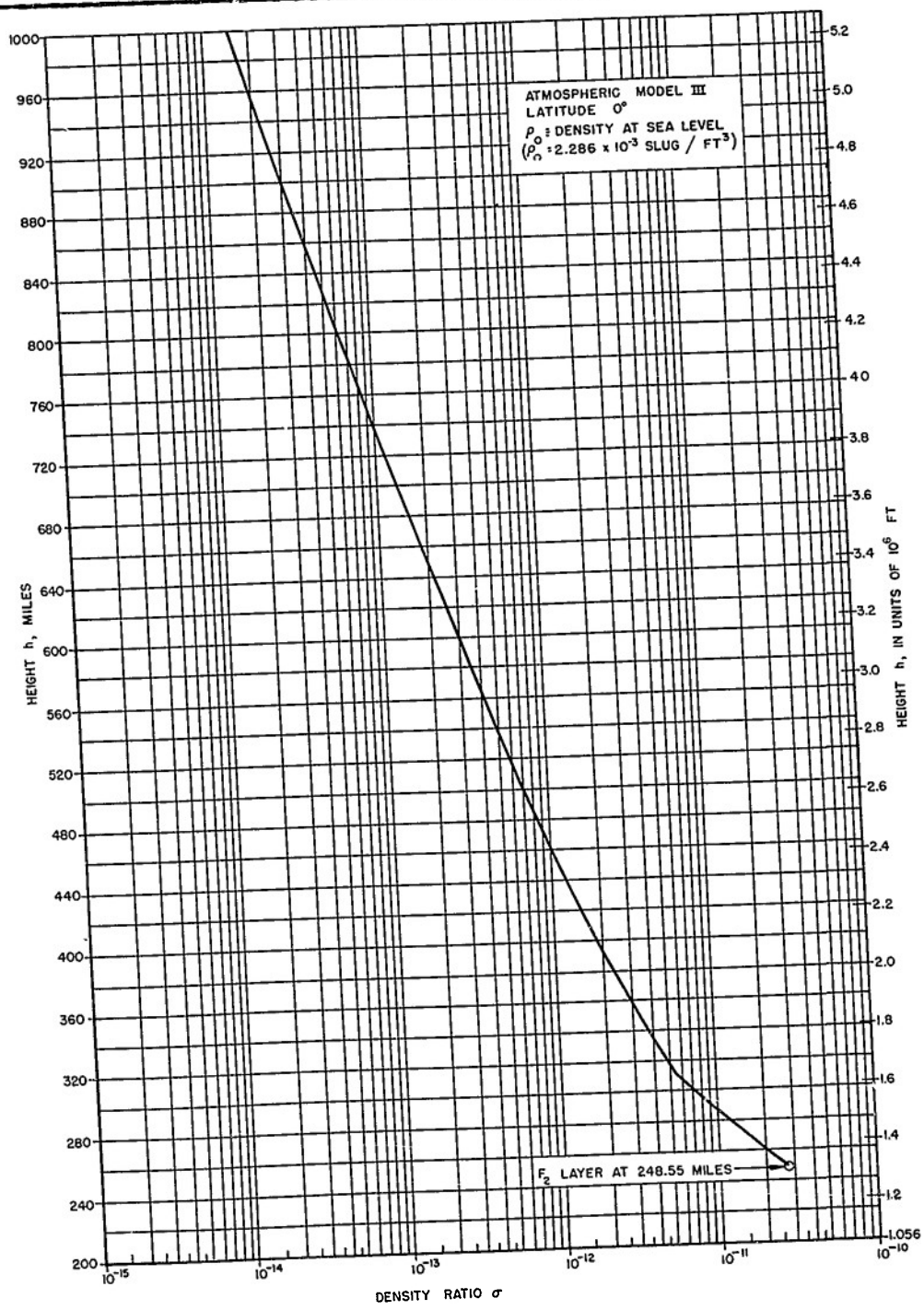


Fig. 3.52 ATMOSPHERIC MODEL III. VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM THE F_2-LAYER UP TO 1000 MILES Latitude 0^o. Engineering Units. Fig. 33 of Ref. 3.20.

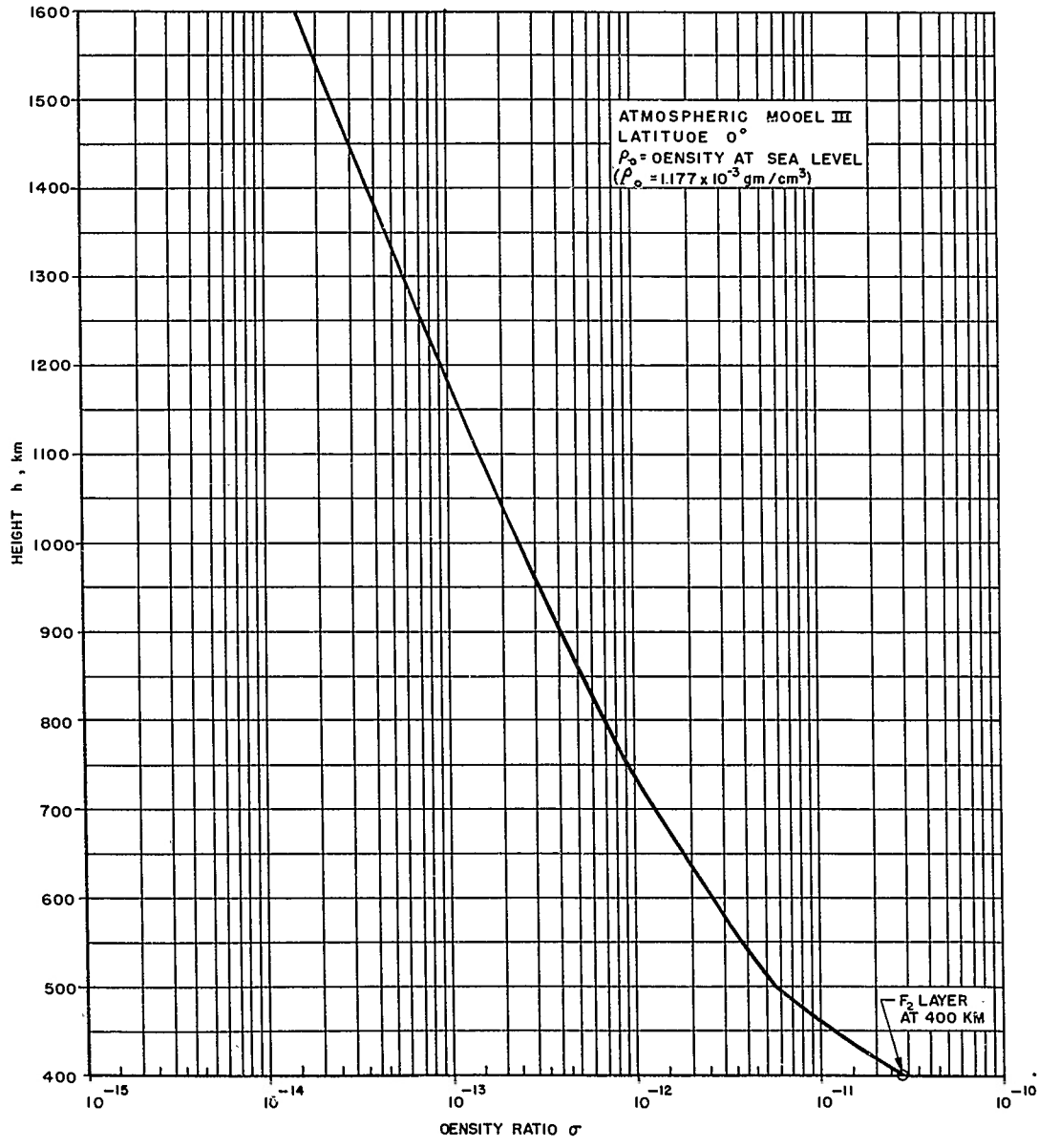


Fig. 3.53 ATMOSPHERIC MODEL III. VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM THE F_2-LAYER UP TO 1600 KM Latitude 0°. Metric Units. Fig. 34 of Ref. 3.20.

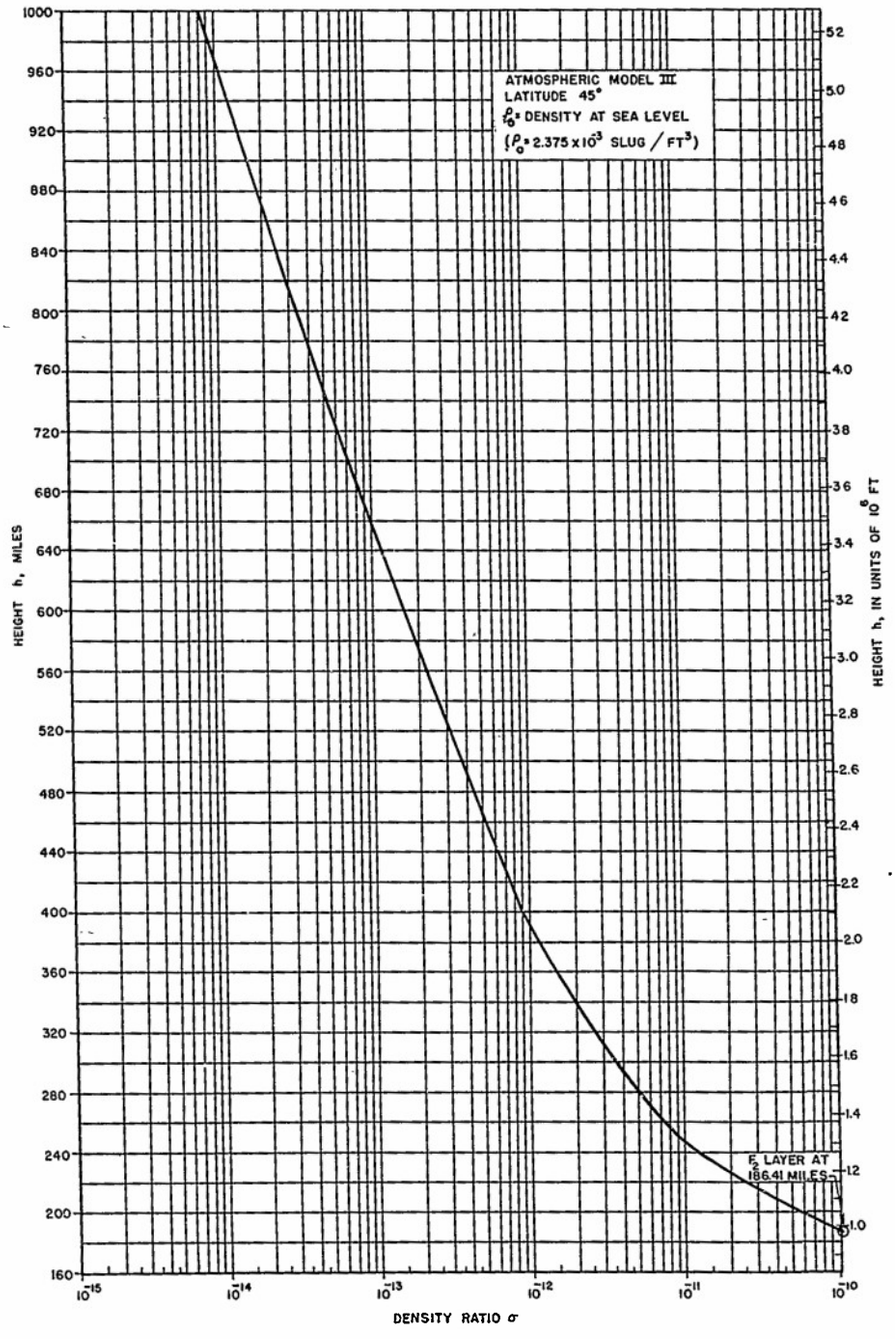


Fig. 3.54 ATMOSPHERIC MODEL III. VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM THE F_2-LAYER UP TO 1000 MILES Latitude 45°. Engineering Units. Fig. 35 of Ref. 3.20.

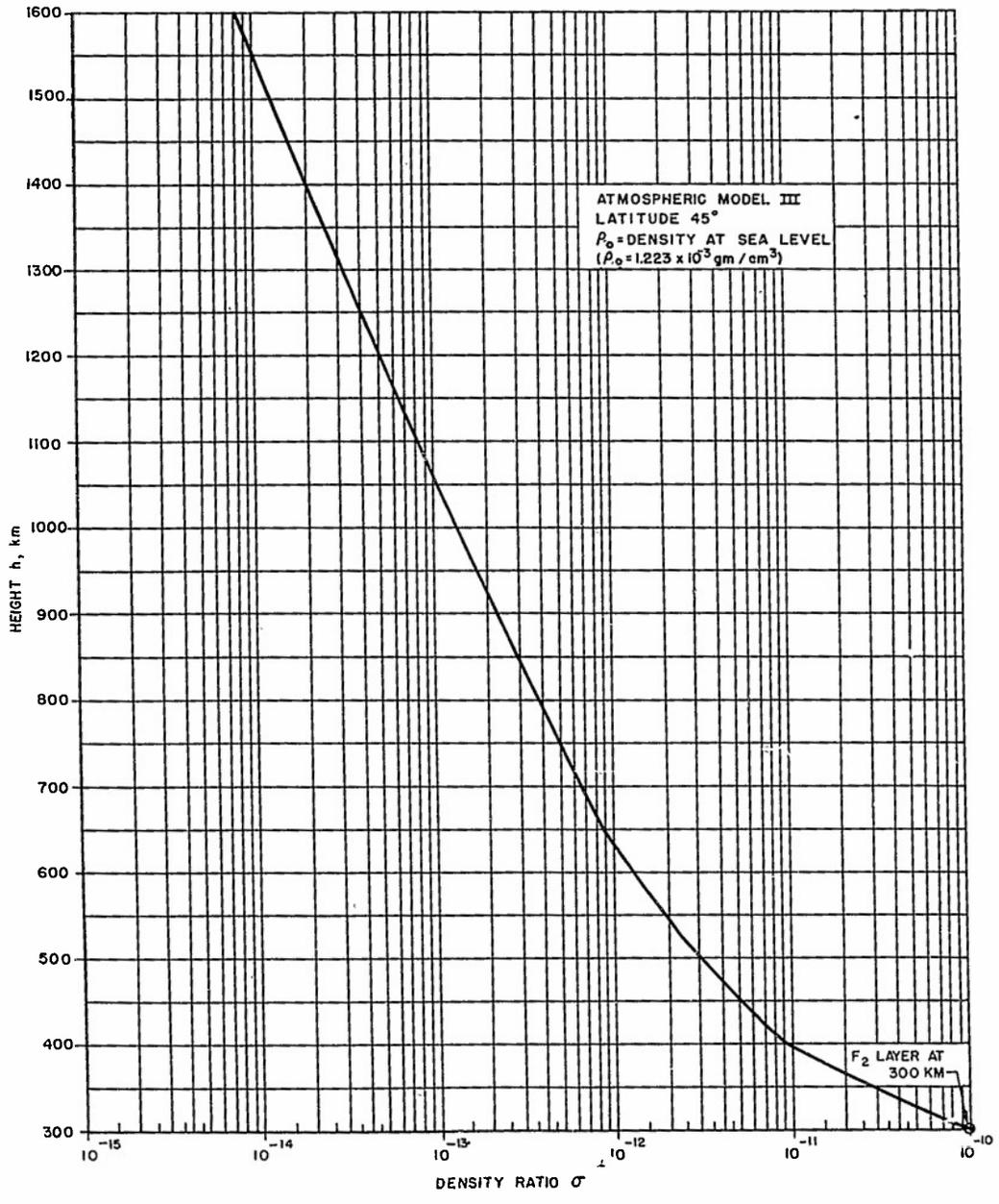


Fig. 3.55 ATMOSPHERIC MODEL III. VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) FROM THE F_2-LAYER UP TO 1600 KM Latitude 45°. Metric Units. Fig. 36 of Ref. 3.20.

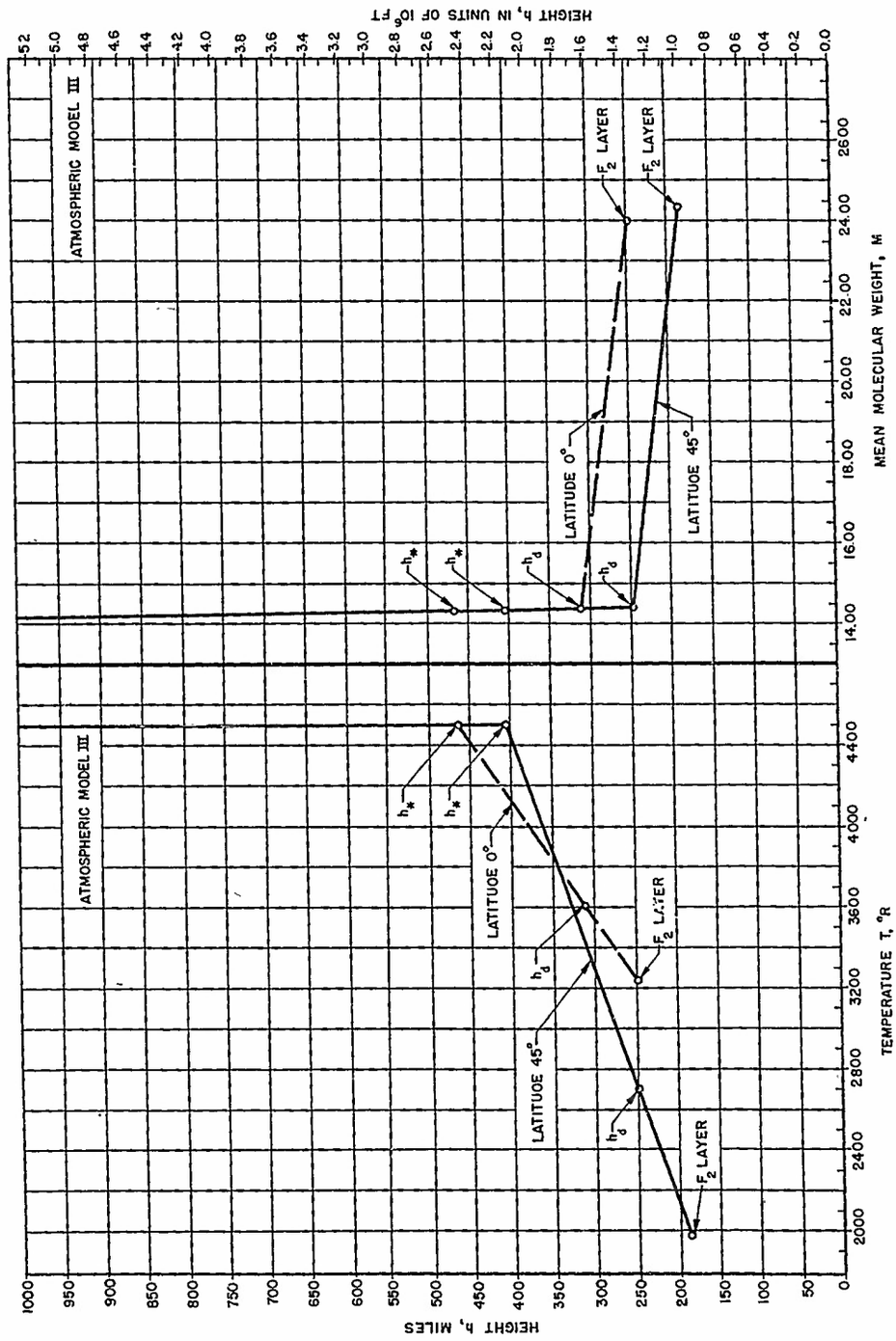


Fig. 3.56 ATMOSPHERIC MODEL III. VERTICAL DISTRIBUTION OF THE TEMPERATURE AND COMPOSITION FROM THE F_2-LAYER UP TO 1000 MILES
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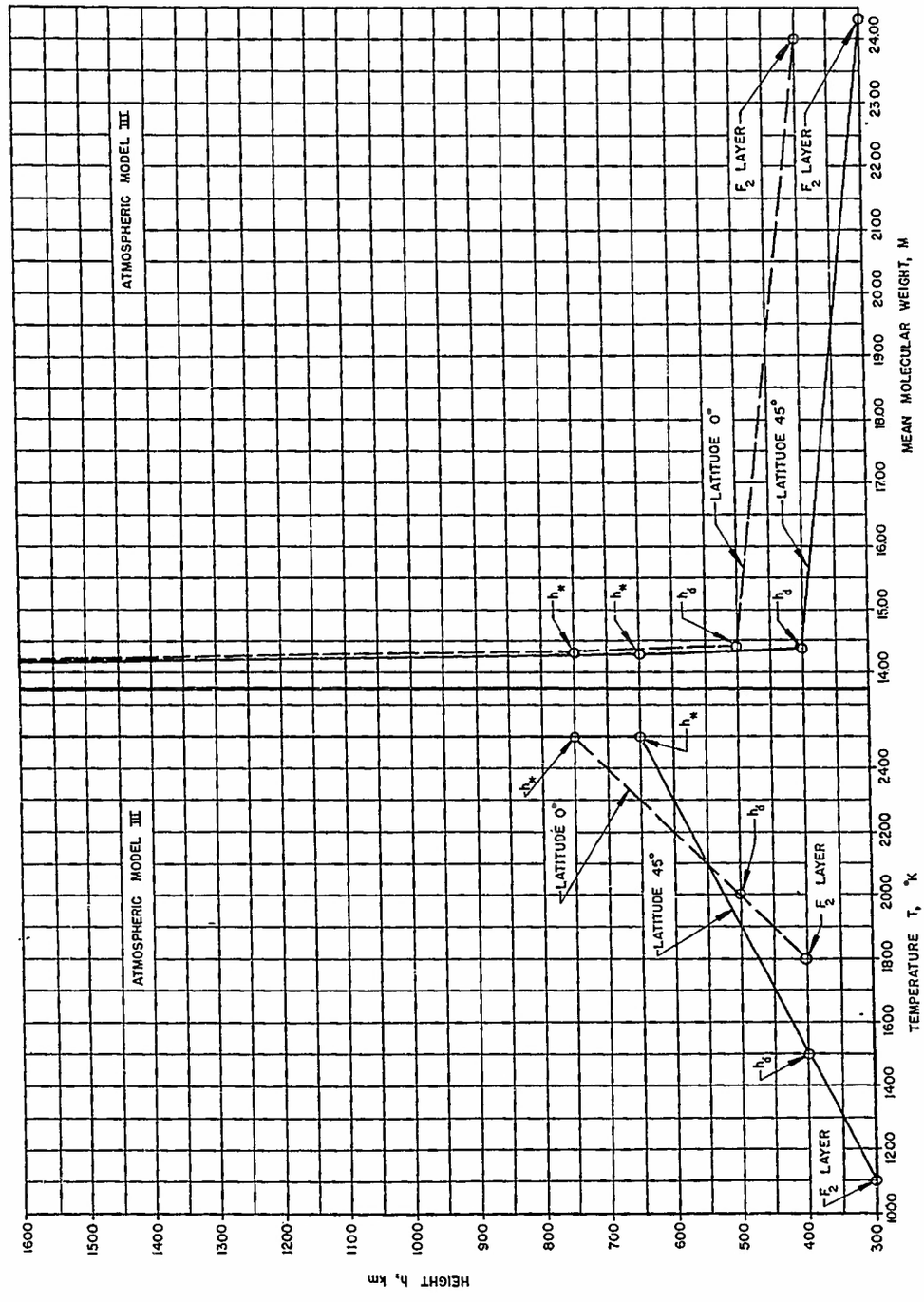


Fig. 3.57 ATMOSPHERIC MODEL III. VERTICAL DISTRIBUTION OF THE TEMPERATURE AND COMPOSITION FROM THE F_2-LAYER UP TO 1600 KM
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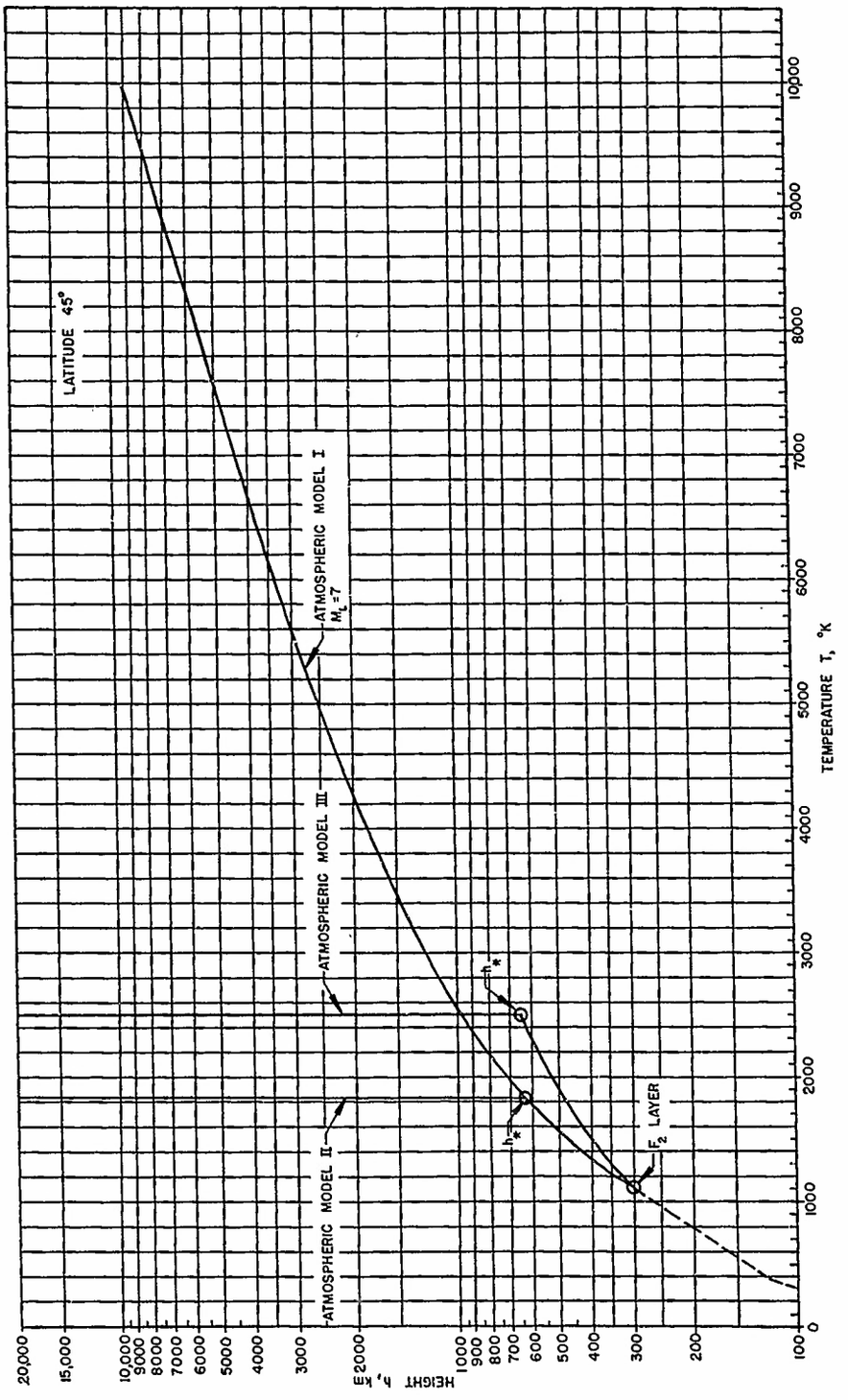


Fig. 3.58 VERTICAL DISTRIBUTION OF TEMPERATURE ABOVE THE F_2-LAYER FOR MODELS I, II AND III
Latitude 45°. Metric Units. Fig. 41 of Ref. 3.20.

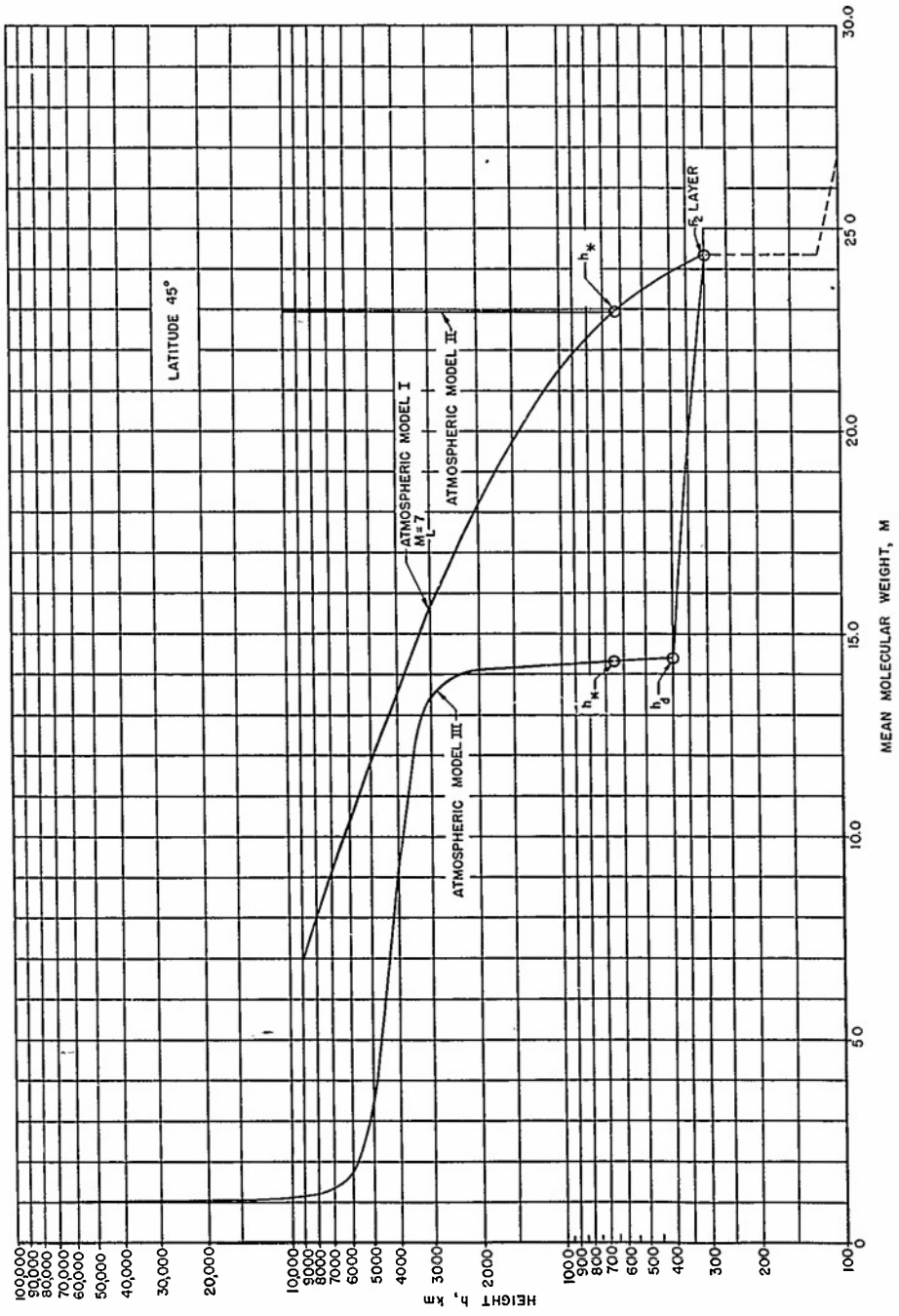


Fig. 3.59 VERTICAL DISTRIBUTION OF MEAN MOLECULAR WEIGHT ABOVE THE F2-LAYER FOR MODELS I, II AND III
Latitude 45°. Fig. 42 of Ref. 3.20.

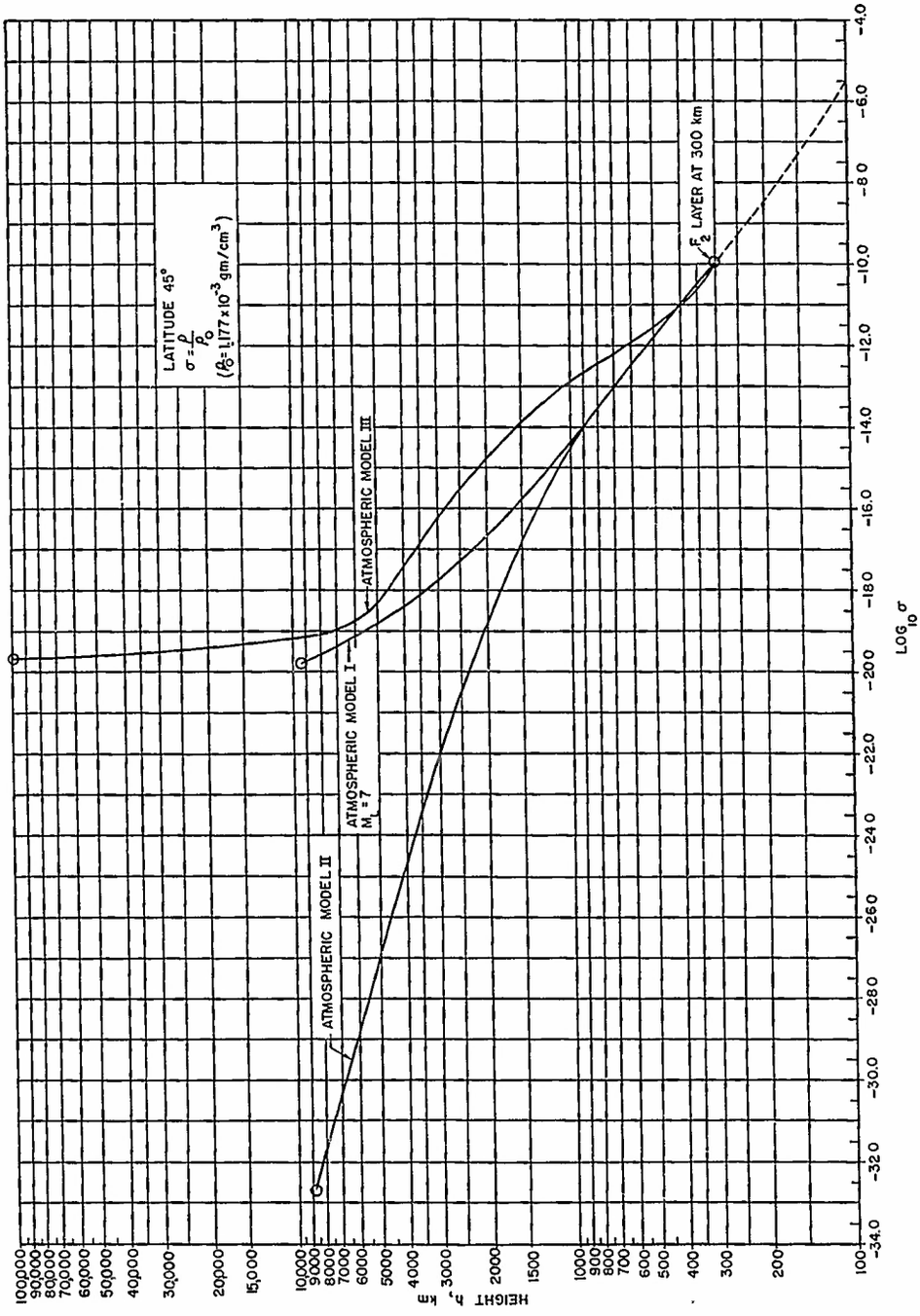


Fig. 3.60 VERTICAL DISTRIBUTION OF THE DENSITY RATIO (σ) ABOVE THE F_2-LAYER FOR MODELS I, II AND III
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SECTION 4 - THE MECHANICS AND THERMODYNAMICS OF STEADY ONE-DIMENSIONAL GAS FLOW

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SECTION 4 - THE MECHANICS AND THERMODYNAMICS OF STEADY ONE-DIMENSIONAL GAS FLOW

SYMBOLS

The following symbols are to be used with the paper entitled: "The Mechanics and Thermodynamics of Steady One-Dimensional Gas Flow with Tables for Numerical Solutions", by A. H. Shapiro, W. R. Hawthorne and G. M. Edelman, taken from Meteor Report No. 14, dated December 1, 1947. This material appears on pages 4.1 to 4.155, inclusive, of the Handbook.

A = cross-sectional area

$$B = \frac{1 + \left[1 + \left(\frac{w_2}{w_1} - 1\right) y - \frac{c_D}{2}\right] k_1 M_1^2}{1 + k_1 M_1^2}$$

c = speed of sound

c_D = drag coefficient of internal bodies, based on duct cross-sectional area

c_p = specific heat at constant pressure

$$\bar{c}_{pg} = \frac{1}{T_{og} - T} \int_T^{T_{og}} c_{pg} dT$$

D = hydraulic diameter

f = friction coefficient of duct ($\tau_w / \frac{1}{2}\rho V^2$)

F = Impulse function ($pA + \rho AV^2$)

dh_{pr} = enthalpy change at temperature T due to change in chemical composition (positive for exothermic reaction), per unit mass of stream

h_{fg} = latent heat at temperature T, per unit mass of evaporating liquid

dH = enthalpy effect due to combustion, phase change, and mixing, namely

$$dH = dh_{pr} - \left(h_{fg} + \frac{V^2 - V_L^2}{2}\right)\frac{dw_L}{} - \left[\bar{c}_{pg}\,(T - T_{og}) + \frac{V^2}{2}\right]\frac{dw_g}{w}$$

k = ratio of specific heats (c_p/c_v)

L = length of duct

L_{max} = maximum length of duct for adiabatic, constant-area, constant-mass flow with friction

M = Mach number

p = static pressure

p_o = isentropic stagnation pressure

Q = heat transfer to stream from external sources, per unit mass of stream

$\bar{R}$ = universal gas constant

r = recovery factor (Figure 4.7 and Equation(4.30d)

dS = total change in entropy of main plus injected streams, per unit mass of main stream

s = entropy per unit mass

T = temperature (absolute)

T_o = stagnation temperature (absolute)

T_{og} = stagnation temperature of injected gas

T_w = wall temperature (Figure 4.7)

T_{wa} = adiabatic wall temperature (Figure 4.7)

U = film coefficient of heat transfer

V = stream velocity

w = mass rate of flow of stream

dw_g = mass rate of flow of injected gas

dw_L = mass rate of flow of evaporated gas

$dw = dw_g + dw_L$

W = molecular weight

W_x = work delivered by stream to surroundings, per unit mass of stream

x = distance along duct

X = drag force on bodies in stream, or component of body force acting on stream in direction opposite to flow

$y_g = V_g'/V$, where V_g' is forward component of velocity with which dw_g enters stream (see Figure 4.1)

$y_L = V_L'/V$, where V_L' is forward component of velocity with which dw_L enters stream

$y = (y_g dw_g + y_L dw_L)/(dw_g + dw_L)$

ρ = mass density of stream

σ = half-angle of divergence of duct

τ_w = shearing stress on walls of duct

$()^*$ = refers to conditions where $M = 1$

$()_g$ = refers to injected gas

$()_L$ = refers to injected fluid which changes phase

$()_1$ = refers to section 1

$()_2$ = refers to section 2

$()'$ = refers to conditions relative to observer moving with unburned gas

$()_x$ = refers to conditions upstream of the shock

$()_y$ = refers to conditions downstream of the shock

SECTION 4 - THE MECHANICS AND THERMODYNAMICS OF STEADY ONE-DIMENSIONAL GAS FLOW

The material appearing on pages 4.1-4.58, inclusive, is a verbatim reproduction of the original paper entitled: "The Mechanics and Thermodynamics of Steady, One-Dimensional Gas Flow", by A. H. Shapiro and W. R. Hawthorne, published in the Journal of Applied Mechanics, Vol. 14, No. 4, pp. A-317 to A-336, December, 1947. Permission for reproducing same in the Handbook has been granted by the authors.

The tables appearing on pages 4.59-4.155, inclusive, are taken from Meteor Report No. 14, "The Mechanics and Thermodynamics of Steady One-Dimensional Gas Flow with Tables for Numerical Solutions", by A. H. Shapiro, W. R. Hawthorne, and G. M. Edelman, dated December 1, 1947. These tables were prepared for the Guided Missiles Program of the Massachusetts Institute of Technology under sponsorship of the Navy Department, Bureau of Ordnance. Permission for reproducing this material has been granted by Project Meteor and by the authors.

1. Preliminary Statement

Recent developments in the fields of propulsion, flow machinery, and high-speed flight have emphasized the need for an improved understanding of the characteristics of compressible flow. A one-dimensional analysis for flow without shocks is presented which takes into account the simultaneous effects of area change, wall friction, drag of internal bodies, external heat exchange, chemical reaction, change of phase, injection of gases, and changes in molecular weight and specific heat. The method of selecting independent and dependent variables, and the organization of the working equations, leads, it is believed, to a better understanding of the influence of the foregoing effects, and also simplifies greatly the analytical treatment of particular problems. Examples are given first of several types of flow, including (a) area change only; (b) heat transfer only; (c) wall friction only; and (d) gas injection only. In addition, examples of flow with combined effects are given, including (a) simultaneous friction and area change; (b) simultaneous friction and heat transfer; and (c) simultaneous liquid injection and evaporation. A one-dimensional analysis for flow through a discontinuity is presented, allowing for energy, shock, drag, and gas-injection effects, and for changes in gas properties. This analysis is applicable to such processes as: (a) the adiabatic normal shock; (b) combustion; (c) moisture condensation shocks; and (d) steady explosion waves.

2. Introduction

a. Statement of problem

The flow of compressible fluids has become a phenomenon

of increasing interest to engineers. Aeronautical engineers have long been interested in the flow of air around wings and fuselages, steam-turbine engineers have been interested in the flow through nozzles, ducts, and buckets. In both these instances the problems are simplified by the assumption of constant stagnation enthalpy with no chemical changes or mixing of injected gases.

Recently, particularly as a result of developments in propulsion, such as the rocket, the ram jet, and the gas turbine, flow with chemical changes, mixing, and heat addition has become more important. The flow of gases through combustion chambers of high output occurs in all ram-jet and gas-turbine combustion chambers. The aircraft radiator and the nuclear pile are examples in which heat is added to a gas moving at high speed. The rocket nozzle offers an example of flow with chemical change; the injector and ejector of mixing and perhaps phase change; the moving flame front and detonation wave of sudden chemical change accompanied by change in density; the moisture condensation shock and the evaporation of liquid sprays are phenomena in which there is a change in stagnation temperature and mass flow of gas.

From this survey it is clear that we must have means for predicting the simultaneous influence of many different effects on the properties of a high-speed stream. These effects include the following: (1) Area change; (2) Wall friction; (3) Drag of internal bodies; (4) External heat exchange; (5) Combustion, or chemical reaction; (6) Change of phase, e.g., evaporation or condensation of water or fuel; (7) Mixing of gases which are injected into the main stream; (8) Changes in molecular weight and specific heat occasioned by combustion, evaporation, gas injection, et cetera.

Because of the complicated nature of the problem, it will be assumed that the flow is one-dimensional, i.e., that all properties are uniform over each cross section.

b. Historical background

The history of one-dimensional gas dynamics appears to have started with the discovery in 1839 by St. Venant that isentropic acceleration of a gas stream could not be accomplished indefinitely through reduction in the channel area, and that, after the stream velocity reached the local sound velocity, higher speeds could be attained only by increasing the channel area. In the latter half of the 19th century this idea was put to use by deLaval in designing the nozzles for his impulse turbine.

Grashof (Ref. 4.1), Zeuner (Ref. 4.2), Stodola (Ref. 4.3), and Hawthorne (Ref. 4.17), investigated the effect of friction on compressible flow at constant area.

The first published works concerning the effects of heating (or cooling) at constant area and without friction were

those of Hawthorne and Cohen (Ref. 4.18), Bailey (Ref. 4.4), Sczceniowski (Ref. 4.5), and Hicks (Ref. 4.15).

Chambre and Lin (Ref. 4.6) presented equations showing the combined effects of heating, combustion, area change, and changes in molecular weight and specific heat.+

A steady flow in ducts with friction and heat addition was studied by Hicks, Montgomery, and Wasserman (Ref. 4.16).

c. Validity of one-dimensional approach

The assumption of one-dimensional flow is justified largely by the great simplifications it makes possible. In addition, there are many important problems where the one-dimensional treatment introduces no significant errors. These may be classified as follows:

When changes in stream properties in the direction of flow are much larger than in the direction normal to flow.

When changes in properties in the direction normal to flow are the same in all planes, that is, the velocity, temperature, and density profiles are unchanged.

In those cases where two- or three-dimensional effects are of prime importance, the one-dimensional point of view often supplies important qualitative results.

An additional assumption is inherent in the one-dimensional analysis, namely, that the effect of turbulence on the computation of the mean properties is small.

3. Analysis of Flow with Continuous Changes, for Variable Molecular Weight and Specific Heat

a. Assumptions

The following assumptions are made:

The flow is one-dimensional.
Changes in stream properties are continuous.
The gas is semiperfect, i.e., it obeys Boyle's and Charles' laws, and has a specific heat which varies only with temperature and composition.

b. Physical equations and definitions

It will be found convenient to express the physical equations and definitions in logarithmic differential form.

+ There appear to be a number of algebraic errors in the equations of Chambre and Lin.

The pressure-density-temperature relation, for example, is written

$$p = \rho \bar{R} T / W \tag{4.1}$$

or

$$\log_e p = \log_e \rho + \log_e \bar{R} + \log_e T - \log_e W$$

and

$$\frac{dp}{p} = \frac{d\rho}{\rho} + \frac{dT}{T} - \frac{dW}{W} \tag{4.2}$$

From the definition of Mach number and the expression for the sound velocity in a semiperfect gas, we get

$$c^2 = k\bar{R}T/W \tag{4.3a}$$

and

$$M^2 = V^2/c^2 = V^2 W/k\bar{R}T \tag{4.3b}$$

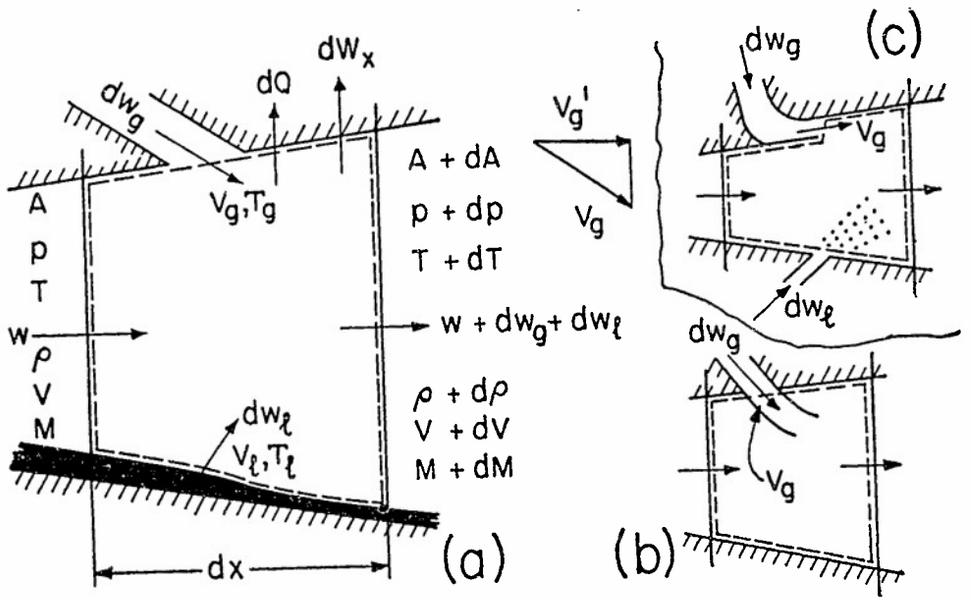


Fig. 4.1 CONTROL SURFACE FOR ANALYSIS OF CONTINUOUS CHANGES
(a, b, c show different methods of gas and liquid injection. In Fig. a, V_g' is the forward component of V_g.)

$$\frac{dc}{c} = \frac{1}{2}\left(\frac{dk}{k} + \frac{dT}{t} - \frac{dW}{W}\right) \tag{4.4a}$$

and

$$\frac{dM^2}{M^2} = \frac{dV^2}{V^2} + \frac{dW}{W} - \frac{dk}{k} - \frac{dT}{T} \tag{4.4b}$$

Using the equation of continuity, we obtain for the control surface of Figure 4.1

$$w = \rho AV \tag{4.5}$$

or

$$\frac{dw}{w} = \frac{d\rho}{\rho} + \frac{dA}{A} + \frac{dV}{V} \tag{4.6}$$

In this expression dw denotes the total increase of mass flow in the main stream and includes both injected gas and evaporated gas, i.e., $dw = dw_L + dw_g$. If vapor is condensed, note that dw_L is negative. It is important to note also that dA refers to the change in cross-sectional area occupied by the main stream, and does not include the cross-sectional area of the injected streams before mixing. It is assumed that the injected streams are perfectly mixed and diffused throughout the main stream at the downstream boundary of the control surface.

In Appendix 4.1 it is shown that the energy equation, Equation (4.66a), may be written as follows:

$$dQ - dW_x + dH = c_p dT + d(V^2/2)$$

whence

$$\frac{dQ - dW_x + dH}{c_p T} = \frac{dT}{T} + \frac{k-1}{2} M^2 \frac{dV^2}{V^2} \tag{4.7}$$

where dH denotes the net enthalpy and kinetic-energy change associated with chemical reaction, phase change, and mixing of injected gas, and is given by

$$dH = dh_{pr} - \left(h_{f_g} + \frac{V^2 - V_L^2}{2}\right)\frac{dw_L}{w} - \left[c_{pg}(T - T_{og}) + \frac{V^2}{2}\right]\frac{dw_g}{w} \tag{4.8}$$

The momentum equation, according to the derivation in Appendix 4.2, may be written

$$\frac{dp}{p} + \frac{kM^2}{2}\left(4f\frac{dx}{D} + \frac{dX}{\frac{1}{2}kpAM^2}\right) + \frac{kM^2}{2}\frac{dV^2}{v^2} + kM^2(1 - y)\frac{dw}{w} = 0 \tag{4.9}$$

Next, a quantity is defined which will be called the impulse function. The change in this function represents the total force exerted by the solid boundaries on the stream. It is useful for evaluating the thrust of propulsion systems. Thus

$$F = pA + \rho AV^2 = pA(1 + kM^2) \tag{4.10}$$

or

$$\frac{dF}{F} = \frac{dA}{A} + \frac{dp}{p} + \frac{kM^2}{1 + kM^2}\frac{dM^2}{M^2} + \frac{kM^2}{1 + kM^2}\frac{dk}{k} \tag{4.11}$$

Application of the second law of thermodynamics is simplified through use of the entropy. For a semiperfect gas, we get (for the case of unchanged chemical composition only) in the case of the main stream

$$\frac{ds}{c_p} = \frac{dT}{T} - \frac{k - 1}{k}\frac{dp}{p} \tag{4.12a}$$

Considering the total entropy change of the main stream plus injected gas and liquid, it may be shown that

$$\frac{dS}{c_p} = \frac{ds}{c_p} + (s - s_g)\frac{dw_g}{w} + (s - s_L)\frac{dw_L}{w} \tag{4.12b}$$

c. Working equations and table of influence coefficients

Among the seven relations given by Equations (4.2), (4.4), (4.6), (4.7), (4.9), (4.11) and (4.12), we find thirteen variables. Consequently, six variables may be chosen as independent and seven as dependent. For the independent variables we select those whose values are most easily controlled in a practical problem, and each of the dependent variables is then expressed in terms of the independent ones. For example, after algebraic combination and manipulation, we get

$$\frac{dM^2}{M^2} = -\frac{2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dA}{A} + \frac{1+kM^2}{1-M^2}\frac{dQ - dW_x + dH}{c_pT}$$

$$+\frac{kM^2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\left[4f\frac{dx}{D} + \frac{dX}{\frac{1}{2}kpAM^2} - 2y\frac{dw}{w}\right]$$

$$+\frac{2(1+kM^2)\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dw}{w} - \frac{1+kM^2}{1-M^2}\frac{dW}{W} - \frac{dk}{K}$$

(4.13)

The coefficients of the independent variables are called "influence" coefficients and prove to be functions of k and M only. In Table 4.1 is a complete list of influence coefficients.

d. General characteristics of flow patterns

Leaving for subsequent discussion the application of Table 4.1 to specific problems the following general conclusions may be reached by inspecting the forms of the influence coefficients:

The influence coefficients for M, V, T, ρ, and p have, with the exception of those pertaining to dk/k, the term $(1 - M^2)$ in the denominator. Thus the values of M, V, T, ρ, and p change at an infinite rate near M = 1. Moreover, the signs of the influence coefficients change at M = 1, thus indicating that the effects of the independent variables (excluding dk/k) are of opposite sign in subsonic and supersonic flow (except for the effect of heating on T, where the influence coefficient changes sign at $M = 1/\sqrt{k}$, as well as at M = 1).

Because of the change in sign of the influence coefficients at M = 1, it is evident that some sort of readjustment in the flow may sometimes be necessary if the independent variables are continuously altered in one direction. This readjustment may be in the form of choking or of shock waves.

The flow in a convergent nozzle is a familiar example of choking. The following interpretation of this phenomenon may clarify the concepts of thermal and frictional choking to be discussed later.

Observe from Equation (4.13) that for area change alone near M = 1, we may write approximately

$$dM^2 \cong - \frac{(k + 1) M^2}{1 - M^2} \frac{dA}{A}$$

Now imagine that following the section where M = 1, a section of decreasing area is added on, i.e., $dA < 0$. If we suppose the mass flow unchanged by this addition, the sign of the approximate expression just given shows that there can be no change of Mach number corresponding to the area reduction; for if M were to become subsonic, it would immediately tend toward unity; and if M were to become supersonic, it would again tend immediately toward unity. Thus the supposition of unchanged mass flow leads to the absurdity of an unlimited decrease in area with no change in Mach number. It is observed experimentally that this difficulty is resolved by a reduction in mass flow proportional to the reduction in throat area. Similar considerations applied to the remaining terms of Equation (4.13) show that choking effects may be attendant on heat effects, frictional effects, mixing, and chemical change.

The individual influence of each independent variable is readily found from Table 4.1.

For example, an increase in area tends to reduce M in subsonic flow and to increase it in supersonic flow.

Heating or combustion tends to increase M at subsonic speeds, and to decrease M at supersonic speeds.

The effect of friction, or drag of internal bodies, acts to increase M at subsonic speeds, and to decrease M at supersonic speeds. Note that the friction term, fdx, and internal-drag term, dX, are always positive, while the other independent variables may be either positive or negative.

An increase in mass flow (with $y < 1$ for the added flow) tends to increase M at subsonic speeds and to decrease M at supersonic speeds.

When the molecular weight is increased, the Mach number tends to drop for subsonic flow and to rise for supersonic flow.

Finally, an increase in the isentropic exponent k always tends to reduce M, for either subsonic or supersonic speeds.

Considering the simple case where there is no combustion, no W_x, and no gas injection, we find from Table 4.1 that

$$ds = \frac{dQ}{T} + c_p \frac{k - 1}{2} M^2 \left[4f \frac{dx}{D} + \frac{dX}{\frac{1}{2} kpAM^2} \right]$$

	$\frac{dA}{A}$	$\frac{dQ - dW_x + dH}{c_pT}$	$4f\frac{dx}{D} + \frac{dX}{\frac{1}{2}kpA\mathrm{M}^2} - 2y\frac{dw}{w}$	$\frac{dw}{w}$	$\frac{dW}{W}$	$\frac{dk}{k}$
$\frac{d\mathrm{M}^2}{\mathrm{M}^2}$	$-\frac{2\left(1+\frac{k-1}{2}\mathrm{M}^2\right)}{1-\mathrm{M}^2}$	$\frac{1+k\mathrm{M}^2}{1-\mathrm{M}^2}$	$\frac{k\mathrm{M}^2\left(1+\frac{k-1}{2}\mathrm{M}^2\right)}{1-\mathrm{M}^2}$	$\frac{2(1+k\mathrm{M}^2)\left(1+\frac{k-1}{2}\mathrm{M}^2\right)}{1-\mathrm{M}^2}$	$-\frac{1+k\mathrm{M}^2}{1-\mathrm{M}^2}$	-1
$\frac{dV}{V}$	$-\frac{1}{1-\mathrm{M}^2}$	$\frac{1}{1-\mathrm{M}^2}$	$\frac{k\mathrm{M}^2}{2(1-\mathrm{M}^2)}$	$\frac{1+k\mathrm{M}^2}{1-\mathrm{M}^2}$	$-\frac{1}{1-\mathrm{M}^2}$	0
$\frac{dc}{c}$	$\frac{\frac{k-1}{2}\mathrm{M}^2}{1-\mathrm{M}^2}$	$\frac{1-k\mathrm{M}^2}{2(1-\mathrm{M}^2)}$	$-\frac{k(k-1)\mathrm{M}^4}{4(1-\mathrm{M}^2)}$	$-\frac{\frac{k-1}{2}\mathrm{M}^2(1+k\mathrm{M}^2)}{1-\mathrm{M}^2}$	$\frac{k\mathrm{M}^2-1}{2(1-\mathrm{M}^2)}$	$\frac{1}{2}$
$\frac{dT}{T}$	$\frac{(k-1)\mathrm{M}^2}{1-\mathrm{M}^2}$	$\frac{1-k\mathrm{M}^2}{1-\mathrm{M}^2}$	$-\frac{k(k-1)\mathrm{M}^4}{2(1-\mathrm{M}^2)}$	$-\frac{(k-1)\mathrm{M}^2(1+k\mathrm{M}^2)}{1-\mathrm{M}^2}$	$\frac{(k-1)\mathrm{M}^2}{1-\mathrm{M}^2}$	0
$\frac{d\rho}{\rho}$	$\frac{\mathrm{M}^2}{1-\mathrm{M}^2}$	$-\frac{1}{1-\mathrm{M}^2}$	$-\frac{k\mathrm{M}^2}{2(1-\mathrm{M}^2)}$	$-\frac{(k+1)\mathrm{M}^2}{1-\mathrm{M}^2}$	$\frac{1}{1-\mathrm{M}^2}$	0
$\frac{dp}{p}$	$\frac{-k\mathrm{M}^2}{1-\mathrm{M}^2}$	$-\frac{k\mathrm{M}^2}{1-\mathrm{M}^2}$	$-\frac{k\mathrm{M}^2[1+(k-1)\mathrm{M}^2]}{2(1-\mathrm{M}^2)}$	$-\frac{2k\mathrm{M}^2\left(1+\frac{k-1}{2}\mathrm{M}^2\right)}{1-\mathrm{M}^2}$	$\frac{k\mathrm{M}^2}{1-\mathrm{M}^2}$	0
$\frac{dF}{F}$	$\frac{1}{1+k\mathrm{M}^2}$	0	$-\frac{k\mathrm{M}^2}{2(1+k\mathrm{M}^2)}$	0	0	0
ds/c_p (Note 2)	0	1	$\frac{(k-1)\mathrm{M}^2}{2}$	$(k-1)\mathrm{M}^2$	0	0

Notes: (1) Each influence coefficient represents the partial derivative of the variable in the left-hand column with respect to the variable in the top row; for example

$$\frac{d\mathrm{M}^2}{\mathrm{M}^2} = -\frac{2\left(1+\frac{k-1}{2}\mathrm{M}^2\right)}{1-\mathrm{M}^2}\frac{dA}{A} + \frac{1+k\mathrm{M}^2}{1-\mathrm{M}^2}\frac{dQ-dW_x+dH}{c_pT} + \cdots\cdots - \frac{dk}{k}$$

(2) For unaltered chemical composition only, and referring to entropy change of main stream. See Equation (4.12b) for total entropy change.

Table 4.1 TABLE OF INFLUENCE COEFFICIENTS

Variable Specific Heat and Molecular Weight

The second law formulation of Clausius (Ref. 4.8) is

$$ds - \frac{dQ}{T} \geqslant 0$$

from which it follows that both fdx and dX are always positive, i.e., negative friction or negative drag would constitute violations of the second law of thermodynamics.

Considering the case when there is no chemical change, no friction, no drag, no W_x, and no liquid injection, we find from Equation (4.12b)

$$dS = \frac{dQ + dH}{T} + c_p(k - 1)\, M^2(1 - y)\, \frac{dw}{w} + (s - s_g)\, \frac{dw_s}{w}$$

As in the preceding paragraph the second law of thermodynamics requires that

$$dS - \frac{dQ}{T} \geqslant 0$$

Examination of this requirement for gas injection shows that it is satisfied under all conditions.

For gas withdrawal, if the foregoing equation for dS is valid, then the second law requirement can only be satisfied if the withdrawn gas crosses the boundary of the control surface with exactly the same properties and direction of motion as the main stream. In other words, the withdrawal must not include an unmixing process, and, in addition, y must be unity. Obviously, gas may be withdrawn at other values of y, but in these instances the gas will cross the boundary at other than the control-surface pressure, and the equation for dS will have to be modified to take into account the added term discussed in the footnote to Equation (4.67), Appendix 4.2.

From this discussion it is to be noted that for gas withdrawal the influence coefficients in Tables 4.1 and 4.2 are applicable only for the condition y = 1.

4. Analysis of Flow with Continuous Changes, for Constant Molecular Weight and Specific Heat

There are many problems where the changes in molecular weight and specific heat may be ignored, and the computations considerably simplified thereby.

a. Assumptions

The assumptions are the same as in the preceding section, except that $dW = dc_p = dk = 0$.

b. Physical equations and definitions

In addition to the equations of the preceding section, which of course remain valid, we define two quantities which are found to be convenient.

The stagnation temperature (sometimes called total temperature) is the temperature which the stream would assume if it were brought to rest adiabatically. It is given by the expression

$$T_o = T + \frac{V^2}{2c_p} = T\left(1 + \frac{k-1}{2}M^2\right) \tag{4.14}$$

or

$$\frac{dT_o}{T_o} = \frac{dT}{T} + \frac{\frac{k-1}{2}M^2}{1 + \frac{k-1}{2}M^2}\frac{dM^2}{M^2} \tag{4.15}$$

This equation is used in place of Equation (4.7), and heat effects are then measured in terms of changes in the stagnation temperature, according to the energy equation

$$dQ = dW_x + dH = c_p dT + d\frac{V^2}{2} = c_p dT_o \tag{4.16}$$

Another important variable, particularly for internal-flow problems, is the isentropic stagnation pressure (sometimes called total pressure), which is defined as the pressure that the stream would assume if it were brought to rest isentropically. It is related to the local static pressure and Mach number through the formula

$$p_o = p\left(1 + \frac{k-1}{2}M^2\right)^{\frac{k}{k-1}} \tag{4.17}$$

or

$$\frac{dp_o}{p_o} = \frac{dp}{p} + \frac{\frac{kM^2}{2}}{1 + \frac{k-1}{2}M^2}\frac{dM^2}{M^2} \tag{4.18}$$

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The change of entropy, in terms of T_o and p_o, is then

$$\frac{ds}{c_p} = \frac{dT_o}{T_o} - \frac{k-1}{k}\frac{dp_o}{p_o}$$

c. Working equations and table of influence coefficients

As in the preceding section, the equations are put into canonical form. The influence coefficients are given in Table 4.2.

The most important working equation is

$$\frac{dM^2}{M^2} = -\frac{2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dA}{A}$$

$$+\frac{(1+kM^2)\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dT_o}{T_o}$$

$$+\frac{kM^2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\left(4f\frac{dx}{D}+\frac{dX}{\frac{1}{2}kpAM^2}-2y\frac{dw}{w}\right)$$

$$+\frac{2(1+kM^2)\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dw}{w} \qquad (4.19)$$

	$\frac{dA}{A}$	$\frac{dT_0}{T_0}$	$4f\frac{dx}{D}+\frac{dX}{\frac{1}{2}kpAM^2}-2y\frac{dw}{w}$	$\frac{dw}{w}$
$\frac{dM^2}{M^2}$	$-\frac{2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}$	$\frac{(1+kM^2)\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}$	$\frac{kM^2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}$	$\frac{2(1+kM^2)\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}$
$\frac{dV}{V}$	$-\frac{1}{1-M^2}$	$\frac{1+\frac{k-1}{2}M^2}{1-M^2}$	$\frac{kM^2}{2(1-M^2)}$	$\frac{1+kM^2}{1-M^2}$
$\frac{dc}{c}$	$\frac{\frac{k-1}{2}M^2}{1-M^2}$	$\frac{\frac{1-kM^2}{2}\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}$	$-\frac{k(k-1)M^4}{4(1-M^2)}$	$-\frac{\frac{k-1}{2}M^2(1+kM^2)}{1-M^2}$
$\frac{dT}{T}$	$\frac{(k-1)M^2}{1-M^2}$	$\frac{(1-kM^2)\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}$	$-\frac{k(k-1)M^4}{2(1-M^2)}$	$-\frac{(k-1)M^2(1+kM^2)}{1-M^2}$
$\frac{d\rho}{\rho}$	$\frac{M^2}{1-M^2}$	$-\frac{1+\frac{k-1}{2}M^2}{1-M^2}$	$-\frac{kM^2}{2(1-M^2)}$	$-\frac{(k+1)M^2}{1-M^2}$
$\frac{dp}{p}$	$\frac{kM^2}{1-M^2}$	$-\frac{kM^2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}$	$-\frac{kM^2[1+(k-1)M^2]}{2(1-M^2)}$	$-\frac{2kM^2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}$
$\frac{dp_0}{p_0}$	0	$-\frac{kM^2}{2}$	$-\frac{kM^2}{2}$	$-kM^2$
$\frac{dF}{F}$	$\frac{1}{1+kM^2}$	0	$-\frac{kM^2}{2(1+kM^2)}$	0
$\frac{ds}{c_p}$	0	$1+\frac{k-1}{2}M^2$	$\frac{(k-1)M^2}{2}$	$(k-1)M^2$

NOTE: Each influence coefficient represents the partial derivative of the variable in the left-hand column with respect to the variable in the top row; for example

$$\frac{dM^2}{M^2}=-\frac{2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dA}{A}+\frac{(1+kM^2)\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dT_0}{T_0}+\frac{kM^2\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\left(4f\frac{dx}{D}+\frac{dX}{\frac{1}{2}kpAM^2}-2y\frac{dw}{w}\right)+\frac{2(1+kM^2)\left(1+\frac{k-1}{2}M^2\right)}{1-M^2}\frac{dw}{w}$$

Table 4.2 TABLE OF INFLUENCE COEFFICIENTS
Constant Specific Heat and Molecular Weight

d. General characteristics of flow patterns

In addition to the general conclusions of the preceding section, certain important results relating to the stagnation pressure may be observed, as follows:

Changes in area have no effect on stagnation pressure.

An increase in stagnation temperature always tends toward a reduction in p_o, be the speed subsonic or supersonic. Thus the stagnation-pressure loss in combustion chambers can never be entirely eliminated.

Friction and drag always act to reduce p_o, for both subsonic and supersonic flow.

Gas injection tends to decrease p_o if $y < 1$, i.e., if the gas is injected with a forward velocity less than that of the main stream; while the stagnation pressure tends to be increased when gas is injected with a forward velocity greater than that of the main stream.

5. Applications and Examples

a. General method of solution

If, in any particular case, the values of the independent variables in Table 4.1 are known, then, for any given set of initial conditions (M_1, p_1, T_1, etc.), the conditions at all other sections of the channel may be found through analytical or numerical integration of Equation (4.13) and equations similar to (4.13) for dp, dT, etc. In fact, Equation (4.13) alone suffices, for, if the values of M and of each independent variable are known the values of p, T, etc., may be found from integral relations given in the following.

b. Variable specific heat and molecular weight

For the case of variable specific heat and molecular weight, the integral relations are obtained from Equations (4.1), (4.3), (4.5), and (4.7), and may be summarized as follows†:

†It is assumed that for a small interval of temperature we may write:

$$\int_{T_1}^{T_2} c_p dT = \left(\frac{c_{p1} + c_{p2}}{2}\right)(T_2 - T_1).$$

$$Q - W_x + \Delta H = c_{p2}T_2\left(1 + \frac{k_2 - 1}{2}M_2^2\right) - c_{p1}T_1\left(1 + \frac{k_1 - 1}{2}M_1^2\right) - (c_{p2} - c_{p1})\frac{T_1 + T_2}{2} \qquad (4.20)$$

$$\frac{p_2}{p_1} = \frac{w_2}{w_1}\frac{A_1}{A_2}\frac{M_1}{M_2}\sqrt{\frac{T_2}{T_1}}\sqrt{\frac{k_1 W_1}{k_2 W_2}} \qquad (4.21)$$

$$\frac{V_2}{V_1} = \frac{M_2}{M_1}\sqrt{\frac{k_2}{k_1}\frac{T_2}{T_1}\frac{W_1}{W_2}} \qquad (4.22)$$

$$\frac{\rho_2}{\rho_1} = \frac{w_2}{w_1}\frac{A_1}{A_2}\frac{V_1}{V_2} = \frac{p_2}{p_1}\frac{T_1}{T_2}\frac{W_2}{W_1} \qquad (4.23)$$

Suppose that in a particular problem, the values of M_1, p_1, T_1, A_1, etc., are known at a section 1, and that the values of A_2, $(Q - W_x + \Delta H)_{1-2}$, $x_2 - x_1$, w_2, W_2, k_2, etc., are known for a section 2, a small distance downstream of section 1. Then, from Equation (4.13), the value of M_2 is found through numerical integration, using the method of isoclines. Next, Equation (4.20) is solved for T_2, Equation (4.21) for p_2, and Equations (4.22) and (4.23) for V_2 and ρ_2, respectively. The procedure is then repeated for a step between section 2 and section 3, and so on.

c. Constant specific heat and molecular weight

For the case of constant specific heat, we obtain in addition to Equations (4.22) and (4.23), the following integral relations:

$$Q - W_x + \Delta H = c_p(T_{o2} - T_{o1}) \qquad (4.24)$$

$$\frac{p_2}{p_1} = \frac{w_2}{w_1}\frac{A_1}{A_2}\frac{M_1}{M_2}\sqrt{\frac{1+\frac{k-1}{2}M_1^2}{1+\frac{k-1}{2}M_2^2}}\sqrt{\frac{T_{o2}}{T_{o1}}} \qquad (4.25)$$

$$\frac{T_2}{T_1} = \frac{T_{o2}}{T_{o1}}\frac{1+\frac{k-1}{2}M_1^2}{1+\frac{k-1}{2}M_2^2} \qquad (4.26)$$

These formulas are used in the same way as Equations (4.20) and (4.21).

d. Approximate solution near M = 1

Many of the influence coefficients approach infinity near M = 1, thus complicating the numerical integration. It is usually possible, however, to integrate Equations (4.13) or (4.19) analytically, with some degree of approximation, between a section where M is nearly unity and a section where M is exactly unity. For example, considering only the second term of Equation (4.19).

$$\frac{1-M^2}{M^2}dM^2 = (1+kM^2)\left(1+\frac{k-1}{2}M^2\right)\frac{dT_o}{T_o}$$

$$\cong (1+k)\left(1+\frac{k-1}{2}\right)\frac{dT_o}{T_o}$$

$$\cong \frac{(k+1)^2}{2}\frac{dT_o}{T_o}$$

Integrating approximately between $M = M$, $T_o = T_o$, and $M = 1$, $T_o = T_o^*$, we get

$$(1-M^2)^2 \cong (k+1)^2\left(\frac{T_o^* - T_o}{T_o}\right)$$

Specific illustrations of both analytical and numerical procedures are given in the examples which follow.

e. Simple types of flow

A simple type of flow is defined here as one in which all but one of the independent differentials in Table 4.2 are zero. Thus simple area change refers to a process in which the area changes without frictional, stagnation-temperature, or gas-injection effects. Similarly, simple T_o - change refers to a process in which the stagnation-temperature changes (due to external heat exchange or to combustion) without area change, friction, or gas injection.

Analytical relations may easily be obtained for the several simple types of flow. For example, consider a simple area change. Using the first influence coefficient in Table 4.2 we obtain

$$\int_{A^*}^{A} \frac{dA}{A} = -\int_{1}^{M} \frac{(1 - M^2)\, dM^2}{2M^2 \left(1 + \frac{k-1}{2} M^2\right)}$$

or

$$\frac{A}{A^*} = \frac{1}{M} \sqrt{\left[\frac{2\left(1 + \frac{k-1}{2} M^2\right)}{k+1}\right]^{\frac{k+1}{k-1}}} \qquad (4.27)$$

The integration is carried out between the sections where $M = 1$, $A = A^*$ and $M = M$, $A = A$. The asterisk then indicates the critical value of A, or the value where the Mach number is unity. Equation (4.27) is the well-known formula giving the ratio of local area to throat area as a function of the local Mach number for an isentropic process.

Referring again to simple area change, we obtain from the first column of Table 4.2

$$\frac{dV/V}{dM^2/M^2} = \frac{(dV/V)/(dA/A)}{(dM^2/M^2)/(dA/A)} = \frac{1}{2\left(1 + \frac{k-1}{2} M^2\right)}$$

Upon integration between $M = 1$, $V = V^*$ and $M = M$, $V = V$, we get

$$\frac{V}{V^*} = M \sqrt{\frac{k+1}{2\left(1 + \frac{k-1}{2} M^2\right)}} \qquad (4.28)$$

where V^* is the velocity where M = 1. This same equation

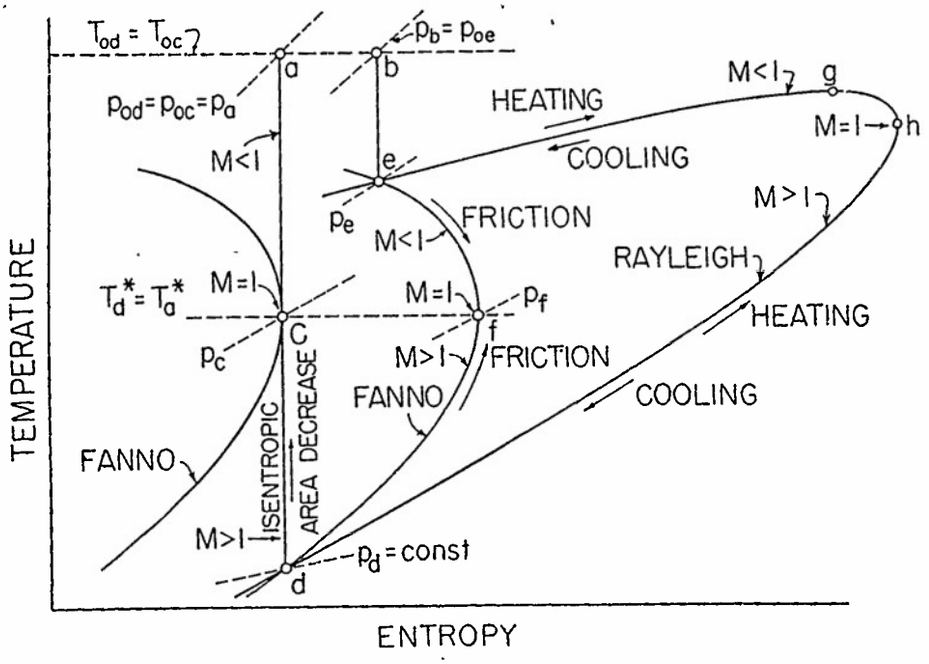


Fig. 4.2 TEMPERATURE-ENTROPY DIAGRAM
(Curves of simple area change, simple friction, and simple T_o- change)

might have been obtained from the integral relations of Equations (4.25), (4.26), (4.22), (4.23).

By continuing this procedure, we obtain not only a set of equations for the case of simple area change, but also a similar set for the other types of simple flow. These formulas are summarized in Table 4.3. Note that the case of simple gas injection with y = 1 is essentially identical with the case of isentropic area change; that this must be so is evident if we consider that this type of gas injection is reversible, involves no change in stagnation temperature, and has as its principal effect an alteration in the mass flow per unit area.

Fig. 4.2 shows on a temperature-entropy diagram the courses of states, beginning with state d, corresponding to simple area change, simple T_o-change, and simple friction, respectively.

The isentropic through d represents simple area change. In going from d to c the area is decreased and M approaches 1. At c the Mach number is unity. Point a represents the isentropic stagnation condition for all points on the line ad.

	Area change only $dT_0 = 0$ $f = 0$ $dw = 0$	Change in T_0 only $dA = 0$ $f = 0$ $dw = 0$	Friction only $dA = 0$ $dT_0 = 0$ $dw = 0$	Gas injection only $p = 0$ $dA = 0$ $dT_0 = 0$ $f = 0$	Gas injection only $p = 0$ $dA = 0$ $dT_0 = 0$ $f = 0$
$\frac{A}{A^*}$	$\frac{1}{M}\sqrt{\left[\frac{2\left(1+\frac{k-1}{2}M^2\right)}{k+1}\right]^{\frac{k+1}{k-1}}}$	1	1	1	1
$\frac{T_0}{T_0^*}$	1	$\frac{2(k+1)M^2\left(1+\frac{k-1}{2}M^2\right)}{(1+kM^2)^2}$	1	1	1
$4f\frac{L_{max}}{D}$	0	0	$\frac{1-M^2}{kM^2}+\frac{k+1}{2k}\log_e\frac{(k+1)M^2}{2\left(1+\frac{k-1}{2}M^2\right)}$	0	0
$\frac{w}{w^*}$	1	1	1	$M\sqrt{\frac{2(k+1)\left(1+\frac{k-1}{2}M^2\right)}{1+kM^2}}$	$M\sqrt{\left[\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}\right]^{\frac{k+1}{k-1}}}$
$\frac{V}{V^*}$	$M\sqrt{\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}}$	$\frac{(k+1)M^2}{1+kM^2}$	$M\sqrt{\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}}$	$M\sqrt{\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}}$	$M\sqrt{\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}}$
$\frac{T}{T^*}=\left(\frac{c}{c^*}\right)^2$	$\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}$	$\frac{(k+1)^2M^2}{(1+kM^2)^2}$	$\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}$	$\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}$	$\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}$
$\frac{\rho}{\rho^*}$	$\left[\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}\right]^{\frac{1}{k-1}}$	$\frac{1+kM^2}{(k+1)M^2}$	$\frac{1}{M}\sqrt{\frac{2\left(1+\frac{k-1}{2}M^2\right)}{k+1}}$	$\frac{2\left(1+\frac{k-1}{2}M^2\right)}{1+kM^2}$	$\left[\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}\right]^{\frac{1}{k-1}}$
$\frac{p}{p^*}$	$\left[\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}\right]^{\frac{k}{k-1}}$	$\frac{k+1}{1+kM^2}$	$\frac{1}{M}\sqrt{\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}}$	$\frac{k+1}{1+kM^2}$	$\left[\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}\right]^{\frac{k}{k-1}}$
$\frac{p_0}{p_0^*}$	1	$\frac{k+1}{1+kM^2}\left[\frac{2\left(1+\frac{k-1}{2}M^2\right)}{k+1}\right]^{\frac{k}{k-1}}$	$\frac{1}{M}\sqrt{\left[\frac{2\left(1+\frac{k-1}{2}M^2\right)}{k+1}\right]^{\frac{k+1}{k-1}}}$	$\frac{k+1}{1+kM^2}\left[\frac{2\left(1+\frac{k-1}{2}M^2\right)}{k+1}\right]^{\frac{k}{k-1}}$	1
$\frac{F}{F^*}$	$\frac{1+kM^2}{M\sqrt{2(k+1)\left(1+\frac{k-1}{2}M^2\right)}}$	1	$\frac{1+kM^2}{M\sqrt{2(k+1)\left(1+\frac{k-1}{2}M^2\right)}}$	1	$\frac{1+kM^2}{k+1}\left[\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}\right]^{\frac{k}{k-1}}$
$\frac{s-s^*}{c_p}$	0	$\log_e M^2\left(\frac{k+1}{1+kM^2}\right)^{\frac{k+1}{k}}$	$\log_e M^2\sqrt{\left[\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)M^2}\right]^{\frac{k+1}{k}}}$	$\log_e\frac{k+1}{2\left(1+\frac{k-1}{2}M^2\right)}\left(\frac{1+kM^2}{k+1}\right)^{\frac{k-1}{k}}$	0

Note: Each quantity in the table represents the value of the variable in the left-hand column under the conditions specified in the top row.

Table 4.3 FORMULAS FOR SIMPLE TYPES OF ONE-DIMENSIONAL FLOW

Constant Specific Heat and Molecular Weight

The Fanno line represents the possible series of states having a constant flow per unit area and a constant stagnation temperature. Two Fanno lines are shown, both having the same stagnation temperature, but with the line passing through c having a larger flow per unit area than the one passing through f. Frictional and drag effects alone are accountable for motion along the Fanno line, and, since we are dealing with an adiabatic process, the entropy can only increase; consequently, the motion along the Fanno line must be to the right. At point f there exists a condition where the stream may undergo a slight pressure change without heat exchange, change in area, or change in entropy; these will be recognized as the conditions under which an infinitesimal sound wave is propagated, so that at f the Mach number is unity. This is also evident by noting that the slope of the tangent to the Fanno line is

$$\frac{dh}{ds} = c_p \frac{dT}{ds}$$

From the appropriate column of Table 4.2

$$\left(c_p \frac{dT}{ds}\right)_{\text{Fanno}} = -\frac{kM^2}{1 - M^2} T$$

which becomes infinitely large when $M = 1$. Above f the flow is subsonic, while below f the flow is supersonic. Thus for simple friction, a subsonic stream can approach $M = 1$, but can never become supersonic. Similarly, a supersonic stream can never become subsonic through continuous changes.

The Rayleigh line shows the series of possible states having a constant impulse F, and a constant flow per unit area. Motion along the Rayleigh line is caused by changes in the stagnation temperature. The slope of the Rayleigh line, $c_p dT/ds$, is found to be, from Table 4.2

$$\left(c_p \frac{dT}{ds}\right)_{\text{Rayleigh}} = \frac{1 - kM^2}{1 - M^2} T$$

At point h, where the slope is infinite, $M = 1$. At point g, where the slope is zero, $M = 1/\sqrt{k}$. Note that at point h, as at point f, there exist the conditions for the sound velocity, namely, an infinitesimal pressure change without variation of the area, entropy, and stagnation temperature. The upper branch of the Rayleigh line corresponds to subsonic speeds, and the lower branch to supersonic speeds. Increases in stagnation temperature must, from the energy equation, produce increases in entropy, and vice versa. Note that

in going from g to h, heating results in a drop in stream temperature. Neither heating alone nor cooling alone can continuously alter the flow from subsonic to supersonic speeds, or the reverse. In the case of heating, M always approaches unity.

The Fanno and Rayleigh lines for the same flow per unit area intersect at two points, d and e. Point e has the same stagnation temperature, same flow per unit area, and same impulse as point d and, therefore, may be reached from d through a normal shock. Since point e may be reached reversibly from d along the Rayleigh line, and since the net area under the Rayleigh curve in passing from d to e must be zero, it follows that e has a greater entropy than d. Consequently, the discontinuity from subsonic to supersonic speeds is not physically possible without violating the second law of thermodynamics.

In interpreting the formulas of Table 4.3 and the charts of Figures 4.3(a), 4.4(a), 4.5(a), and 4.6, it must be remembered that the conditions where $M = 1$ (asterisk conditions) are different for the several types of flow. For example, referring to Figure 4.2, points c, f, and h represent, respectively, the asterisk conditions for simple area change, simple friction, and simple T_o-change. The quantities marked with asterisks are best regarded as reference values which remain constant in any one type of simple flow.

Figures 4.3, 4.4, 4.5 and 4.6 are representations of the formulas of Table 4.3 which will be found useful for both numerical and illustrative purposes.

f. Simple area change

Figure 4.3(a) shows the curves of A/A^*, p/p^*, V/V^*, etc., all against M. The important curve on this chart is that of A/A^*.

In using the chart, we begin with certain initial values of M_1, p_1, T_1, etc., and a known area ratio. For the known value of M_1, we find the corresponding values from the chart of $(A/A^*)_1$, $(p/p^*)_1$, $(T/T^*)_1$, etc. Then using the known area ratio, (A_2/A_1), we set

$$\frac{A_2}{A_1} = \frac{(A/A^*)_2}{(A/A^*)_1}$$

and solve for the value of $(A/A^*)_2$. From the chart we then find the corresponding value of M_2, and from the latter, the values of $(p/p^*)_2$, $(T/T^*)_2$, etc. Finally, we solve for p_2, T_2, etc., with the equations

$$\frac{p_2}{p_1} = \frac{(p/p^*)_2}{(p/p^*)_1}; \quad \frac{T_2}{T_1} = \frac{(T/T^*)_2}{(T/T^*)_1}; \text{ etc.}$$

In Figure 4.3(b), are illustrative curves showing the way in which, for a fixed value of A_2/A_1, the value of M_2 depends on M_1. Since for each initial M_1 and each A_2/A_1, there are two possible values of M_2 to be found from Figure 4.3(a), a distinction is made in Figure 4.3(b) between those values of M_2 which are reached through a monotonic change of area and those which are reached through a throat.

g. Simple T_o-change

Figure 4.4(a) which applies to simple T_o-change, is interpreted in the same way as Figure 4.3(a), and is useful for approximate calculations in such processes as combustion, where the effects of stagnation-temperature change far outweigh those of area change, friction, and changes in specific heat or molecular weight.

The important curve in Figure 4.4(a) is the one labelled T_o/T_o^*. If the stagnation temperature is increased, perhaps through radiation or exothermic chemical reaction, the Mach number is increased when $M < 1$ and is decreased when $M > 1$. Thus increasing the stagnation temperature always tends to make M approach unity, as was seen from Figure 4.2.

From the change in T_o, one may find from Figure 4.3(a), the change in M; and, from the latter, the changes in p, T, V, etc. The direction of the changes in p, T, V, etc., will of course check with the signs of the influence coefficients in the second column of Table 4.2. It is clearly evident from Figure 4.4(a) that, in simple T_o-change, the stagnation pressure can be increased only by reducing the stagnation temperature. Later it will be shown how this characteristic might be employed for the pumping of a highspeed stream.

The value of T/T^* reaches a maximum at $M = 1/\sqrt{k}$, and this maximum corresponds to point g in Figure 4.2.

For fixed initial values of M and T_o, Figure 4.4(a) shows, as did Figure 4.2, that there is a maximum possible rise in stagnation temperature. What will happen if one attempts to increase the rise in T_o above this limiting value? It has been suggested, Ref. 4.5, for the case where T_o is increased by heating the stream with heat-exchange surface, that the surface coefficient of heat transfer approaches zero as M approaches unity.

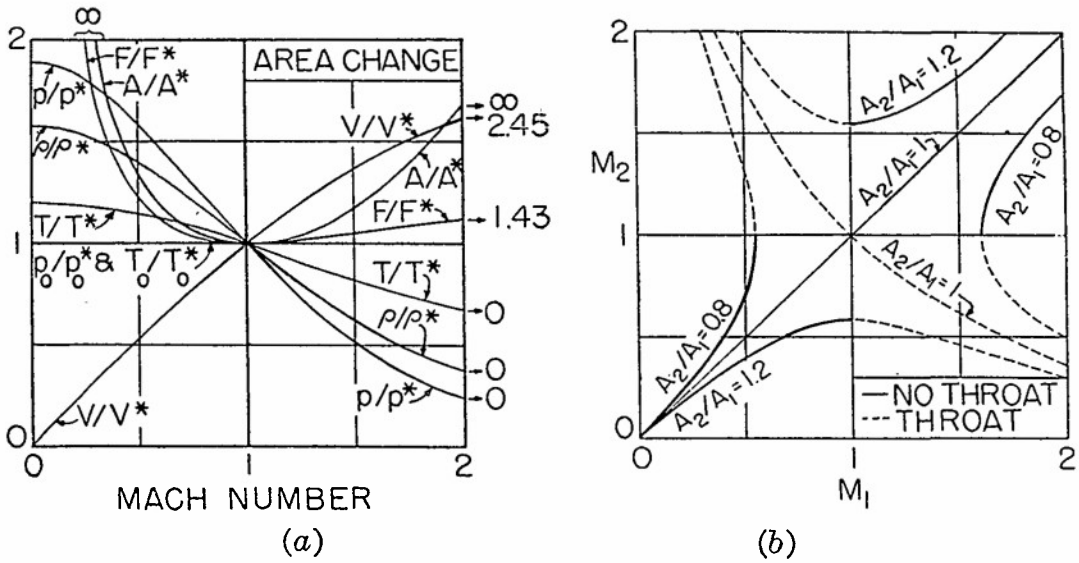


Fig. 4.3 SIMPLE AREA CHANGE, k = 1.4
(a, generalized chart; numbers at upper and right-hand edges indicate values where M = 0 and M = ∞, respectively. Chart b shows M_2 versus M_1 for constant values of A_2/A_1.)

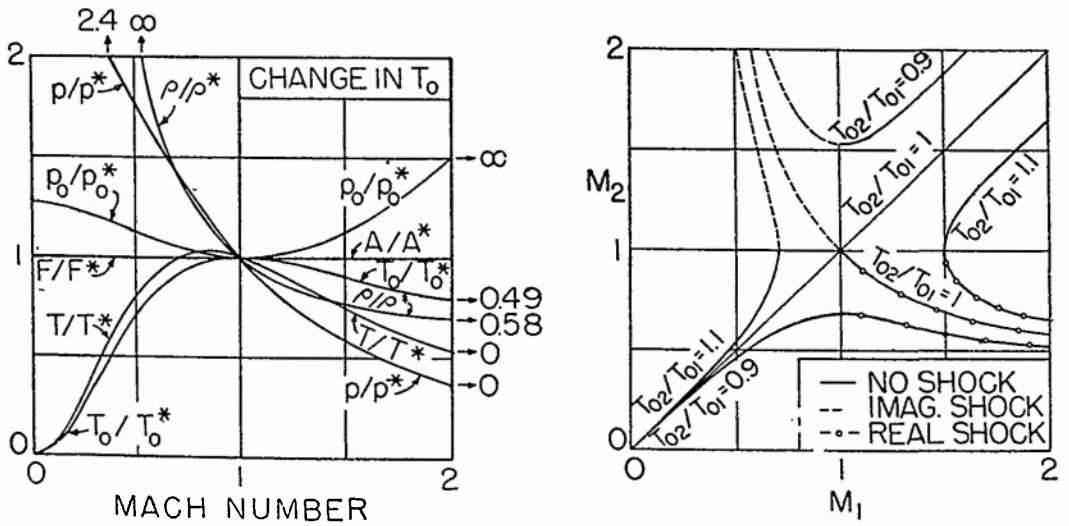


Fig. 4.4 SIMPLE T_0-CHANGE, k = 1.4
(a, generalized chart; numbers at upper and right-hand edges indicate values where M = 0 and M = ∞, respectively. Chart b shows M_2 versus M_1 for constant values of T_{02}/T_{01}.)

For the case where T_o is increased by combustion, it has been further suggested, Ref. 4.6, that the flame would go out if the amount of fuel burned produces more than the limiting increase in T_o. Both these conclusions, while appearing to fit Figure 4.4(a), are physically implausible, because the mechanisms of heat transfer and of combustion are in nowise connected with the phenomena under discussion here. An alternative explanation is that the flow is choked when T_o is increased above its limiting value, i.e., the flow rate is reduced and, consequently, the initial value of M is diminished until the specified increase in T_o yields at the exit a stream which is exactly sonic.† This description of the state of affairs is not only more plausible physically, but it is in accord with experience. The significance of this, together with an example of the use of Figure 4.4(a), is best given as follows:

Let us suppose that a ram-jet combustion chamber of uniform cross-sectional area is at first operating cold with an air velocity of about 500 fps, corresponding to $M \sim 0.5$, and with T_o= 500 R. Suppose also that it is desired to burn enough fuel to raise the stagnation temperature to 2000 R, corresponding to a four-fold increase in T_o. From Figure 4.4(a), however, we see that, with an initial M of 0.5, the value of T_o (or of T_o/T_o^*) may be increased by only about 45 per cent. Thus when combustion begins, the flow is choked until the leaving M is unity. We therefore set $M_2 = 1$, and write

$$(T_o/T_o^*)_2/(T_o/T_o^*)_1 = T_{o2}/T_{o1} = 4$$

Since $(T_o/T_o^*)_2 = 1$, it follows that $(T_o/T_o^*)_1 = 0.25$, and, from Figure 4.4(a), $M_1 = 0.246$, so that the maximum air speed at inlet is about 250 fps. Also, from Figure 4.4(a), $(p_o/p_o^*)_1 = 1.219$ and $p_{o2}/p_{o1} = (p_o/p_o^*)_2/(p_o/p_o^*)_1 = 1/1.219 = 0.82$. Similarly, $p_2/p_1 = 0.45$; $V_2/V_1 = \rho_1/\rho_2 = 7.5$; and $T_2/T_1 = 3.4$.

These results are of practical interest, as the stagnation temperatures just given are in the range of interest for aircraft propulsion and for gas turbines. We see that the entering air velocity is limited to about 250 fps, so that this represents an additional restriction on the capacity of high-output combustors.

†It is assumed that the back pressure (the pressure in the exhaust space into which the duct discharges) is kept so low that it has no effect on flow rate, i.e., a decrease, or a limited increase, of back pressure does not make its effect felt on the flow in the duct.

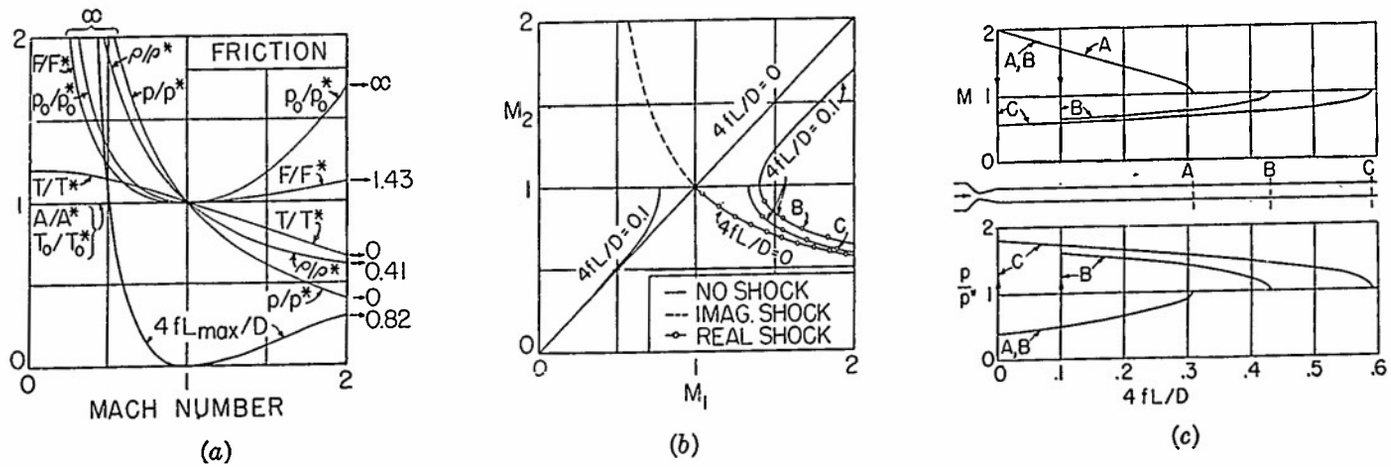


Fig. 4.5 SIMPLE FRICTION, k = 1.4

(a - Generalized chart; numbers at upper and right-hand edges indicate values where M = 0 and M = ∞ , respectively. Chart b shows M_2 versus M_1 for constant values of 4fL/D. Curve B is applicable when normal shock occurs at the end of the duct length, while curve C is for normal shock at the beginning of the duct length. Chart c shows effect of duct length on flow in tube, for initial M of 2. When duct length is less than for curves A, the latter are applicable up to the end of the tube.)

Also, with this speed, a loss in stagnation pressure of at least 18 per cent is inevitable if the combustor is of constant cross-sectional area.

From Figure 4.4(a) we see that for each value of T_o/T_o^* there are two values of M_2. These correspond to the Mach numbers fore and aft of a normal shock, since the conditions for the shock include only constancy of area, of stagnation temperature, and of impulse.

If $M_1 > 1$, both values of M_2 corresponding to a given value of T_{o2}/T_{o1} are real; one value of M_2 is reached without a shock and one is reached by a combination of a normal shock and either heat exchange or chemical reaction. If $M_1 < 1$ only one of the two values of M_2 found in Figure 4.4(a) for a prescribed T_{o2}/T_{o1} is real; the value of M_2 which is greater than unity then corresponds to a negative shock, and involves a violation of the second law of thermodynamics.

These ideas are illustrated in Figure 4.4(b) where there are plotted illustrative curves (derived entirely from Figure 4.4(a) of M_2 versus M_1 for fixed values of T_{o2}/T_{o1}. The several portions of each curve are labeled as to whether they represent flow without shocks, flow with real shocks, or flow with imaginary (negative) shocks. One of the curves for $T_{o2}/T_{o1} = 1$ is for the trivial case where the stream undergoes no change, and the other gives the solution of the normal-shock equations.

h. Simple friction

Figure 4.5(a) is interpreted in the same way as Figure 4.3(a), except for the curve of $4fL_{max}/D$. On this curve L_{max} is the length of duct between the point where $M = M$ and the point where $M = 1$ (it has been previously shown that the sonic velocity represents the limiting condition). The final M_2 corresponding to a given M_1 and given L/D is found with the help of the relation

$$\frac{4f}{D} L = (4fL_{max}/D)_2 - (4fL_{max}/D)_1$$

In using Figure 4.5(a) it must be remembered that when $M < 1$, the value of M can only increase; while for $M > 1$, the value of M can only decrease.

For each initial Mach number, there is a maximum length-diameter ratio of duct which may be used. This is often a serious restriction as indicated by the following table, based on $f = 0.0025$:

M	0	0.25	0.5	0.75	1	1.5	2	3	∞
L_{max}/D	∞	850	110	12	0	14	31	52	82

At high Mach number the wall friction is very costly with respect to stagnation-pressure loss. For example, with $M_1 = 3.0$ and $f = 0.0025$, the Mach number is reduced to 2.0 in 21 diameters of duct, and at the same time the stagnation pressure is reduced by 60 per cent.

Choking may be caused by simple friction, just as it may by simple area change or simple T_0-change. If, with a given subsonic M_1 and a given inlet pressure, the duct is so long that $M_2 = 1$, any further increase in duct length will cause a reduction in mass flow. The amount of adjustment in flow rate will be such that the value of $4fL_{max}/D$ corresponding to the new M_1 will correspond exactly to the adjusted length of duct, or, in other words, the leaving velocity will be exactly sonic.

When the initial M_1 is greater than unity, an increase in the duct length over and above the value corresponding to $(4fL_{max}/D)_1$ will not at first produce choking. Instead, a normal shock will appear in the tube, so that part of the flow will be subsonic, but with the flow upstream of the shock unaltered. In Figure 4.5(a) the end conditions for the normal shock are found by taking the two intersections of a horizontal line with the

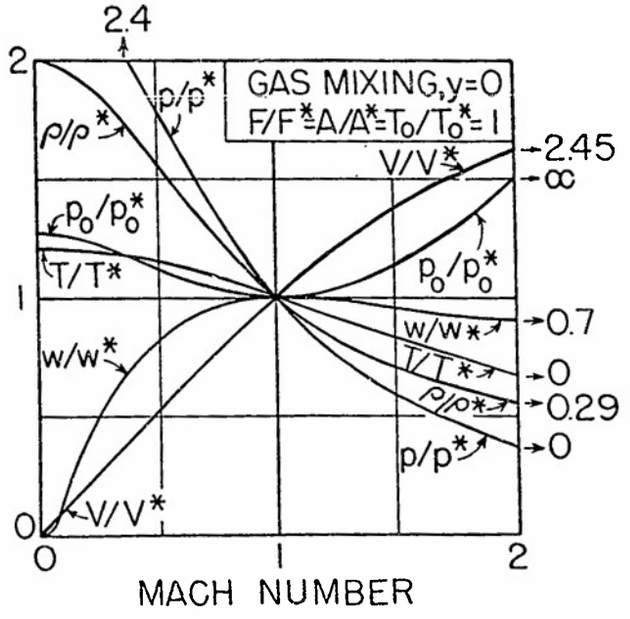


Fig. 4.6 SIMPLE GAS MIXING; $k = 1.4$, $y = 0$

Numbers at top and right-hand edges indicate values for $M = 0$ and $M = \infty$, respectively.

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F/F^*-curve.[+] For a constant value of the friction coefficient f, it may be shown from Figure 4.5(a) or analytically, that when a normal shock occurs the value of L_{max}/D is increased. Thus with an initially supersonic flow, an increase in duct length ultimately leads to a normal shock whose position is such that M = 1 at the end of the duct. The shock moves upstream as the duct length is increased. With sufficiently great length, the shock moves into the nozzle which produces the supersonic stream. Ultimately the shock moves past the throat of the nozzle, the entire flow becomes subsonic, and subsequent increases in length act to choke the flow.[++] Figure 4.5(c), which is derived from Figure 4.5(a), illustrates the above ideas.

In Figure 4.5(b) are illustrative curves of M_2 versus M_1 for fixed values of 4fL/D. When a shock occurs somewhere in a given length, the end state depends upon the location of the shock. For the example shown, the results are given for the two extreme locations of the shock.

i. Simple gas injection

The solution for the case of simple gas injection depends upon the forward velocity with which the gas is injected, i.e., upon the value of y. When y = 1, the curves in Figure 4.3(a), properly interpreted, may be used for gas injection or withdrawal. When y = 0, Figure 4.6 shows the types of flow variations to be expected for gas injection. For reasons given previously, Figure 4.6 cannot be used for gas withdrawal.

j. Combined friction and area change

As a simple instance where combined effects occur, let us examine the problem of designing a long insulated duct for constant Mach number along its length. Changes in specific heat will be ignored.

From the first line of influence coefficients in Table 4.2, setting dM, dT_o, dX and dw equal to zero, we get

$$\frac{dA}{A} = \frac{kM^2}{2} 4f \frac{dx}{D} \qquad (4.29a)$$

[+] The normal-shock requirements, namely, that the values of A, T_o, and F be constant, are thus satisfied.

[++] It is assumed for the foregoing argument that the back pressure on the duct is so low as to have no effect on the flow in the duct.

now

$$dA/A = 2dD/D \tag{4.29b}$$

so that

$$\tan \sigma = \frac{dD/2}{dx} = \frac{kM^2}{2} f \tag{4.29c}$$

where σ is the half-angle of divergence. For a constant friction coefficient, σ is constant, and the duct is conical. As a concrete example, let us take $f = 0.0025$, $k = 1.4$, and $M = 2$; then $\sigma = 0.4$ deg. Note that the duct must diverge for both subsonic and supersonic flow.

From the second line of influence coefficients in Table 4.2 we get, using Equation (4.29a)

$$(1 - M^2) \frac{dV}{V} = - \frac{dA}{A} + \frac{kM^2}{2} 4f \frac{dx}{D} = 0$$

Thus the velocity is constant. Similarly, the temperature and impulse are found to be constant.

For the pressure change, we find from Table 4.2 and Equation (4.29a) that

$$\frac{dp}{p} = - \frac{dA}{A}; \text{ so that } p_1 A_1 = p_2 A_2$$

In like manner, we obtain

$$\frac{dp_o}{p_o} = - \frac{kM^2}{2} 4f \frac{dx}{D} = - \frac{kM^2 f}{\tan \sigma} \frac{dD}{D} = - 2 \frac{dD}{D}$$

or

$$\frac{p_{o2}}{p_{o1}} = \frac{A_1}{A_2}$$

and, since the area must always increase, the stagnation pressure is always diminished.

The foregoing results for V, T, F, p, and p_o might just as well have been found from Equations (4.22) to (4.26).

k. Combined friction and heat transfer

The mechanism of friction is so closely associated with that of heat transfer that the latter cannot be considered without at the same time considering the former. In this example we shall confine our attention to flow in a constant-area duct having walls at a constant temperature T_w, and will neglect changes in specific heat.

Equation (4.20) may be written in the form

$$wdQ = \frac{\pi}{4} D^2 \rho V c_p dT_o = U \pi D (T_w - T_{wa}) dx \qquad (4.30a)$$

In this expression the temperature difference for heat transfer is taken to be the difference between the actual wall temperature T_w, and the temperature T_{wa}, which the wall would assume for the same flow conditions but with zero heat flux. This definition seems to give consistent results as regards (a) independence of heat-transfer coefficient with respect to temperature differential, and (b) obtaining the same heat-transfer coefficients for incompressible flow and for compressible flow up to Mach number unity (Ref. 4.9). The relation between the various temperatures is shown schematically in Figure 4.7(a).

It appears that for subsonic flow the Reynolds analogy (Ref. 4.10) gives a fair correlation between heat-transfer coefficient (using the temperature differential just defined) and wall-friction coefficient (Refs. 4.9 and 4.11). The Reynolds analogy may be written

$$U/c_p \rho V = f/2 \qquad (4.30b)$$

Combination of Equations (4.30a) and (4.30b) yields

$$\frac{dT_o}{T_o} = \left(\frac{T_w}{T_o} - \frac{T_{wa}}{T_o} \right) 2f \frac{dx}{D} \qquad (4.30c)$$

Next, we introduce the definition of the recovery factor (see Figure 4.7a)

$$r = \frac{T_{wa} - T}{T_o - T} = \frac{T_{wa} - T}{V^2/2c_p} \qquad (4.30d)$$

which gives, after combination with Equations (4.3) and (4.14)

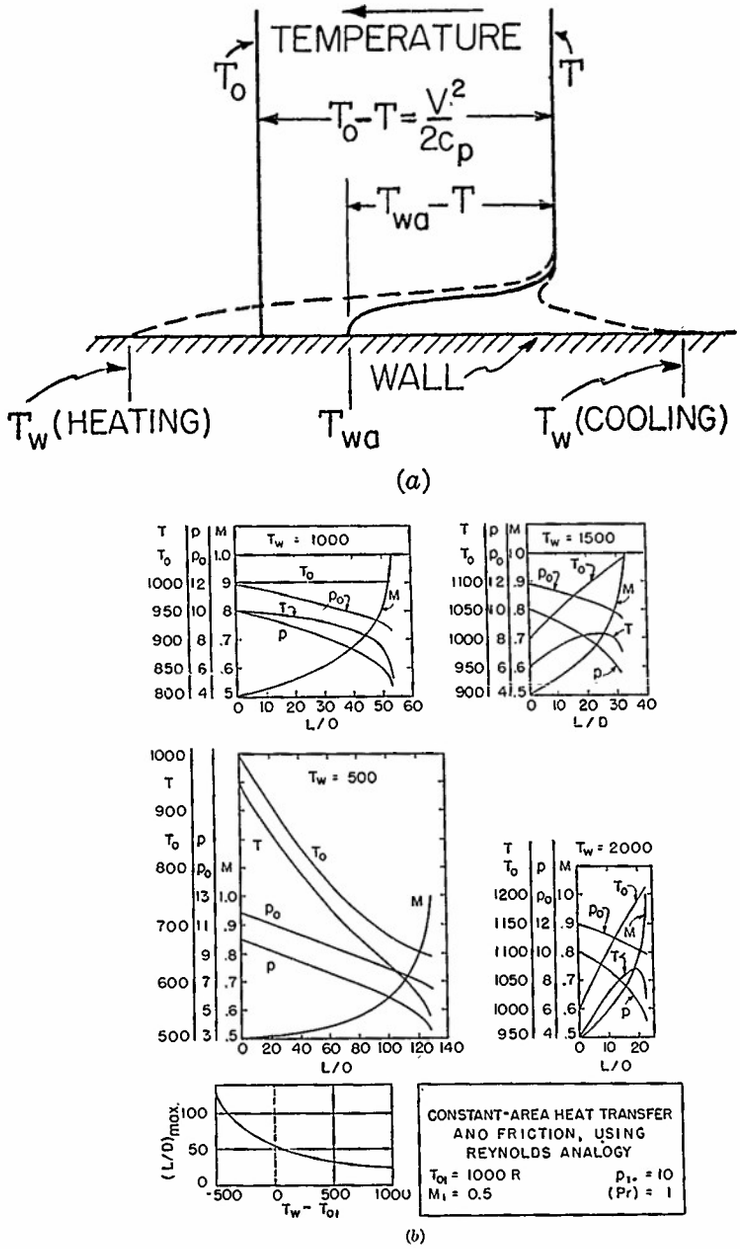


Fig. 4.7 COMBINED FRICTION AND HEAT TRANSFER AT CONSTANT AREA USING REYNOLDS ANALOGY; k = 1.4

(a, Schematic relation between temperatures; recovery factor = $(T_{wa} - T)/(T_o - T)$; b, Curves of stream properties versus L/D; T_{o1} = 1000, p_1 = 10 M_1 = 0.5, f = 0.005, recovery factor = 1.)

$$\frac{T_{wa}}{T_o} = 1 - \frac{(1 - r)\,\frac{k-1}{2}\,M^2}{1 + \frac{k-1}{2}\,M^2} \qquad (4.30e)$$

Substituting Equation (4.30e) into (4.30c), we obtain

$$\frac{dT_o}{T_o} = \left[\frac{T_w}{T_o} - 1 + \frac{(1 - r)\,\frac{k-1}{2}\,M^2}{1 + \frac{k-1}{2}\,M^2}\right] 2f\,\frac{dx}{D} \qquad (4.30f)$$

Equation (4.19) combined with Equation (4.30f) then yields

$$dM^2 = \frac{M^2\left(1 + \frac{k-1}{2}\,M^2\right)}{1 - M^2}\,2f\,\frac{dx}{D}\,X$$
$$\left\{1 + kM^2\left[\frac{T_w}{T_o} - 1 + \frac{(1 - r)\,\frac{k-1}{2}\,M^2}{1 + \frac{k-1}{2}\,M^2}\right] + 2kM^2\right\} \qquad (4.30g)$$

Using numerical integration, these equations may be employed for constructing flow patterns. The integration is carried out in stepwise fashion, using the following approximations:

(1) $$\int\frac{dT_o}{T_o} = \frac{T_{o2} - T_{o1}}{(T_{o2} + T_{o1})/2}$$

(2) The coefficients of fdx/D in Equations (4.30f) and (4.30g) are taken at $M_{12} = (M_1 + M_2)/2$.

To illustrate, let us assume that at a section 1 of the duct we have the known values M_1, p_1, T_{o1}, T_1, etc., and that f, T_w, D, and r are known at each section of the duct. For a section 2 at a distance $x_2 - x_1$ downstream from section 1, we carry out the following computations: (a) estimate M_2; (b) find $M_{12} = (M_1 + M_2)/2$; (c) calculate $2(T_{o2} - T_{o1})/(T_{o2} + T_{o1})$ from Equation (4.30f); (d) find M_2 from Equation (4.30g) and compare with the assumed

value of M_2; (e) repeat the previous steps with an improved value of M_2 found from step (d). After convergence is obtained, the process is repeated to find the Mach number at a section 3. Satisfactory convergence is usually obtained with one or two tries. Having the values of M and T_o at each section, Equations (4.22) to (4.26) are used for computing other properties.

The results of such computations[+] for four different values of T_w, and for $T_{o1} = 1000$, $M_1 = 0.5$, $p_1 = 10$, $f = 0.005$, and $r = 1$, are shown in Figure 4.7(b). For the case where $T_w = 1000$, the flow is adiabatic, and the results may be compared with Figure 4.5(a). The agreement between the approximate numerical and the exact analytical solutions is quite good even when as few as five intervals between $M = 0.5$ and $M = 1.0$ are used for the numerical method.

1. Pumping of gas through cooling

The fundamental problem in the pumping of a gas, as for instance in driving a windtunnel, is to raise the stagnation pressure, p_o. It appears from Table 4.2 that this might be accomplished through cooling (reduction in T_o) without using mechanical equipment.[++] Two simple methods of cooling present themselves: (1) heat exchangers, and (2) injection and evaporation of a volatile liquid.

(1) Cooling with heat exchangers

As pointed out in the preceding section, heat exchange is always associated with friction. Experimental data indicate that the most favorable ratio of heat-transfer rate to pumping power is obtained when form drag is absent, i.e., when all the drag is due to skin friction. Therefore the Reynolds analogy may be used, and the equations of the preceding section are consequently applicable. In addition, we obtain from Table 4.2

$$\frac{dp_o}{p_o} = -\frac{kM^2}{2}\left(\frac{dT_o}{T_o} + 4f\frac{dx}{D}\right) \qquad (4.31a)$$

[+]Carried out by students in the Mechanical Engineering Department at Massachusetts Institute of Technology, and organized by W. A. Loeb.

[++]A pumping device which operates on this principle needs auxiliary starting apparatus, e.g., a rocket used as an ejector.

Introducing Equation (4.30f), and rearranging, we get

$$\frac{dp_o}{p_o} = - kM^2 f \frac{dx}{D} \left[\frac{T_w}{T_o} + 1 + \frac{(1 - r) \frac{k - 1}{2} M^2}{1 + \frac{k - 1}{2} M^2} \right] \qquad (4.31b)$$

Thus the condition that a stagnation-pressure increase be obtained is that

$$\frac{T_w}{T_o} < - 1 - \frac{(1 - r)(k - 1) M^2}{2 + (k - 1) M^2} \qquad (4.31c)$$

For gases, the recovery factor is between 0 and 1. In this range the stagnation pressure may increase only if the absolute wall temperature is negative, as shown in Figure 4.8. Thus because of the losses due to friction, it is impossible to raise the stagnation pressure by means of heat exchangers.

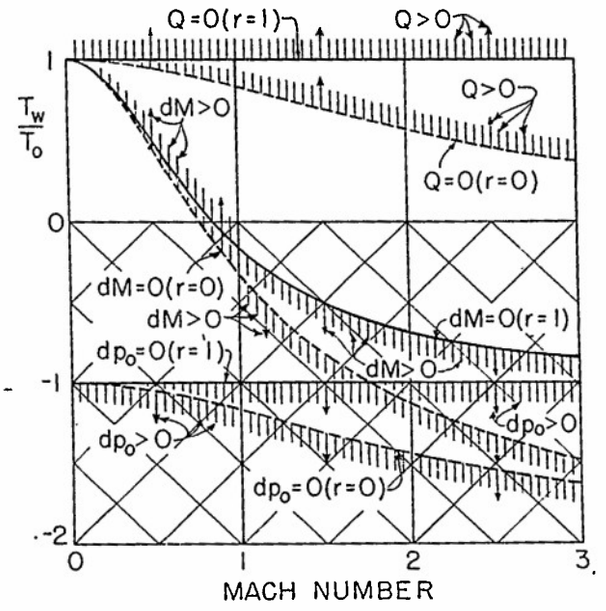


Fig. 4.8 COMBINED FRICTION AND HEAT TRANSFER; k = 1.4
(T_w/T_o versus M, showing curves of $dp_o = 0$, $dM = 0$, and $Q = 0$, for recovery factors of zero and unity. The positive side of each line is shown by the vertical shading. The cross-hatched region represents impossible wall temperatures.)

As a matter of interest, Figure 4.8 shows also the ranges in which M increases and decreases, respectively, as found by analysis of Equation (4.30g); and the ranges in which the heat transfer is positive and negative, respectively, as determined by the sign of $(T_w - T_{wa})$. Note that above $M \sim 0.7$ the Mach number always approaches unity, no matter how great the attempts to cool the stream (compare with Figure 4.2 and 4.4a).

(2) Cooling by means of evaporation

Let us suppose that liquid evaporates into the main stream at the rate dw. To simplify the computation, changes in specific heat and molecular weight will be ignored. Also, since it is probably impracticable to inject the liquid with a speed comparable to that of a high-speed gas stream, we will set y = 0.

From Table 4.2 we get

$$\frac{dp_o}{p_o} = -\frac{kM^2}{2}\left(\frac{dT_o}{T_o} + 2\frac{dw}{w}\right) \tag{4.32a}$$

The energy relation, Equation (4.16), may, if we assume the specific heat of the evaporated liquid to be constant, be written approximately in the form

$$dQ + dH = -(h_v - h_L)\frac{dw}{w} = c_p dT_o \tag{4.32b}$$

where h_v and h_L, respectively, are the enthalpies of the vapor (at T) and the injected liquid (at T_L).

Introducing Equation (4.32b) into (4.32a), and rearranging, we obtain

$$\frac{dp_o}{p_o} = -\frac{kM^2}{2}\left(1 - \frac{2c_pT_o}{h_v - h_L}\right)\frac{dT_o}{T_o} \tag{4.32c}$$

Thus in order to obtain a rise in stagnation pressure, it is necessary that

$$\frac{h_v - h_L}{c_pT_o} > 2 \tag{4.32d}$$

Now $(h_v - h_L)$ is of the order of magnitude of the latent heat, h_{fg}. The most desirable type of fluid for this purpose is therefore one with a large latent heat. Water immediately comes to mind, because aside from its many practical advantages, it is almost unsurpassed with respect to latent heat. To obtain an idea of order of magnitude, we take a latent heat of 1000 Btu per lb for water, $c_p \cong 0.25$ Btu/(lb F) for air, $c_p \cong 0.5$ Btu/(lb F) for water vapor, and $T_L \cong 500$ R. We then get the following approximate values of $(h_v - h_L)/c_pT_o$:

T_o(deg R)	Injection of water into air	Injection of water into stream
500	8	4
1000	5	2.5
2000	3.5	1.75
3000	3.0	1.50
4000	2.75	1.37

Comparing these figures with the criterion of Equation (4.32d), it is evident that evaporation of water in air holds considerable promise as a pumping scheme.

This scheme is now being investigated for the operation of large supersonic wind tunnels because of the prodigious requirements of such tunnels in the way of rotating machinery and power. The actual amount of stagnation-pressure rise obtainable depends upon the initial magnitudes of T_o, T, p, and M, on the relation between the saturation pressure and saturation temperature of the water vapor (which determines how much vapor may be absorbed by the air), and on the way in which the process is controlled, i.e., whether at constant Mach number, constant temperature, constant cross-sectional area, etc. Using Table 4.2 and Equation (4.32), analytical relations between M, T, p, T_o, p_o, etc., may be derived for these various cases.

As an example, the case of evaporation at constant area will be considered. The following equations are approximate in that $h_v - h_L$ is assumed constant during the process

$$\frac{T_{o2}}{T_{o1}} \exp\left\{\frac{2c_pT_{o1}}{h_v - h_L}\left(1 - \frac{T_{o2}}{T_{o1}}\right)\right\} =$$

$$\left[\frac{M_2^2\left(1 + \frac{k-1}{2}M_2^2\right)}{(1 + kM_2^2)^2}\right]\left[\frac{(1 + kM_1^2)}{M_1^2\left(1 + \frac{k-1}{2}M_1^2\right)}\right] = \left[\frac{(T_o/T_o^*)\,M_2}{(T_o/T_o^*)\,M_1}\right]_{\substack{\text{simple}\\ T_o\text{-change}}} \qquad (4.33a)$$

$$\frac{p_{o2}}{p_{o1}} = \frac{1 + kM_1^2}{1 + kM_2^2}\left(\frac{1 + \frac{k-1}{2}M_2^2}{1 + \frac{k-1}{2}M_1^2}\right)^{\frac{k}{k-1}}$$

$$= \left[\frac{(p/p^*)M_2}{(p/p^*)M_1}\right]_{\substack{\text{simple}\\ T_o\text{-change}}} \times \left[\frac{(p/p^*)M_1}{(p/p^*)M_2}\right]_{\substack{\text{simple}\\ \text{area-change}}} \qquad (4.33b)$$

$$\frac{p_2}{p_1} = \frac{1 + kM_1^2}{1 + kM_2^2} = \left[\frac{(p/p^*)M_2}{(p/p^*)M_1}\right]_{\substack{\text{simple}\\ T_o\text{-change}}} \qquad (4.33c)$$

$$\frac{T_2}{T_1} = \frac{T_{o2}}{T_{o1}}\frac{1 + \frac{k-1}{2}M_1^2}{1 + \frac{k-1}{2}M_2^2} = \frac{T_{o2}}{T_{o1}} \times \left[\frac{(T/T^*)M_2}{(T/T^*)M_1}\right]_{\substack{\text{simple}\\ \text{A-change}}} \qquad (4.33d)$$

$$\frac{w_2}{w_1} = 1 + \frac{\Delta w}{w_1} = \exp\left\{\frac{c_p T_{o1}}{h_v - h_L}\left(1 - \frac{T_{o2}}{T_{o1}}\right)\right\} \qquad (4.33e)$$

The expressions on the extreme right of Equations (4.33a) to (4.33d) refer to quantities which are plotted in Figs. 4.3(a) and 4.4(a), as may be verified by comparing Equations (4.33) with Table 4.3. For example, referring to Equation (4.33a) and to Table 4.3, we note that

$$\left(\frac{T_o}{T_o^*}\right)_{\substack{\text{simple}\\ T_o\text{-change}}} = \frac{2(k+1)M^2\left(1 + \frac{k-1}{2}M^2\right)}{(1 + kM^2)^2}$$

The computations are greatly simplified by taking advantage of the relations between Equations (4.33a) to (4.33d) and the charts in Figures 4.3 to 4.6.

If, at a section 1, the values of T_1, p_1, T_{o1}, p_{o1}, and M_1 are known, we proceed as follows: (a) Select a value of T_{o2}; (b) from Equation (4.33a) compute M_2; (c) calculate p_{o2}, p_2,

and T_2 from Equations (4.33b), (4.33c) and (4.33d); (d) find the amount of water evaporated Δw, from Equation (4.33e); (e) repeat this process for other values of T_{02}. From the amount of water vapor per unit mass of air, the partial pressure of the water vapor may be computed; when the latter approaches the saturation pressure, no further evaporation is possible.

Figure 4.9 shows a possible wind-tunnel arrangement and approximate results for the pressure rise obtainable with evaporation at constant area. With maximum temperatures of only 2000° F. the stagnation pressure may be increased about twofold. In practice, the effects of variations in molecular weight and specific heat make the pressure rise much smaller than indicated here.

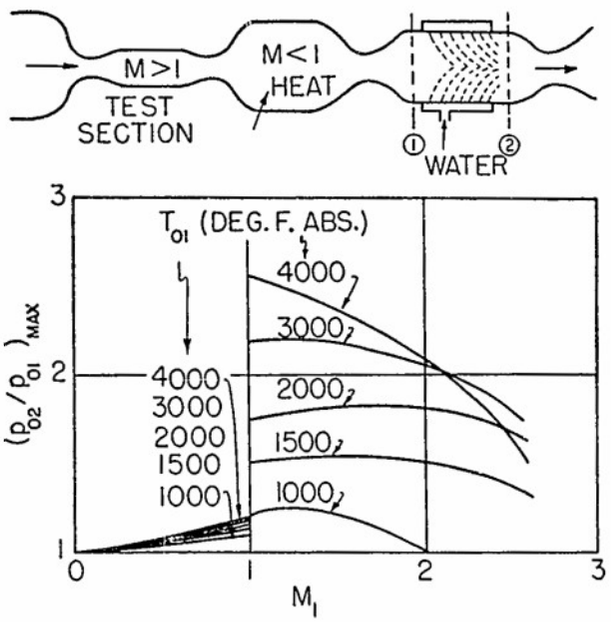


Fig. 4.9 PUMPING OF WIND TUNNEL BY WATER INJECTION AT CONSTANT AREA

(Atmospheric air passes in series through a supersonic nozzle, supersonic test section, diffuser, subsonic heating section, supersonic nozzle, constant-area supersonic section where water is evaporated, and back to the atmosphere through a diffuser. It is assumed that p_{01} = 14.7 psia, k = 1.4, and that there is negligible humidity at section 1. The curves, which are approximate, show the maximum value of p_{02}/p_{01}, corresponding to saturation at section 2, as a function of M_1 and T_{01}.)

6. Analysis of a Discontinuity

In many problems, because of the boundary conditions, discontinuities in the flow represent the only way in which solutions may be obtained.+ For the present purpose, we will define a discontinuity as a finite change which occurs without variation of cross-sectional area, and without external heat or work effects.

a. Analysis of a stationary discontinuity

Considering the steady flow through the control surface

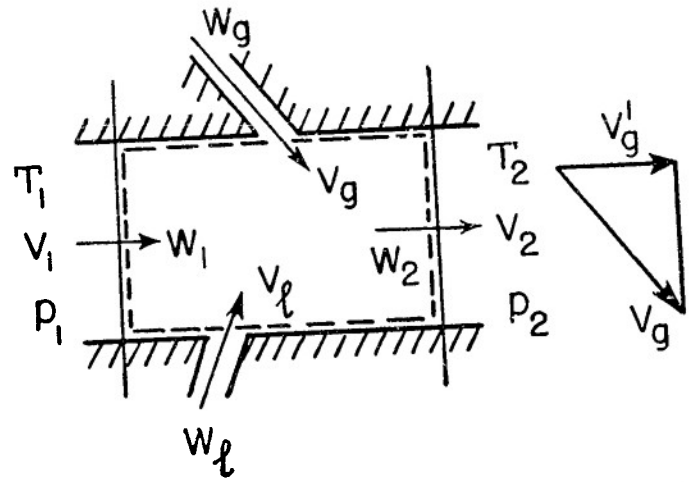


Fig. 4.10 CONTROL SURFACE FOR ANALYSIS OF DISCONTINUITY

in Figure 4.10, the following equations may be written

Semi-perfect gas:

$$\frac{p_2}{p_1} = \frac{\rho_2}{\rho_1}\frac{W_1}{W_2}\frac{T_2}{T_1} \tag{4.34}$$

Continuity:

$$\frac{W_2}{W_1} = 1 + \frac{W_g}{W_1} + \frac{W_L}{W_1} = \frac{\rho_2}{\rho_1}\frac{V_2}{V_1} \tag{4.35}$$

+Consideration is not given here to the possibility of other than one-dimensional changes, or to longitudinal viscosity and heat-conduction effects.

Sound velocity:

$$\frac{c_2}{c_1} = \sqrt{\frac{k_2}{k_1}\frac{W_1}{W_2}\frac{T_2}{T_1}} \tag{4.36}$$

Mach number:

$$\frac{M_2^2}{M_1^2} = \frac{V_2^2}{V_1^2}\frac{W_2}{W_1}\frac{T_1}{T_2}\frac{k_1}{k_2} \tag{4.37}$$

Momentum:

$$(p_1 - p_2)A = w_2V_2 - w_1V_1 - (w_2 - w_1)y\,V_1 + c_DA\rho_1V_1^2/2$$

where c_D is the drag coefficient of the wall or of internal bodies between sections 1 and 2, based on the cross-sectional area of the duct and on the dynamic head at section 1; and

$$y = \frac{w_gy_g + w_Ly_L}{w_g + w_L}$$

where $y_g = V_g'/V_1$, etc. (see Figure 4.10).

Remembering that $w = \rho VA$ and that $\rho V^2 = kpM^2$, the momentum equation is reformed as follows:

$$\frac{p_2}{p_1} = \frac{1 + \left[1 + \left(\frac{w_2}{w_1} - 1\right)y - \frac{c_D}{2}\right]k_1M_1^2}{1 + k_2M_2^2} \tag{4.38}$$

Energy: In applying the steady-flow energy relation, we equate the increase of enthalpy flux to the decrease of kinetic-energy flux, thus

$$w_2h_2 - w_1h_1 - w_Lh_L - w_gh_g = w_1\frac{V_1^2}{2} + w_L\frac{V_L^2}{2} + w_g\frac{V_g^2}{2} - w_2\frac{V_2^2}{2} \tag{4.39}$$

If tables of properties relating the enthalpy to the temperature, pressure, and chemical composition were available, Equations (4.34) to (4.39) would furnish all the information necessary to the solution of problems. However, a tedious trial-and-error computation is then required. It seems advantageous to

seek a simplification, at the cost, if necessary, of some slight decrease in accuracy. Such a simplification is achieved by assuming that the specific heat c_p, is independent of temperature, and depends only upon chemical composition. The errors caused by neglecting the variation of c_p with temperature may then be partially eliminated by choosing specific heats for each species at a mean temperature for the process. Using this simplification, the enthalpy change in Equation (4.39) is evaluated by imagining that the injected gas and liquid are first brought to T_1, that the change in chemical composition and in phase occur at T_1, and that the mixture with properties of section 2 is raised in temperature from T_1 to T_2. We then obtain

$$w_g c_{pg}(T_1 - T_g) + w_L c_{pL}(T_1 - T_L) - w_1(\Delta h_{pr})_{T1} + w_L(h_{fg})_{T1} + w_2 c_{p2}(T_2 - T_1) + w_2 \frac{V_2^2}{2} - w_1 \frac{V_1^2}{2} - w_g c_{pg} \frac{V_g^2}{2} - w_L c_{pL} \frac{V_L^2}{2} = 0$$

This may be reduced to the form

$$\frac{w_2}{w_1}\frac{c_{p2}}{c_{p1}} T_{o2} - T_{o1} = \left(\frac{w_2}{w_1}\frac{c_{p2}}{c_{p1}} - 1\right) T_1 + \frac{(\Delta h_{pr})_{T1}}{c_{p1}} - \frac{w_L}{w_1}\frac{(h_{fg})_{T1}}{c_{p1}} + \frac{w_g}{w_1}\frac{c_{pg}}{c_{p1}}(T_{og} - T_1) + \frac{w_L}{w_1}\frac{c_{pL}}{c_{p1}}(T_{oL} - T_1) = 0 \qquad (4.40)$$

where

$$T_o = T + V^2/2c_p = T\left(1 + \frac{k-1}{2} M^2\right)$$

$$T_{og} = T_g + \frac{V_g^2}{2c_{pg}}$$

$$T_{oL} = T_L + \frac{V_L^2}{2c_{pL}}$$

$(h_{fg})_{T1}$ = latent heat for liquid-vapor change at T_1

$(\Delta h_{pr})_{T1}$ = change in enthalpy in going from products to reactants at the temperature T_1, per unit mass of mixture at section 1 (positive for exothermic reaction).

The temperature T_o is the stagnation temperature of the gas stream, and is the temperature reached through an adiabatic deceleration to zero speed without change in chemical composition or specific heat. Energy effects are then measured in terms of the stagnation temperature T_o, and are evaluated with the help of Equation (4.40). The stagnation temperature is related to the stream temperatures and Mach numbers as follows:

$$\frac{T_{o2}}{T_{o1}} = \frac{T_2}{T_1} \frac{\left(1 + \frac{k_2 - 1}{2} M_2^2\right)}{\left(1 + \frac{k_1 - 1}{2} M_1^2\right)} \tag{4.41}$$

Stagnation pressure

$$\frac{p_{o2}}{p_{o1}} = \frac{p_2}{p_1} \frac{\left(1 + \frac{k_2 - 1}{2} M_2^2\right)^{\frac{k_2}{k_2-1}}}{\left(1 + \frac{k_1 - 1}{2} M_1^2\right)^{\frac{k_1}{k_1-1}}} \tag{4.42}$$

Impulse

$$\frac{F_2}{F_1} = \frac{p_2}{p_1} \frac{(1 + k_2 M_2^2)}{(1 + k_1 M_1^2)} \tag{4.43}$$

After combination and rearrangement of Equations (4.34), (4.35), (4.36), (4.37), (4.38), (4.41), (4.42), (4.43), the following working equations are obtained

$$\frac{T_{o2}}{T_{o1}} = \frac{k_2 M_2^2}{k_1 M_1^2} \left(\frac{1 + \left[1 + \left(\frac{w_2}{w_1} - 1\right) y - \frac{c_D}{2}\right] k_1 M_1^2}{1 + k_2 M_2^2} \right)^2 \times \frac{1 + \frac{k_2 - 1}{2} M_2^2}{1 + \frac{k_1 - 1}{2} M_1^2} \frac{W_2}{W_1} \left(\frac{w_1}{w_2}\right)^2 \tag{4.44a}$$

or

$$\frac{T_{o2}}{T_{o1}} = \frac{(T_o/T_o^*)_{M_2,k_2}}{(T_o/T_o^*)_{M_1,k_1}} \frac{W_2}{W_1} \left(\frac{w_1}{w_2}\right)^2 \frac{k_2}{k_1} \frac{k_1 + 1}{k_2 + 1} B^2 \qquad (4.44b)$$

where

$$B = \frac{1 + \left[1 + \left(\frac{w_2}{w_1} = 1\right) y - \frac{c_D}{2}\right] k_1 M_1^2}{1 + k_1 M_1^2} \qquad (4.44c)$$

and

$$(T_o/T_o^*)_{M_2,k_2} = \frac{2(k_2 + 1)\, M_2^2 \left(1 + \frac{k_2 - 1}{2} M_2^2\right)}{(1 + k_2 M_2^2)^2}, \text{ etc.}$$

By comparison with Table 4.3 it is evident that $(T_o/T_o^*)_{M_2,k_2}$ may be found from a curve similar to the T_o/T_o^* curve in Figure 4.4(a), but having the appropriate value of k.

Similarly, we get

$$\frac{p_2}{p_1} = \frac{(p/p^*)_{M_2,k_2}}{(p/p^*)_{M_1,k_1}} \frac{k_1 + 1}{k_2 + 1} B \qquad (4.45)$$

$$\frac{T_2}{T_1} = \frac{(T/T^*)_{M_2,k_2}}{(T/T^*)_{M_1,k_1}} \frac{k_2}{k_1} \left(\frac{k_1 + 1}{k_2 + 1}\right)^2 \frac{W_2}{W_1} \left(\frac{w_1}{w_2}\right)^2 B^2 \qquad (4.46)$$

$$\frac{\rho_2}{\rho_1} = \frac{(\rho/\rho^*)_{M_2,k_2}}{(\rho/\rho^*)_{M_1,k_1}} \frac{k_1}{k_2} \frac{k_2 + 1}{k_1 + 1} \left(\frac{w_2}{w_1}\right)^2 \frac{1}{B} \qquad (4.47)$$

$$\frac{V_2}{V_1} = \frac{(V/V^*)_{M_2,k_2}}{(V/V^*)_{M_1,k_1}} \frac{k_2}{k_1} \frac{k_1 + 1}{k_2 + 1} \frac{w_1}{w_2} B \qquad (4.48)$$

$$\frac{c_2}{c_1} = \frac{(c/c^*)_{M_2,k_2}}{(c/c^*)_{M_1,k_1}} \frac{k_2}{k_1} \frac{k_1 + 1}{k_2 + 1} \frac{w_1}{w_2} B \qquad (4.49)$$

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$$\frac{F_2}{F_1} = B$$

$$\frac{p_{o2}}{p_{o1}} = \frac{(p_o/p_o^*)_{M_2,k_2}}{(p_o/p_o^*)_{M_1,k_1}} \frac{(k_2+1)^{\frac{1}{k_2-1}}}{(k_1+1)^{\frac{1}{k-1}}} B \qquad (4.51)$$

Each of the quantities, such as $(p/p^*)_{M_2,k_2}$, $(T/T^*)_{M_1,k_1}$ etc., refers to the formulas in Table 4.3 under the heading "Simple T_o-change". Thus if Figure 4.4(a) is extended so that there are families of curves for different k values, the numerical solutions to Equations (4.44) through (4.51) are much simplified.

Figure 4.11, which is similar to Figure 4.4(a), shows the curves for simple T_o-change with values of k of 1.4 and of 1. For small changes in k, such as occur in the combustion of hydrocarbons with air, Figure 4.11 indicates the change in k to be of secondary importance, except possibly at very high supersonic speeds. The effect on p/p^* at low Mach numbers should, however, be noted.

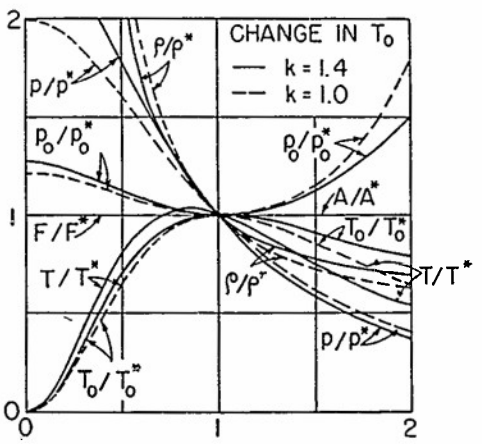


Fig. 4.11 CURVES FOR SIMPLE T_o-CHANGE

(Effect of k is shown. Curves for k = 1.4 are identical with those of Fig. 4.4a. Charts like this are for use with Equations (4.40) and (4.44) through (4.51), inclusive.)

b. Analysis of a discontinuity moving at constant speed

Problems in which a discontinuity, such as a flame front or pressure wave, is moving with uniform rate through a fluid initially at rest may be handled by using the methods of the preced-

ing section. The equations of that section are applicable if the observer moves with the discontinuity and if the quantities in Equations (4.44) to (4.51) refer to quantities relative to the moving observer. However, it is convenient to have expressions in terms of quantities relative to an observer at rest. This involves changes in only those quantities which contain a velocity term, e.g., Mach number, impulse, stagnation-temperature-pressure, and-enthalpy. Note that the static pressure, stream temperature, and sound velocity are the same for either observer. Also, the discontinuity moves with the velocity V_1 relative to the observer at rest. To clarify this, Figure 4.12(a) shows the steady flow through a flame-front discontinuity which is fixed relative to the observer; in Figures 4.12(b), (c), and (d), which will be explained more fully later, the observer is at rest, relative to the unburned gas, and the front moves to the left with a constant speed V_1 relative to the unburned gas.

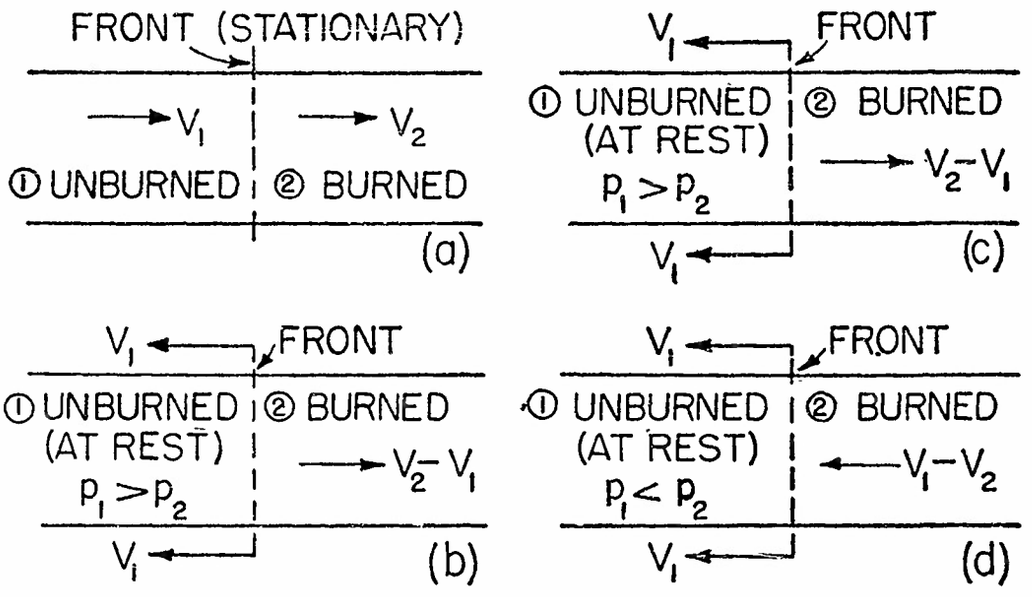


Fig. 4.12 EXPLOSION WAVES

(a, Observer at rest with respect to flame front. In b, c, and d, observer is at rest with respect to unburned gas, and flame front moves to left with velocity V_1. b, Slow burning; $V_1 < c_1$; $V_2 < c_2$; $V_2 > V_1$; burned gas flows away from the front, and pressure drops during burning. c, Deflagration; $V_1 < c_1$; $V_2 > c_2$; $V_2 > V_1$; burned gas flows away from front, and pressure drops during burning. d, Detonation; $V_1 > c_1$; $V_2 \leqq c_2$; $V_2 < V_1$; burned gas flows toward front, and pressure rises during burning.)

Using M', T_o', p_o', and F' to denote quantities relative to the observer at rest with respect to the gas toward which the discontinuity moves, the following relations indicate the changes which must be made before Equations (4.44) to (4.51) may be used

$$M_1 = V_1/c_1; \quad M_1' = 0 \tag{4.52}$$

$$M_2 = V_2/c_2; \quad M_2' = \frac{V_2 - V_1}{c^2} = M_2 - \frac{c_1}{c_2} M_1 \tag{4.53}$$

$$T_{o1} = T_1 \left(1 + \frac{k_1 - 1}{2} M_1^2\right); \quad T_{o1}' = T_1 \tag{4.54}$$

$$T_{o2} = T_2 \left(1 + \frac{k_2 - 1}{2} M_2^2\right); \quad T_{o2}' = T_2 + \frac{(V_2 - V_1)^2}{2c_{p2}}$$

$$= T_2 \left[1 + \frac{k_2 - 1}{2} (M_2')^2\right] \tag{4.55}$$

$$p_{o1} = p_1 \left(1 + \frac{k_1 - 1}{2} M_1^2\right)^{\frac{k_1}{k_1 - 1}}; \quad p_{o1}' = p_1 \tag{4.56}$$

$$p_{o2} = p_2 \left(1 + \frac{k_2 - 1}{2} M_2^2\right)^{\frac{k_2}{k_2 - 1}};$$

$$p_{o2}' = p_2 \left[1 + \frac{k_2 - 1}{2} (M_2')^2\right]^{\frac{k_2}{k_2 - 1}} \tag{4.57}$$

In Equation (4.53) the ratio c_1/c_2 is found from Equation (4.49) and Table 4.3. Note that the change in stagnation temperature is dependent upon the observer's motion, as indicated by the following expressions

$$\Delta T_o = T_{o2} - T_{o1} = T_2 - T_1 + \frac{V_2^2}{2c_{p2}} - \frac{V_1^2}{2c_{p1}}$$

$$\Delta T_o' = T_{o2}' - T_{o1}' = T_2 - T_1 + \frac{(V_2 - V_1)^2}{2c_{p2}}$$

When $c_{p2} = c_{p1}$, these yield

$$\Delta T_o' = \Delta T_o + \frac{V_1(V_1 - V_2)}{c_p}$$

The steady-flow energy relation, Equation (4.40), may be used only with T_{o2} and T_{o1}.

7. Applications and Examples of Discontinuous Flow

a. Stationary discontinuities

As examples of the problems to which the discontinuity analysis of the preceding section may be applied are the following:

Adiabatic Normal Shock. Equations (4.40) and (4.44) to (4.51) are used, with $T_{o2} = T_{o1}$, $W_2/W_1 = 1$, $w_2/w_1 = 1$, and $k_2/k_1 = 1$.

Combustion. In using Equations (4.40) and (4.44) to (4.51), knowledge of the final chemical composition is necessary.+ With data on the final composition, T_{o2} may be found from Equation (4.40) and then, for given values of M_1, p_1, T_1, etc., the values of M_2, p_2, T_2, etc., may be computed from Equations (4.44) to (4.51). Note from Figure 4.4(a) that there are usually two solutions to the equations. When the initial Mach number is subsonic, the solution with $M_2 > 1$ is usually not realizable because it would violate the second law of thermodynamics. When the initial Mach number is supersonic, both solutions are possible; the solution with $M_2 < 1$ may then be thought of as the combination of a thermal discontinuity and an adiabatic normal shock.

+ Prediction of the final composition requires additional considerations, such as reaction rate, intermediate reactions, etc.

Moisture-Condensation Shock. One of the principal problems in the design of supersonic wind tunnels concerns the formation of moisture-condensation shocks when the water vapor, which remains in vapor form long after the air is saturated, precipitates rather suddenly. During the condensation there is a change both in the mass flow and stagnation temperature of the gas stream. Equation (4.40) may be employed for computing the final stagnation temperature. In applying Equations (4.44) through (4.51), y may be taken as unity, and $w_1 - w_2$ represents the amount of water condensed.

The strength of the shock depends upon the amount of precipitation. An estimate of this may be made by assuming that equilibrium conditions with a certain average size of droplets subsist after the shock, i.e., that the air is saturated with water vapor after the shock.+

The condensation of water vapor may, however, give rise to a phenomenon similar to thermal choking. If we assume that equilibrium exists between vapor and liquid after the shock, then for certain combinations of temperature, pressure and humidity, thermal choking will define an upper limit to the size of droplets formed. In other words, if larger droplets are assumed to be in equilibrium with the vapor, no numerical solutions can be obtained to the flow equations. An alternative possibility is that equilibrium is not established after the shock, that only a fraction of the water vapor is condensed, and that the Mach number downstream of the shock remains at unity until the expanding flow reduces the pressure to the point where equilibrium is reached, whereupon the Mach number once again increases.

These speculations are of interest, but without further experimental data it is impossible to predict the exact course of events when thermal choking plays a part.

Similar considerations apply to the flow of supersaturated steam through turbine nozzles. Yellot (Ref. 4.12) mentions tests on steam nozzles where, in at least one case, the computations (based upon a certain radius of droplets after condensation) yielded only imaginary answers for the final condition. This was probably a case of thermal choking.

+ The effect of surface tensions on the latent heat and on the vapor pressure-temperature equilibrium curve must be taken into account.

b. Steadily moving discontinuities (explosion waves)

As an example of a steadily moving discontinuity, consider a plane flame front moving into an inflammable gas initially at rest.

To simplify the qualitative discussion, changes in specific heat and molecular weight will be ignored and drag and gas-injection effects will be omitted. Equations (4.52) to (4.57) are then simplified by setting $k_1 = k_2$.

Any particular reaction will have associated with it a particular change in stagnation temperature, $T_{o2} - T_{o1}$, the value of which, from Equation (4.40) is given approximately by the enthalpy of combustion at constant p and T, divided by the specific heat at constant pressure. Using Equation (4.54), the following relation, based upon $k_1 = k_2$, gives the ratio of stagnation-temperature rise to initial temperature in terms of the end Mach numbers

$$\frac{T_{o2} - T_{o1}}{T_1} = \frac{\Delta T_o}{T_1} = \left(1 + \frac{k-1}{2} M_1^2\right)\left(\frac{T_{o2}}{T_{o1}} - 1\right) \qquad (4.58)$$

The relation between T_{o2}/T_{o1}, M_1 and M_2 is found from Equation (4.44), or from Figure 4.13.

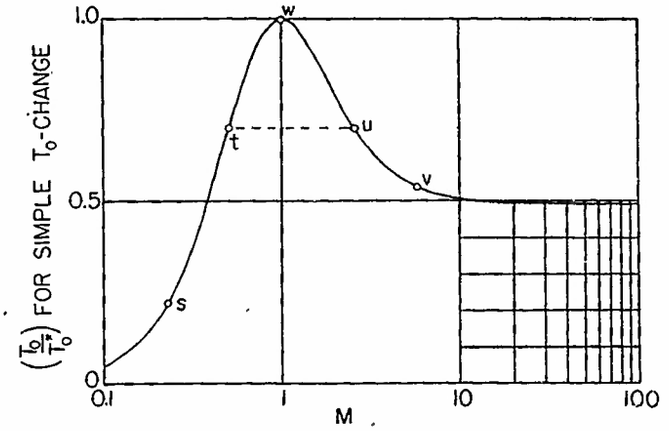


Fig. 4.13 TYPES OF EXPLOSION WAVES

(Curve of $(T_o/T_o)^*$ versus M for simple T_o-change with k = 1.4; see Fig. 4.12. Process s-t is one of slow combustion. Process s-u is one of deflagration. Process v-u, v-t, or v-w, is one of detonation.)

Note that the parameter $\Delta T_o/T_1$ is more useful than T_{o2}/T_{o1} for the steadily moving discontinuity because it depends upon the particular chemical reaction and the temperature of the unburned gas and not upon the flame speed M_1. Curves of M_2 versus M_1 at constant values of $\Delta T_o/T_1$ are presented in Fig 4.14(a).

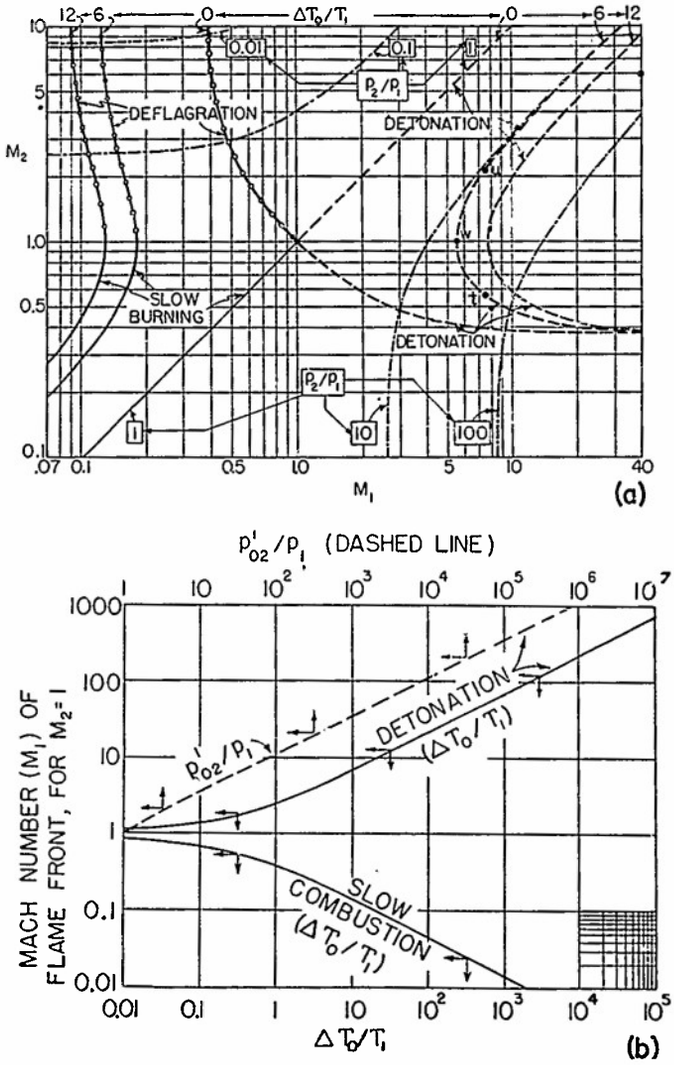


Fig. 4.14 EXPLOSION WAVES; k = 1.4

(a, Chart showing M_2 versus M_1 for fixed values of $\Delta T_o/T_1$, with curves of constant p_2/p_1. The several branches for each $\Delta T_o/T_1$ may be compared with the representations of Figs. 4.12 and 4.13. b, Chart showing M_1 and p_{o2}/p_1 versus $\Delta T_o/T_1$ for the limiting case where $M_2 = 1$.)

Three different types of explosion waves may be identified. These are illustrated in Figs. 4.12, 4.13, and 4.14(a). The relative magnitudes of the pressures and velocities fore and aft of the wave are found either from Equations (4.38) and (4.53), or from inspection of Figs. 4.4(a) and 4.14(a).

Slow burning. The speed of the flame front is subsonic relative to the unburned gas, and the latter flows away from the front. The pressure drops as the flame front passes the observer.

Deflagration. The speed of the flame front is subsonic relative to the unburned gas, and the latter flows away from the front. The pressure drops as the flame front passes the observer. Although these effects are qualitatively the same as in slow burning, the magnitudes of the changes in velocity and pressure are very much greater than for slow burning. Deflagration might be thought of crudely as the combination of a thermal shock and a negative (i.e., expansion) adiabatic shock. Because of the latter circumstance, it is probable that deflagration violates the second law of thermodynamics.

Detonation. The speed of the flame front is supersonic relative to the unburned gas, and the latter flows toward the front. The pressure rises as the flame front passes the observer. Relative to the front, the flow behind the shock, i.e., in region 2, may be either subsonic or supersonic.

For a given value of $\Delta T_o/T_1$ corresponding to a given chemical reaction the equations of continuity, momentum, and energy, according to Figure 4.14(a), can be satisfied by an infinite number of values of M_1 to each of which are related, in general, two possible values of M_2; except that in a certain range of values of M_1, on either side of the value $M_1 = 1$, no steady-state solution is possible. In order to predict the values of M_1 and M_2 which will occur in a given instance, consideration must be given to the kinetics of chemical reaction and to the boundary conditions in space and time. Also, it should be noted that for steady motion of the flame front the flame speed (kinetically speaking) must be identical with the velocity of the discontinuity.

When a flame is initiated in a quiet inflammable mixture the flame velocity is at first quite low. Then, as a result of pressure waves initiated during the combustion process and reflected from nearby boundaries, the temperature of the unburned gas just ahead of the flame front may attain values large enough to increase the flame speed very markedly (Ref. 4.14). After the speed of the flame reaches the limiting value for slow combustion shown in Figure 4.14(a), pressure waves, by means of the temperature rise accompanying them, can cause a further increase in the speed of the chemical reactions in the flame, but no increase in the steady speed of the discontinuity can be found which will sat-

isfy the conditions of continuity, momentum, and energy. A transient condition then sets in and oscillations in flame speed are observed experimentally (Ref. 4.14).

It seems probable that the mechanism by which the flame passes into the detonation type of combustion is by means of a sufficiently large oscillation or pressure wave which raises the temperature in the unburned gas to the point where the flame speed is equal to or greater than the minimum value for detonation. As soon as this occurs it is possible to satisfy the conditions of continuity, energy, and momentum for a steadily moving discontinuity.

Although any point on the appropriate curve for $\Delta T_o/T_1$ in the detonation region will satisfy the physical conditions, the results of experiments show that only at a point such as w, Figs. 4.13 and 4.14(a), where $M_2 = 1$, are steady conditions attained. If conditions corresponding to the point t are established, then, since M_2 is less than 1, a rarefaction wave formed in the burned gas can overtake the flame front and cause a decrease in M_1 toward point w. Conversely, a pressure wave can cause an increase in M_1. The flame front is thus continually exposed to the effects of pressure and rarefaction waves, and, with suitable boundary conditions, it is possible for point w to be reached, at which condition M_2 is unity; then the flame front can no longer be influenced by expansion waves or by infinitesimal compression waves.

In considering the possibility that a steady condition, corresponding to point u (Figs. 4.13 and 4.14(a), might be attained, most writers (Ref. 4.14) have argued that it is a less probable state than that corresponding to point t, because point t has a greater entropy but the same stagnation temperature as point u. The difficulty in this argument is that it would appear to make any supersonic flow improbable in view of the fact that there is always a corresponding subsonic state of higher entropy and the same stagnation temperature. A convincing conclusion cannot rest on thermodynamic reasons alone, but must rely upon the consideration of the physical and chemical mechanisms which cause detonation. In this respect it might be noted that whereas point t represents a solution which includes a compression shock, for point u, on the other hand, no shock is involved. As the mechanism for raising the flame speed to the large values associated with detonation appears to be a pressure shock slightly preceding the point of ignition, it is questionable whether a steady condition corresponding to point u can be attained.

In virtually all reported experiments on detonation, it appears that the boundary conditions and chemical kinetics were such as to lead to point w ($M_2 = 1$) as the steady-state condition (Ref. 4.14).

Considering now the case where $M_2 = 1$, Figure 4.14(b) shows the maximum M_1 for slow burning and the minimum M_1 for detonation, both as functions of $\Delta T_o/T_1$. Using the approximation that $k_2 = k_1$, the relation between these quantities is found from Equations (4.44) and (4.58) to be

$$\left(\frac{\Delta T_o}{T_1}\right)_{M_2=1} = \frac{(1 - M_1^2)^2}{2(k + 1)\, M_1^2} \tag{4.59}$$

The rise in temperature associated with an adiabatic pressure shock ($\Delta T_o = 0$) is of interest in detonation phenomena

$$\frac{T_2}{T_1} = \frac{1 + \frac{k - 1}{2} M_1^2}{1 + \frac{k - 1}{2} M_2^2} =$$

$$\left(\frac{2}{k + 1}\right)^2 \frac{1 + \frac{k - 1}{2} M_1^2}{M_1^2} \left(kM_1^2 - \frac{k - 1}{2}\right) \tag{4.59a}$$

An estimate of the damage produced by a steady-state detonation wave[+] is provided by the value of p_{o2}'/p_1 found from Equations (4.45) and (4.57)

$$\left(\frac{p_{o2}'}{p_1}\right)_{M_2=1} = \frac{1 + kM_1^2}{k + 1} \left[1 + \frac{k - 1}{2} \left(\frac{M_1^2 - 1}{1 + kM_1^2}\right)^2\right]^{\frac{k}{k-1}} \tag{4.60}$$

This ratio is also plotted versus M_1 in Figure 4.14(b).

[+] It should be remembered that in most explosions the reaction soon ceases for want of fuel, so that the wave strength, shown in Fig. 4.14(b), is of very short duration.

In the usual hydrocarbon explosion, T_1 is about 520 R, $\Delta T_o/T_1$ is about 6, and the speed of sound is about 1000 fps. From Figure 4.14(b) it may be seen that the flame-front speed is then about 5500 fps, and the stagnation pressure rises to about 25 atm. Also, from Equation (4.59a) the temperature after an adiabatic shock traveling at 5500 fps is about 3000 F; thus as indicated previously, there is considerable preheating effect available for increasing the flame speed to values necessary for detonation.

The temperatures in an atomic explosion are said to be measured in millions of degrees. Assuming for such an explosion that $\Delta T_o/T_1 = 104$, Figure 4.14(b) indicates a wave speed of the order of magnitude of 200,000 fps, and a stagnation pressure of the order of magnitude of 40,000 atm!

APPENDIX 4.1

DERIVATION OF ENERGY EQUATION

In applying the steady-flow energy equation to the flow through the control surfaces of Figures 4.1(a), (b), and (c), the liquid stream, whether it be in the form of filaments or droplets, is considered to be external to the system. Only the liquid crossing the control-surface boundary and evaporating within the control surface is taken into account in evaluating the flux of enthalpy. Changes in temperature of the liquid traveling along with the stream are then taken to be the result of external heat exchange to or from the main stream. Therefore the liquid crossing the boundary is saturated and at the temperature of the gas stream, and, as it passes out of the control surface in the form of vapor mixed with the main stream, it is at the temperature of the latter.

The energy equation of steady flow relates the external work effect and the external heat exchange to the increase in the flux of enthalpy, kinetic energy, and potential energy passing through the control surface; thus

$$w(dQ - dW_x) = w(h + dh) + (h_g)_T\, dw_g + (h_L)_T\, dw_L - wh$$

$$- (h_g)_{T_g}\, dw_g - (h_L)_{T_L} dw_L + (w + dw_g + dw_L)\left(\frac{V^2}{2} + d\frac{V^2}{2}\right)$$

$$- w\,\frac{V^2}{2} - \frac{V_g^2}{2}\, dw_g - \frac{V_L^2}{2}\, dw_L + (w + dw_g + dw_L)(z + dz) - wz - z_g dw_g$$

$$- z_L dw_L \qquad (4.61)$$

In this expression, dQ is the net heat added to the stream from sources external to the main gaseous stream, per unit mass of gas entering the control surface. Likewise, dW_x is the net external work delivered to outside bodies per unit mass of gas entering the control boundary. The external work includes such things as shaft work, electrical work, and shear work on moving bodies adjacent to the control-surface boundaries. The elevation z_g is taken at the height where h_g and V_g are measured; similarly for z_L. The symbols $(h_g)_T$ and $(h_g)_{Tg}$ denote, respectively, the enthalpies of the injected gas dw_g at the temperature T, and at the temperature T_g at which dw_g crosses the control surface. The symbol $(h_L)_T$ denotes the enthalpy of the evaporated liquid at the temperature T, and $(h_L)_{TL}$ denotes the enthalpy of the evaporating liquid as it crosses the control surface at the temperature T.

Equation (4.61) may be reduced as follows

$$dQ - dW_x = dh + d\frac{V^2}{2} + dz$$

$$+ \left[(h_g)_T - (h_g)_{Tg} + \frac{V^2 - V_g^2}{2} + z - z_g\right]\frac{dw_g}{w}$$

$$+ \left[(h_L)_T - (h_L)_{TL} + \frac{V^2 - V_L^2}{2} + z - z_L\right]\frac{dw_L}{w} \qquad (4.62)$$

Now the enthalpy change of the main gas stream, dh, is the sum of the changes due to chemical reaction and to temperature change; thus

$$dh = - dh_{pr} + c_p dT \qquad (4.63)$$

where dh_{pr} is the enthalpy increase at the temperature T and pressure p for a change from products to reactants, and is positive for exothermic reactions. It is often called the heat of reaction, or heat of combustion at constant pressure and temperature. In evaluating dh_{pr}, one considers of course only the chemical changes which actually occur, but computes dh_{pr} per unit mass of total gas stream.

We may also write

$$(h_g)_T - \left[(h_g)_{Tg} + \frac{V_g^2}{2}\right] = (h_g)_T - h_{og} = \bar{c}_{pg}(T - T_{og}) \qquad (4.64a)$$

$$c_{pg} = \int_{T_{og}}^{T} c_{pg} dT \Big/ (T - T_{og}) \qquad (4.64b)$$

where h_{og} is the stagnation enthalpy of the injected gas stream, and T_{og} is its stagnation temperature.

Also

$$(h_L)_T - (h_L)_{TL} = h_{fg} \qquad (4.65)$$

where h_{fg} is the latent heat of evaporation of the injected liquid at the temperature T.

Inserting Equations (4.63), (4.64a), and (4.65) into (4.62) and rearranging, the energy equation is finally put into the form

$$dQ - dW_x + dH = \bar{c}_p dT + d(V^2/2) + dz \qquad (4.66a)$$

$$dH = dh_{pr} - \left[c_{pg}(T - T_{og}) + V^2/2 + (z - z_g)\right] \frac{dw_g}{w} - \left[h_{fg} + \frac{V^2 - V_L^2}{2} + (z - z_L)\right] \frac{dw_L}{w} \qquad (4.66b)$$

Except for meteorological problems, the differences in elevation can usually be ignored, and are omitted in the remainder of the paper.

APPENDIX 4.2

DERIVATION OF MOMENTUM EQUATION

For steady-flow problems, Newton's second law of motion is most conveniently applied by equating the net force acting on a control surface to the increase of momentum flux of the streams flowing through the control surface.

Consider forces in the direction of flow acting on the control surface in Figure 4.1(a). Assuming that the injected gas and liquid streams are at the control-surface pressure as they cross the boundary and that the angle of divergence of the walls is small, the momentum equation yields+

+If the injected gas stream is not at the control-surface pressure as it crosses the boundary, the term $(p_g - p)dA_g'$ should be added to the left-hand side of Eq.(4.67), where p_g is the pressure of the injected stream at the boundary and dA_g' is the projected area of the control surface occupied by the injected gas stream.

$$pA + pdA - (p + dp)(A + dA) - \tau_w dA_w - dX$$

$$= (w + dw_g + dw_L)(V + dV) - V_g' dw_g - V_L' dw_L - wV \qquad (4.67)$$

In the foregoing expression τ_w represents the frictional shearing stress acting on the wall area dA_w; dX is the sum of (1) the drag of bodies immersed in the stream within the control-surface boundaries, and (2) the component of body or gravity forces acting on the fluid within the control surface in the direction opposite to that of the velocity vector; V_g' is the forward component of the velocity V_g with which the injected gas dw_g crosses the control surface, and similarly for V_L'.

The wall shearing stress is related to the coefficient of friction f, though the definition

$$\tau_w = f\rho V^2/2 \qquad (4.68)$$

Also, we define the quantities

$$y_g = V_g'/V, \text{ and } y_L = V_L'/V \qquad (4.69)$$

From the definition of the hydraulic diameter D, we obtain

$$dA_w/A = 4\,dx/D \qquad (4.70)$$

After substituting Equations (4.68), (4.69), and (4.70) into Equation (4.67), and noting that $\rho V^2 = kpM^2$, we obtain, following rearrangement

$$\frac{dp}{p} + \frac{kM^2}{2}\frac{dV^2}{V^2} + \frac{kM^2}{2}\left(4f\frac{dX}{D} + \frac{dX}{\frac{1}{2}kpAM^2}\right) + kM^2(1 - y)\frac{dw}{w} = 0 \qquad (4.71)$$

where

$$(1 - y)\frac{dw}{w} = (1 - y_g)\frac{dw_g}{w} + (1 - y_L)\frac{dw_L}{w} \qquad (4.72a)$$

$$\frac{dw}{w} = \frac{dw_g}{w} + \frac{dw_L}{w} \qquad (4.72b)$$

$$y \frac{dw}{w} = y_g \frac{dw_g}{w} + y_L \frac{dw_L}{w} \qquad (4.72c)$$

These same equations apply for the methods of injection in Figure 4.1 (b and c), provided A is always taken as the cross-sectional area of the main gas stream.

APPENDIX 4.3

EXAMPLES

General. The numerical solution of problems is greatly facilitated by numerical tables of functions. At the back of this report are thirty tables of such functions, with the aid of which virtually any problem in one-dimensional gas dynamics can be carried out conveniently.

The tables are divided into five groups, each pertaining to a certain kind of process; and in each group are six tables, each referring to a particular value of the specific-heat ratio, k.

Tables 4.4 to 4.9, inclusive, give values of the influence coefficients, and will be found useful for problems involving combined effects.

Tables 4.10 to 4.15, inclusive, give values of the functions for isentropic flow.

Tables 4.16 to 4.21, inclusive, give values of the functions for "simple T_o-change", that is, constant-area flow without friction.

Tables 4.22 to 4.27, inclusive, give values of the functions for "simple friction", that is, adiabatic flow at constant area.

Tables 4.28 to 4.33, inclusive, give values of the functions for a normal shock.

In the sections below are numerical examples illustrating the use of the tables.

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Examples of Use of Tables of Influence Coefficients. For convenience in performing numerical calculations, the influence coefficients given in Tables 4.1 and 4.2 are slightly modified. In the case of variable specific heat and molecular weight the principal working equation is a modified form of Equation (4.13), namely,

$$dM^2 = F_A \frac{dA}{A} + F_Q \frac{dQ - dW_x + dH}{c_p T} + F_f \left[4f \frac{dx}{D} + \frac{dX}{\frac{1}{2}kpAM^2} - 2y \frac{dw}{w} \right] + F_w \frac{dw}{w} + F_W \frac{dW}{W} - \frac{dk}{k} \qquad (4.73)$$

For constant specific heat and molecular weight, the principal working equation is a modified form of Equation (4.19), namely,

$$dM^2 = F_A \frac{dA}{A} + F_{T_o} \frac{dT_o}{T_o} + F_f \left[4f \frac{dx}{D} + \frac{dX}{\frac{1}{2}kpAM^2} - 2y \frac{dw}{w} \right] + F_w \frac{dw}{w} \qquad (4.74)$$

where

$$F_A = - \frac{2M^2 \left(1 + \frac{k-1}{2} M^2 \right)}{1 - M^2} \qquad (4.75a)$$

$$F_Q = - F_W = \frac{M^2 (1 + kM^2)}{1 - M^2} \qquad (4.75b)$$

$$F_f = \frac{kM^4 \left(1 + \frac{k-1}{2} M^2 \right)}{1 - M^2} \qquad (4.75c)$$

$$F_{T_o} = \frac{F_w}{2} = \frac{M^2 (1 + kM^2) \left(1 + \frac{k-1}{2} M^2 \right)}{1 - M^2} \qquad (4.75d)$$

The influence coefficients F_A, F_Q, F_f, and F_{T_o} are given as functions of M in Tables 4.4 to 4.7 for values of k from 1.0 to 1.67. Note that the influence coefficients of Equation (4.75) are greater by the ratio M^2 than the corresponding coefficients defined in Tables 4.1 and 4.2.

Consider the case of combined friction and heat transfer in a duct of constant area, which was discussed in sub-section (11). For simplicity, the Reynolds Analogy will be used, the recovery factor will be taken as unity, variations in specific heat will be ignored, and the wall temperature will be assumed constant.

Suppose that at section 1 of the duct the Mach Number M_1 is 0.5, and the ratio of wall temperature to stagnation temperature T_w/T_{o1} is 4. Also, let the friction coefficient f be 0.005 and the ratio of specific heats k be 1.4. The problem is to find the variations of all stream properties with respect to distance along the duct. We proceed in stepwise fashion by first solving for conditions at a section where $M_2 = 0.53$.

From Equation (4.30f), we have

$$\frac{dT_o}{T_w - T_o} = 2f \frac{dx}{D} \tag{4.76}$$

Since the wall temperature has been assumed constant, we may integrate analytically, and obtain:

$$\frac{x_2 - x_1}{D} = \frac{1}{2f} \ln \frac{\frac{T_w}{T_{o1}} - 1}{\frac{T_w}{T_{o1}} - \frac{T_{o2}}{T_{o1}}} \tag{4.77}$$

Combination of Equations (4.74) and (4.76) yields

$$dM^2 = F_{T_o} \frac{dT_o}{T_o} + F_f 4f \frac{dx}{D}$$

$$= \left[F_{T_o} \frac{2F_f}{(T_w/T_o) - 1} \right] \frac{dT_o}{T_o} \tag{4.78}$$

Equation (4.78) is integrated approximately over a short step by assuming the influence coefficients to have constant values corresponding to the value of $(M_1 + M_2)/2$, and by assuming that the magnitude of T_o is constant during the integration with a value of $(T_{o2} + T_{o1})/2$. With these approximations, we get for the first step of the integration,

$$M_2^2 - M_1^2 = 2\left(\frac{T_{o2}}{T_{o1}} - 1\right)\left[\frac{\bar{F}_{T_o}}{(T_{o2}/T_{o1})+1} + \frac{2\bar{F}_f}{2(T_w/T_{o1}) - (T_{o2}/T_{o1}) - 1}\right] \tag{4.79}$$

where $\bar{F}$ represents an influence coefficient at the mean Mach number $\bar{M}$.

Now $M_1 = 0.50$

$M_1^2 = 0.2500$

$M_2 = 0.53$

$M_2^2 = 0.2809$

$\bar{M} = 0.515$

$M_2^2 - M_1^2 = 0.0309$

From Table 4.8 we get $\bar{F}_{T_o} = 0.522$, and $\bar{F}_f = 0.142$.

We solve Equation (4.79) for T_{o2}/T_{o1} by trial-and-error, making use of the fact that T_{o2}/T_{o1} is approximately unity. As a first trial, we assume T_{o2}/T_{o1} as unity for the terms in the square bracket of Equation (4.79), and obtain

$$0.0309 = 2\left(\frac{T_{o2}}{T_{o1}} - 1\right)\left[\frac{0.522}{2} \quad \frac{2(0.142)}{6}\right],$$

from which we get $T_{o2}/T_{o1} = 1.05$. Using this value for the second trial, we write

$$0.0309 = 2\left(\frac{T_{o2}}{T_{o1}} - 1\right)\left[\frac{0.522}{2.05} + \frac{2(0.142)}{5.95}\right],$$

from which we obtain $T_{o2}/T_{o1} = 1.0511$. Using this for the third trial, we obtain in similar fashion

$$\frac{T_{o2}}{T_{o1}} = 1.0511 ,$$

which indicates that the second trial was adequate.

To find the distance in which this temperature rise is accomplished, we substitute into Equation (4.77), and obtain

$$\frac{x_2 - x_1}{D} = \frac{1}{2(.005)} \ln \frac{4 - 1}{4 - 1.0511} = 1.72$$

so that section 2 is 1.72 diameters downstream of section 1.

The values of other stream properties at section 2 in relation to the corresponding properties at section 1 are found from Equations (4.26), (4.21), (4.22), (4.23), and (4.17), respectively:

$$\frac{T_2}{T_1} = \frac{T_{o2}}{T_{o1}} \frac{1 + \frac{k-1}{2} M_1^2}{1 + \frac{k-1}{2} M_2^2} = 1.0449$$

$$\frac{p_2}{p_1} = \frac{M_1}{M_2} \sqrt{\frac{T_2}{T_1}} = 0.9643$$

$$\frac{V_2}{V_1} = \frac{M_2}{M_1} \sqrt{\frac{T_2}{T_1}} = 1.0835$$

$$\frac{\rho_2}{\rho_1} = \frac{p_2}{p_1} \frac{T_1}{T_2} = 0.9229$$

$$\frac{p_{o2}}{p_{o1}} = \frac{p_2}{p_1}\left[\frac{1 + \frac{k-1}{2} M_2^2}{1 + \frac{k-1}{2} M_1^2}\right]^{\frac{k}{k-1}} = 0.9843$$

Example of Use of Tables of Isentropic Functions. A supersonic wind-tunnel nozzle is to be designed for a Mach Number of 2, with a test section one square foot in area. The supply pressure and temperature at the nozzle inlet, where the velocity is negligible, are to be 10 psia and 100°F, respectively. The initial design of the nozzle will be based on the assumptions that the flow is isentropic, with k = 1.4, and that at the throat and test section the flow is one-dimensional.

We will begin by determining the stream properties at the test section. Using Table 4.14, we find that at M = 2,

$$M^* = 1.6330$$
$$p/p_o = 0.12780$$
$$\rho/\rho_o = 0.23005$$
$$T/T_o = 0.55556$$
$$A/A^* = 1.6875$$

Therefore,

$$p = 0.1278(10) = 1.278 \text{ psia}$$

and

$$T = 0.55556(459.7 + 100) = 310.9^\circ R = -148.8^\circ F$$

Also,

$$\rho = \frac{p}{RT} = \frac{1.278(144)}{53.35(310.9)} = 0.01110 \text{ lb/ft}^3$$

$$c = \sqrt{kRT} = \sqrt{(1.4)(53.35)(32.174)(310.9)} = 864.4 \text{ ft/sec}$$

$$V = Mc = 2(864.4) = 1728.8 \text{ ft/sec}$$

The flow rate is $w = \rho AV = 0.01110(1728.8) = 19.19$ lb/sec.

Next, we will determine conditions at the throat. First, the throat area is found to be

$$A^* = \frac{A}{A/A^*} = \frac{1}{1.6875} = 0.5926$$

At the throat the Mach Number is unity; hence we get from Table 4.14

$$p^*/p_o = 0.52828$$

$$p^* = 10(0.52828) = 5.2828 \text{ psia}$$

and

$$T^*/T_o = 0.83333$$

$$T^* = (559.7)(0.83333) = 466.4^\circ R$$

$$\rho^* = \frac{p^*}{RT^*} = \frac{(5.2828)(144)}{(53.35)(466.4)} = 0.03057 \text{ lb/ft}^3$$

$$V^* = c^* = \sqrt{kRT^*} = \sqrt{(1.4)(53.35)(32.174)(466.4)}$$
$$= 1059 \text{ ft/sec}$$

The final column in the isentropic tables gives the value of $(p/p_o)(A/A^*)$. This function is useful in experimental work involving supersonic flow in ducts. If the entire flow is assumed to be adiabatic, and if the flow to the throat of the supply nozzle is isentropic as well, then it may be shown that the Mach Number M corresponding to a pressure p and area A at some section of the duct may be found from the function $(p/p_o)(A/A^*)$. An example of its use is given in the example involving simple friction, in sub-section (8).

Example of Use of Tables for Simple T_o-Change. A gaseous mixture of air and fuel enters a ram-jet combustion chamber with a velocity of 200 ft/sec, at a temperature of 120°F, and at a pressure of 5 psia. The heat of reaction of the mixture for the particular fuel-air ratio employed is 500 Btu per pound of mixture. It is desired to find the stream properties at the exit of the combustion chamber. It will be assumed that friction is negligible, that the cross-sectional area is constant, and that the properties of both the reactants and products are equivalent to air as regards molecular weight and specific heat.

We begin by computing additional properties at the inlet, which will be called section 1. The sound velocity c_1 is

$$c_1 = \sqrt{kRT_1} = \sqrt{(1.4)(53.35)(32.174)(579.7)}$$
$$= 1180.3 \text{ ft/sec}$$

and $M_1 = V_1 / c_1 = 200/1180.3 = 0.16945$

The stagnation temperature and isentropic stagnation pressure at section 1 are found for this value of M_1 from Table 4.14. Thus,

$$\left(\frac{p}{p_o}\right)_1 = 0.9801$$

$$p_{o1} = \frac{5}{0.9801} = 5.102 \text{ psia}$$

$$\left(\frac{T}{T_o}\right)_1 = 0.99429$$

$$T_{o1} = \frac{579.7}{0.99429} = 583.0^\circ R$$

To analyze the changes in the combustion process, we first find from Table 4.20 the ratios of stream properties to the corresponding properties at M = 1. For $M_1 = 0.16945$, we find

$$(T_o/T_o^*)_1 = 0.128$$

$$(T/T^*)_1 = 0.153$$

$$(p/p^*)_1 = 2.308$$

$$(p_o/p_o^*)_1 = 1.2435$$

$$(V/V^*)_1 = 0.0663$$

Next, we find the exit stagnation temperature from Equation (4.24):

$$T_{o2} - T_{o1} = \Delta H/c_p$$

Now, $\Delta H = 500$ Btu/lb,

and

$$c_p = \frac{k}{k-1} R = \frac{1.4}{0.4} \frac{53.35}{778.3} = 0.23991 \text{ Btu/lb}^\circ\text{F}$$

so that

$$T_{o2} - T_{o1} = \frac{500}{0.23991} = 2084.1^\circ\text{F}$$

$$T_{o2} = 2084.1 + 583.0 = 2667.1^\circ\text{R}$$

$$T_{o2}/T_{o1} = 2667.1/583.0 = 4.5748$$

The properties at section 2 are found with the help of the T_{o2}/T_{o1} ratio. We first compute

$$\left(\frac{T_o}{T_o^*}\right)_2 = \left(\frac{T_o}{T_o^*}\right)_1 \left(\frac{T_{o2}}{T_{o1}}\right) = (0.128)(4.5748) = 0.5856$$

With this value of $(T_o/T_o^*)_2$, we enter Table 4.20 again, and find that

$$M_2 = 0.4329$$
$$(T/T^*)_2 = 0.677$$
$$(p/p^*)_2 = 1.9012$$
$$(p_o/p_o^*)_2 = 1.1425$$
$$(V/V^*)_2 = 0.3563$$

Finally, we obtain the remaining properties at section 2 with the relations

$$T_2 = T_1 \frac{(T/T^*)_2}{(T/T^*)_1} = 579.7 \frac{0.677}{0.153} = 2560^\circ\text{R}$$

$$p_2 = p_1 \frac{(p/p^*)_2}{(p/p^*)_1} = 5 \frac{1.9012}{2.308} = 4.119 \text{ psia}$$

$$p_{o2} = p_{o1} \frac{(p_o/p_o^*)_2}{(p_o/p_o^*)_1} = 5.102 \frac{1.1425}{1.2435} = 4.688 \text{ psia}$$

$$V_2 = V_1 \frac{(V/V^*)_2}{(V/V^*)_1} = 200 \frac{0.3563}{0.0663} = 1075 \text{ ft/sec}$$

It is also of interest to find the maximum heat of reaction for which flow with the specified initial conditions may be maintained. Choking will occur when the exit Mach Number is unity. Hence, denoting the choking condition by subscript 3,

$$T_{o3} = T_{o1} \frac{(T_o/T_o^*)_3}{(T_o/T_o^*)_1} = \frac{583.0}{0.128} = 4550^\circ R$$

and

$$(\Delta H)_{max} = c_p (T_{o3} - T_{o1})$$

$$= (0.2399)(4550 - 583) = 952 \text{ Btu/lb}$$

After the fuel-air ratio has been increased to the value corresponding to this maximum heat of reaction, further enrichment of the mixture will produce a reduction in mass rate of flow and a consequent reduction in the initial Mach Number.

Attention is called to the use of Tables 4.16 to 4.21, inclusive, for problems involving flow through a discontinuity, especially when energy effects are involved. Sub-section f explains the methods to be used with these Tables.

Example Involving Simple Friction. When a test rig consisting of a converging-diverging nozzle attached to a smooth, round tube was used, the following data were obtained for the purpose of measuring friction coefficients for the supersonic flow of air:

Pressure upstream of nozzle = 516 cm. Hg. abs.
Temperature upstream of nozzle = 107.3°F.
Throat diameter = 0.2416 inches.
Diameter of nozzle exit and of tube = 0.5009 inches.
Pressure of stream at a point 1.75 diameters from tube inlet = 18.25 cm. Hg. abs.
Pressure of stream at a point 29.60 diameters from tube inlet = 37.1 cm. Hg. abs.

It is desired to calculate the average friction coefficients between the sections where x/D = 1.75 and x/D = 29.60. It will be assumed that the flow to the throat of the nozzle is isentropic and that the flow in the entire system is adiabatic

Since the flow to the throat is isentropic and the entire flow is adiabatic, the column labelled $(p/p_o)(A/A^*)$ in Table 4.14 may be used for finding the Mach Numbers at the upstream section.

$$(A/A^*)_1 = (0.5009/0.2416)^2 = 4.2986$$
$$(p/p_o)_1 = 18.25/516 = 0.03537$$
$$(p/p_o)_1\ (A/A^*)_1 = (0.03537)(4.2986) = 0.1520$$

From Table 4.14, then, $M_1 = 2.524$.
Using this value of M_1, we get the following values from Table 4.26 for simple friction:

$$(p/p^*)_1 = 0.2878$$
$$(4fL_{max}/D)_1 = 0.4371$$

Now, since

$$\frac{p_2}{p_1} = \frac{(p/p^*)_2}{(p/p^*)_1}$$

we obtain

$$(p/p^*)_2 = \frac{37.1}{18.25}\ (0.2878) = 0.5850$$

Entering Table 4.26 with this value of $(p/p^*)_2$, we find that

$$M_2 = 1.542$$
$$(4fL_{max}/D)_2 = 0.1512$$

Therefore,

$$4f\ \frac{\Delta L}{D} = 0.4371 - 0.1512 = 0.2859$$

and, since

$$\Delta L/D = 29.60 - 1.75 = 27.85,$$

the average friction coefficient is

$$f = \frac{0.2859}{4(27.85)} = 0.257$$

Example of Use of Tables of Normal-Shock Functions. The relations between the stream properties on the upstream and downstream sides of an adiabatic normal shock when changes in specific heat and molecular weight are absent are presented in Tables 4.28 to 4.33, inclusive. In these tables, subscript x denotes conditions upstream of the shock, and subscript y denotes conditions downstream of the shock.

As an example, consider a stream of air with a Mach Number of 2, pressure of 10 psia, and temperature of 30°F which passes through a normal shock. Then

$$M_x = 2$$

$$p_x = 10$$

and

$$T_x = 489.7$$

From Table 4.14, we find the value of the initial stagnation pressure:

$$\left(\frac{p}{p_o}\right)_x = 0.12780$$

$$p_{ox} = \frac{10}{0.12780} = 78.247 \text{ psia}$$

With a value of M_x of 2, we enter Table 4.32 and obtain

$$M_y = 0.57735$$

$$p_y/p_x = 4.5000$$

$$T_y/T_x = 1.6875$$

$$\frac{p_{oy}}{p_{ox}} = 0.72088$$

Using these ratios, we compute the properties at section y:

$$p_y = (4.5000)(10) = 45.000 \text{ psia}$$

$$T_y = (1.6875)(489.7) = 826.4°R = 366.7°F$$

$$p_{oy} = (0.72088)(78.247) = 56.407 \text{ psia}$$

The column labelled p_{oy}/p_{ox} is also labelled A^*_x/A^*_y, because, for isentropic flow, the throat area required to

pass a given flow is inversely proportional to the stagnation pressure. Thus, if a supersonic nozzle is followed by a supersonic diffuser, the starting condition requires that the diffuser throat be larger than the nozzle throat. If the Mach Number of the nozzle is 2, we see from Table 4.32 that $A^*_x/A^*_y = 0.72088$, so that the throat area of the diffuser must be about 39% greater than the throat area of the nozzle.

The column labelled p_{oy}/p_x is useful for reducing data obtained with supersonic pitot tubes. The measurements usually yield the static pressure upstream of the detached bow wave lying ahead of the probe, and the isentropic stagnation pressure of the streamline which comes to rest at the probe after passing through the normal portion of the bow wave. These are, respectively, p_x and p_{oy}. The ratio p_{oy}/p_x is a function of M_x, as given in Tables 4.28 to 4.33.

M	F_A	F_f	F_{To} / $F_w/2$	F_Q / $-F_w$
0	0	0	0	0
.05	−.00,500	.0 5,625	.00,251	.00,251
.10	−.02,020	.0 3,101	.01,020	.01,020
.15	−.04,604	.0 3,518	.02,354	.02,354
.20	−.08,334	.001,67	.04,327	.04,327
.25	−.13,33	.004,17	.07,084	.07,084
.30	−.19,78	.008,90	.10,78	.10,78
.35	−.27,92	.01,710	.15,67	.15,67
.40	−.38,09	.03,048	.22,10	.22,10
.45	−.50,78	.05,142	.30,53	.30,53
.50	−.66,67	.08,333	.41,67	.41,67
.55	−.86,74	.13,12	.5,649	.5,649
.60	−1.1,25	.20,25	.7,650	.7,540
.65	−1.4,63	.3,091	1.0,41	1.0,41
.70	−1.9,22	.4,708	1.4,32	1.4,32
.75	−2.5,71	.7,232	2.0,09	2.0,09
.80	−3.,556	1.1,38	2.,916	2.,916
.85	−5.,207	1.,881	4.,485	4.,485
.90	−,8.526	3.,453	,7.716	,7.716
.95	−1,8.51	8.,354	1,7.61	1,7.61
1.00	∞	∞	∞	∞
1.05	2,1.51	−11.,86	−2,2.61	−2,2.61
1.10	1,1.52	−6.,972	−1,2.73	−1,2.73
1.15	8.,202	−5.,423	−9.,524	−9.,524
1.20	6.,545	−4.7,13	−7.,985	−7.,985
1.25	5.5,56	−4.3,40	−7.1,18	−7.1,18
1.30	4.8,99	−4.1,39	−6.5,89	−6.5,89
1.35	4.4,32	−4.0,38	−6.2,54	−6.2,54
1.40	4.0,83	−4.00,2	−6.0,43	−6.0,43
1.45	3.8,14	−4.01,0	−5.9,17	−5.9,17
1.50	3.60,0	−4.05,0	−5.8,50	−5.8,50
1.55	3.42,6	−4.11,6	−5.82,9	−5.82,9
1.60	3.28,2	−4.20,1	−5.84,3	−5.84,3
1.65	3.16,1	−4.30,3	−5.88,4	−5.88,4
1.70	3.05,8	−4.41,9	−5.94,8	−5.94,8

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0 3429 signifies .000429. The notation 5370 4 signifies 5,370,000.

Table 4.4 INFLUENCE COEFFICIENTS (k = 1.0 exactly)

M	F_A	F_f	F_{T_o} $F_w/2$	F_Q $-F_W$
1.75	2.97,0	−4.54,7	−6.03,2	−6.03,2
1.80	2.89,3	−4.68,6	−6.13,3	−6.13,3
1.85	2.82,6	−4.83,5	−6.24,8	−6.24,8
1.90	2.76,6	−4.99,3	−6.37,6	−6.37,6
1.95	2.71,4	−5.15,9	−6.51,6	−6.51,6
2.00	2.66,7	−5.33,3	−6.66,7	−6.66,7
2.05	2.625	−5.51,5	−6.82,8	−6.82,8
2.10	2.587	−5.70,3	−6.99,7	−6.99,7
2.15	2.552	−5.89,8	−7.17,5	−7.17,5
2.20	2.521	−6.10,0	−7.36,1	−7.36,1
2.25	2.492	−6.30,9	−7.55,5	−7.55,5
2.30	2.466	−6.52,4	−7.75,6	−7.75,6
2.35	2.442	−6.74,4	−7.96,5	−7.96,5
2.40	2.420	−6.97,0	−8.18,0	−8.18,0
2.45	2.400	−7.20,2	−8.40,2	−8.40,2
2.50	2.381	−7.44,0	−8.63,1	−8.63,1
2.55	2.363	−7.68,4	−8.86,6	−8.86,6
2.60	2.347	−7.93,4	−9.10,7	−9.10,7
2.65	2.332	−8.18,9	−9.35,5	−9.35,5
2.70	2.318	−8.44,9	−9.60,8	−9.60,8
2.75	2.305	−8.71,5	−9.86,7	−9.86,7
2.80	2.292	−8.98,6	−10.13	−10.13
2.85	2.281	−9.26,3	−10.40	−10.40
2.90	2.270	−9.54,5	−10.68	−10.68
2.95	2.260	−9.83,2	−10.96	−10.96
3.00	2.250	−10.12	−11.25	−11.25
3.50	2.178	−13.34	−14.43	−14.43
4.00	2.133	−17.07	−18.13	−18.13
4.50	2.104	−21.30	−22.35	−22.35
5.00	2.083	−26.04	−27.08	−27.08
6.00	2.057	−37.03	−38.06	−38.06
7.00	2.042	−50.02	−51.04	−51.04
8.00	2.032	−65.02	−66.03	−66.03
9.00	2.025	−82.01	−83.02	−83.02
10.00	2.020	−101.01	−102.02	−102.02
∞	2.000	$-\infty$	$-\infty$	$-\infty$

Table 4.4 INFLUENCE COEFFICIENTS (k = 1.0 exactly) (Concluded)

M	F_A	F_f	F_{T_o} / $F_w/2$	F_Q / $-F_W$
0	0	0	0	0
.05	−.00,500	.0 5,688	.00,251	.00,251
.10	−.02,021	.0 3,111	.01,022	.01,021
.15	−.04,609	.0 3,570	.02,362	.02,359
.20	−.08,351	.001,84	.04,353	.04,350
.25	−.13,38	.004,60	.07,147	.07,125
.30	−.19,87	.009,84	.10,92	.10,87
.35	−.28,09	.01,893	.15,94	.15,84
.40	−.38,40	.03,379	.22,58	.22,40
.45	−.51,30	.05,714	.31,36	.31,05
.50	−.67,50	.09,281	.43,03	.42,50
.55	−.8,805	.14,65	.5,868	.5,780
.60	−1.1,45	.22,68	.7,994	.7,852
.65	−1.4,94	.3,472	1.0,942	1.0,716
.70	−1.9,69	.5,306	1.5,149	1.4,786
.75	−2.6,44	.8,179	2.1,40	2.0,81
.80	−3.,669	1.2,92	3.,126	3.,029
.85	−5.,395	2.,144	4.,842	4.,673
.90	−,8.872	3.,952	,8.388	,8.062
.95	−1,9.35	9.,604	1,9.27	1,8.45
1.00	∞	∞	∞	∞
1.05	2,2.70	−13.,76	−2,5.11	−2,3.80
1.10	1,2.22	−8.,133	−1,4.24	−1,3.43
1.15	8.,744	−6.,360	−1,0.73	−10.,07
1.20	7.,017	−5.5,57	−9.,066	−8.,457
1.25	5.9,90	−5.1,47	−8.1,42	−7.5,52
1.30	5.3,12	−4.9,38	−7.5,94	−7.0,02
1.35	4.8,35	−4.8,47	−7.2,65	−6.6,58
1.40	4.4,84	−4.8,33	−7.0,75	−6.4,44
1.45	4.2,15	−4.87,4	−6.9,82	−6.3,18
1.50	4.00,5	−4.95,6	−6.9,59	−6.2,55
1.55	3.83,8	−5.07,1	−6.99,0	−6.24,0
1.60	3.70,2	−5.21,3	−7.06,4	−6.26,2
1.65	3.59,1	−5.37,8	−7.17,3	−6.31,4
1.70	3.50,0	−5.56,3	−7.31,3	−6.39,0

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_3429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.5 INFLUENCE COEFFICIENTS (k = 1.1 exactly)

M	F_A	F_f	$\frac{F_{T_o}}{F_w/2}$	$\frac{F_Q}{-F_w}$
1.75	3.42,4	−5.76,8	−7.48,0	−6.48,7
1.80	3.36,1	−5.99,0	−7.67,1	−6.60,2
1.85	3.30,9	−6.22,9	−7.88,4	−6.73,2
1.90	3.26,6	−6.48,4	−8.11,7	−6.87,6
1.95	3.23,0	−6.75,4	−8.36,9	−7.03,2
2.00	3.20,0	−7.04,0	−8.64,0	−7.20,0
2.05	3.17,6	−7.34,1	−8.92,9	−7.37,9
2.10	3.157	−7.65,7	−9.23,5	−7.56,7
2.15	3.142	−7.98,8	−9.56,0	−7.76,4
2.20	3.131	−8.33,4	−9.90,0	−7.97,1
2.25	3.123	−8.69,6	−10.26	−8.18,6
2.30	3.119	−9.07,3	−10.63	−8.40,9
2.35	3.117	−9.46,6	−11.02	−8.63,9
2.40	3.117	−9.87,5	−11.43	−8.87,7
2.45	3.120	−10.30	−11.86	−9.12,3
2.50	3.125	−10.74	−12.31	−9.37,5
2.55	3.132	−11.20	−12.77	−9.63,4
2.60	3.141	−11.68	−13.25	−9.90,0
2.65	3.151	−12.17	−13.75	−10.17
2.70	3.163	−12.68	−14.26	−10.45
2.75	3.176	−13.21	−14.80	−10.74
2.80	3.191	−13.76	−15.36	−11.03
2.85	3.207	−14.33	−15.93	−11.33
2.90	3.224	−14.91	−16.52	−11.63
2.95	3.243	−15.52	−17.14	−11.94
3.00	3.263	−16.15	−17.78	−12.26
3.50	3.512	−23.66	−25.42	−15.76
4.00	3.840	−33.79	−35.71	−19.84
4.50	4.234	−47.16	−49.27	−24.48
5.00	4.688	−64.45	−66.80	−29.69
6.00	5.760	−114.0	−116.9	−41.76
7.00	7.044	−189.8	−193.4	−56.04
8.00	8.533	−300.4	−304.6	−72.53
9.00	10.23	−455.6	−460.7	−91.23
10.00	12.12	−666.7	−672.7	−112.12
∞	∞	−∞	−∞	−∞

Table 4.5 INFLUENCE COEFFICIENTS (k = 1.1 exactly) (Concluded)

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M	F_A	F_f	F_{T_o} / $F_w/2$	F_Q / $-F_W$
0	0	0	0	0
.05	−.00,500	.0 5,750	.00,251	.00,251
.10	−.02,022	.0 3,120	.01,023	.01,022
.15	−.04,614	.0 3,623	.02,371	.02,364
.20	−.08,367	.002,01	.04,378	.04,367
.25	−.13,42	.005,03	.07,212	.07,167
.30	−.19,96	.010,78	.11,06	.10,96
.35	−.28,26	.02,077	.16,21	.16,01
.40	−.38,70	.03,716	.23,07	.22,70
.45	−.51,81	.06,295	.32,20	.31,56
.50	−.6,833	.10,25	.44,42	.43,33
.55	−.8,936	.16,22	.6,090	.5,911
.60	−1.1,66	.2,518	.8,345	.8,055
.65	−1.5,25	.3,866	1.1,49	1.1,03
.70	−2.0,16	.5,926	1.6,00	1.5,26
.75	−2.7,16	.9,167	2.2,75	2.1,54
.80	−3.,783	1.,453	3.,344	3.,143
.85	−5.,583	2.,420	5.,212	4.,861
.90	−,9.217	4.,479	,9.088	,8.407
.95	−2,0.18	10.,93	2,1.02	1,9.28
1.00	∞	∞	∞	∞
1.05	2,3.88	−15.,30	−2,7.74	−2,4.99
1.10	1,2.92	−9.,379	−1,5.84	−1,4.13
1.15	9.,286	−7.,369	−12.,01	−10.,61
1.20	7.,488	−6.,470	−10.,21	−8.,928
1.25	6.4,24	−6.0,22	−9.2,34	−7.9,86
1.30	5.7,26	−5.8,07	−8.6,70	−7.4,16
1.35	5.2,39	−5.7,29	−8.3,49	−7.0,62
1.40	4.8,84	−5.7,43	−8.1,85	−6.8,44
1.45	4.6,16	−5.8,23	−8.1,31	−6.7,18
1.50	4.4,10	−5.95,4	−8.1,59	−6.6,60
1.55	4.24,9	−6.12,5	−8.2,50	−6.65,2
1.60	4.12,2	−6.33,2	−8.39,3	−6.68,2
1.65	4.02,2	−6.56,9	−8.58,0	−6.74,4
1.70	3.94,2	−6.83,5	−8.80,6	−6.83,2

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0 3429 signifies .000429. The notation 5370 4 signifies 5,370,000.

Table 4.6 INFLUENCE COEFFICIENTS (k = 1.2 exactly)

M	F_A	F_f	$\frac{F_{T_o}}{F_w/2}$	$\frac{F_Q}{-F_w}$
1.75	3.87,9	−7.12,8	−9.06,8	−6.94,2
1.80	3.83,0	−7.44,6	−9.36,1	−7.07,0
1.85	3.79,3	−7.78,8	−9.68,4	−7.21,5
1.90	3.76,5	−8.15,5	−10.04	−7.37,5
1.95	3.74,5	−8.54,5	−10.42	−7.54,8
2.00	3.73,3	−8.96,0	−10.83	−7.73,3
2.05	3.72,7	−9.39,9	−11.27	−7.93,0
2.10	3.72,7	−9.86,2	−11.73	−8.13,7
2.15	3.732	−10.35	−12.22	−8.35,5
2.20	3.741	−10.86	−12.74	−8.58,1
2.25	3.754	−11.40	−13.28	−8.81,7
2.30	3.771	−11.97	−13.85	−9.06,7
2.35	3.791	−12.56	−14.46	−9.31,3
2.40	3.814	−13.18	−15.09	−9.57,4
2.45	3.840	−13.83	−15.75	−9.84,3
2.50	3.869	−14.51	−16.44	−10.12
2.55	3.900	−15.22	−17.16	−10.40
2.60	3.934	−15.96	−17.92	−10.69
2.65	3.970	−16.73	−18.71	−10.99
2.70	4.008	−17.53	−19.53	−11.30
2.75	4.048	−18.37	−20.39	−11.61
2.80	4.090	−19.24	−21.28	−11.93
2.85	4.134	−20.15	−22.21	−12.26
2.90	4.179	−21.09	−23.18	−12.59
2.95	4.226	−22.07	−24.18	−12.93
3.00	4.275	−23.08	−25.22	−13.28
3.50	4.846	−35.61	−38.04	−17.10
4.00	5.547	−53.25	−56.02	−21.55
4.50	6.364	−77.33	−80.51	−26.61
5.00	7.292	−109.38	−113.02	−32.29
6.00	9.463	−204.4	−209.1	−45.46
7.00	12.05	−354.2	−360.1	−61.05
8.00	15.03	−577.3	−584.9	−79.04
9.00	18.43	−895.6	−904.8	−99.43
10.00	22.22	−1333.	−1344.	−122.22
∞	∞	−∞	−∞	−∞

Table 4.6 INFLUENCE COEFFICIENTS (k = 1.2 exactly) (Concluded)

M	F_A	F_f	F_{T_o} / $F_w/2$	F_Q / $-F_W$
0	0	0	0	0
.05	—.00,500	.0 $_5$,813	.00,251	.00,251
.10	—.02,023	.0 $_3$1,31	.01,025	.01,023
.15	—.04,619	.0 $_3$,676	.02,377	.02,369
.20	—.08,383	.002,18	.04,403	.04,383
.25	—.13,46	.005,47	.07,277	.07,208
.30	—.20,05	.01,173	.11,19	.11,05
.35	—.28,43	.02,264	.16,48	.16,18
.40	—.39,01	.04,057	.23,56	.23,01
.45	—.52,33	.06,889	.33,05	.32,08
.50	—.69,17	.11,24	.4,582	.44,17
.55	—.9,067	.17,83	.6,317	.6,042
.60	—1.1,86	.2,775	.8,703	.8,258
.65	—1.5,56	.4,273	1.2,05	1.1,33
.70	—2.0,63	.6,570	1.6,88	1.5,73
.75	—2.7,88	1.0,20	2.4,14	2.2,26
.80	—3.,897	1.,621	3.,570	3.,257
.85	—5.,772	2.,710	5.,596	5.,049
.90	—,9.562	,5.035	,9.816	,8.752
.95	—2,1.02	1,2.33	2,2.84	2,0.12
1.00	∞	∞	∞	∞
1.05	2,5.07	—1,7.97	—3,0.50	—2,6.17
1.10	1,3.62	—1,0.71	—1,7.52	—1,4.82
1.15	9.,829	—8.,449	—13.,36	—11.,15
1.20	7.,959	—7.,450	—11.,43	—9.,399
1.25	6.8,58	—6.9,65	—10.,39	—8.4,20
1.30	6.1,40	—6.7,45	—9.8,15	—7.8,30
1.35	5.6,43	—6.6,85	—9.5,07	—7.4,66
1.40	5.2,84	—6.7,32	—9.3,74	—7.2,44
1.45	5.0,17	—6.8,56	—9.3,65	—7.1,19
1.50	4.8,15	—7.0,42	—9.4,49	—7.0,65
1.55	4.66,0	—7.27,8	—9.6,09	—7.06,3
1.60	4.54,2	—7.55,8	—9.8,30	—7.10,2
1.65	4.45,2	—7.87,8	—10.1,0	—7.17,5
1.70	4.38,4	—8.23,5	—10.4,2	—7.27,4

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0 $_3$429 signifies .000429. The notation 5370 $_4$ signifies 5,370,000.

Table 4.7 INFLUENCE COEFFICIENTS ($k = 1.3$ exactly)

M	F_A	F_f	F_{T_o} / $F_{w/2}$	F_Q / $-F_W$
1.75	4.33,4	−8.62,7	−10.79	−7.39,6
1.80	4.29,9	−9.05,3	−11.20	−7.53,9
1.85	4.27,6	−9.51,3	−11.65	−7.69,9
1.90	4.26,4	−10.01	−12.14	−7.87,4
1.95	4.26,1	−10.53	−12.67	−8.06,4
2.00	4.26,7	−11.09	−13.23	−8.26,7
2.05	4.27,9	−11.69	−13.83	−8.48,1
2.10	4.29,7	−12.32	−14.47	−8.70,8
2.15	4.32,2	−12.99	−15.15	−8.94,5
2.20	4.35,1	−13.69	−15.86	−9.19,1
2.25	4.385	−14.43	−16.62	−9.44,7
2.30	4.423	−15.21	−17.42	−9.71,3
2.35	4.465	−16.03	−18.26	−9.98,8
2.40	4.511	−16.89	−19.1,4	−10.27
2.45	4.560	−17.7,9	−20.0,7	−10.56
2.50	4.613	−18.7,4	−21.0,5	−10.86
2.55	4.669	−19.7,3	−22.0,7	−11.17
2.60	4.728	−20.7,7	−23.1,4	−11.49
2.65	4.789	−21.8,6	−24.2,5	−11.81
2.70	4.853	−22.9,9	−25.4,2	−12.14
2.75	4.919	−24.1,8	−26.6,4	−12.48
2.80	4.988	−25.4,2	−27.9,1	−12.83
2.85	5.059	−26.7,1	−29.2,4	−13.18
2.90	5.133	−28.0,6	−30.6,3	−13.54
2.95	5.209	−29.4,7	−32.0,7	−13.91
3.00	5.288	−30.93	−33.58	−14.29
3.50	6.179	−49.20	−52.29	−18.43
4.00	7.253	−75.44	−79.06	−23.25
4.50	8.495	−111.8	−116.1	−28.74
5.00	9.896	−160.8	−165.8	−34.90
6.00	13.17	−308.1	−314.7	−49.17
7.00	17.05	−543.0	−551.5	−66.05
8.00	21.54	−895.9	−906.7	−85.54
9.00	26.63	−1402.	−1415.	−107.6
10.00	32.32	−2101.	−2117.	−132.3
∞	∞	−∞	−∞	−∞

Table 4.7 INFLUENCE COEFFICIENTS (k = 1.3 exactly) (Concluded)

M	M^2	$1-M^2$	F_A	F_f	F_{T_0} / $F_w/2$	F_Q / $-F_w$
0	0	1.0000	0	0	0	0
.01	.0001	.9999	—.0 ₃2,00	.0 ₇,140	.0 ₃1,00	.0 ₃1,00
.02	.0004	.9996	—.0 ₃8,00	.0 ₆,224	.0 ₃4,00	.0 ₃4,00
.03	.0009	.9991	—.0018,0	.0 ₅1,14	.0 ₃9,02	.0 ₃9,01
.04	.0016	.9984	—.0032,1	.0 ₃3,59	.0016,1	.0016,1
.05	.0025	.9975	—.0050,1	.0 ₃8,78	.0025,1	.0025,2
.06	.0036	.9964	—.0072,3	.0 ₄1,82	.0036,3	.0036,3
.07	.0049	.9951	—.0098,6	.0 ₄3,38	.0049,6	.0049,6
.08	.0064	.9936	—.0129,0	.0 ₄5,78	.0065,1	.0065,0
.09	.0081	.9919	—.0163,6	.0 ₄9,28	.0082,7	.0082,6
.10	.0100	.9900	—.0202,4	.0 ₃14,2	.0102,6	.0102,4
.11	.0121	.9879	—.0245,5	.0 ₃20,8	.0124,9	.0124,6
.12	.0144	.9856	—.0293,0	.0 ₃29,5	.0149,4	.0149,0
.13	.0169	.9831	—.034,49	.0 ₃40,8	.0176,5	.0175,9
.14	.0196	.9804	—.040,14	.0 ₃55,1	.0206,2.	.0205,4
.15	.0225	.9775	—.046,24	.0 ₃72,8	.0238,5	.0237,4
.16	.0256	.9744	—.052,81	.0 ₃94,6	.0273,5	.0272,1
.17	.0289	.9711	—.059,86	.0012,1	.0311,4	.0309,6
.18	.0324	.9676	—.067,40	.0015,3	.0352,3	.0350,0
.19	.0361	.9639	—.075,44	.0019,1	.0396,3	.0393,4
.20	.0400	.9600	—.084,00	.0023,5	.0443,5	.0440,0
.21	.0441	.9559	—.093,08	.0028,7	.0494,1	.0489,8
.22	.0484	.9516	—.102,71	.0034,8	.0548,3	.0543,1
.23	.0529	.9471	—.112,89	.0041,8	.0606,2	.0599,9
.24	.0576	.9424	—.123,65	.0049,8	.0668,1	.0660,5
.25	.0625	.9375	—.135,00	.0059,0	.0734,1	.0725,0
.26	.0676	.9324	—.146,96	.0069,5	.0804,3	.0793,6
.27	.0729	.9271	—.159,55	.0081,4	.087,92	.086,66
.28	.0784	.9216	—.172,80	.0094,8	.095,89	.094,41
.29	.0841	.9159	—.186,73	.0109,9	.104,36	.102,63
.30	.0900	.9100	—.201,36	.0126,8	.113,36	.111,36
.31	.0961	.9039	—.216,72	.0145,8	.122,94	.120,62
.32	.1024	.8976	—.232,83	.0166,9	.133,10	.130,44
.33	.1089	.8911	—.249,73	.0190,4	.143,90	.140,84
.34	.1156	.8844	—.267,45	.0216,4	.155,37	.151,86
.35	.1225	.8775	—.286,03	.0245,3	.167,55	.163,54
.36	.1296	.8704	—.305,51	.0277,2	.180,47	.175,91
.37	.1369	.8631	—.325,92	.0312,3	.194,19	.189,02
.38	.1444	.8556	—.347,29	.0351,0	.208,75	.202,89
.39	.1521	.8479	—.369,68	.0393,6	.224,20	.217,58
.40	.1600	.8400	—.393,14	.044,03	.240,60	.233,14
.41	.1681	.8319	—.417,72	.049,15	.258,01	.249,62
.42	.1764	.8236	—.443,48	.054,76	.276,50	.267,08
.43	.1849	.8151	—.470,47	.060,89	.296,13	.285,56
.44	.1936	.8064	—.498,75	.067,59	.316,96	.305,15

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0 ₃429 signifies .000429. The notation 5370 ₄ signifies 5,370,000.

Table 4.8 INFLUENCE COEFFICIENTS (k = 1.4 exactly)

M	M^2	$1-M^2$	F_A	F_f	F_{To} / $F_w/2$	F_Q / $-F_w$
.45	.2025	.7975	−.528,40	.074,90	.339,10	.325,90
.46	.2116	.7884	−.559,50	.082,87	.362,62	.347,90
.47	.2209	.7791	−.592,12	.091,56	.387,62	.371,22
.48	.2304	.7696	−.626,34	.101,02	.414,19	.395,94
.49	.2401	.7599	−.662,27	.111,31	.442,44	.422,17
.50	.2500	.7500	−.700,00	.122,50	.472,50	.450,90
.51	.2601	.7399	−.739,64	.134,67	.504,49	.479,54
.52	.2704	.7296	−.781,31	.147,89	.538,55	.510,92
.53	.2809	.7191	−.825,14	.162,25	.574,82	.544,25
.54	.2916	.7084	−.871,27	.177,84	.613,48	.579,68
.55	.3025	.6975	−.919,86	.194,78	.654,71	.617,36
.56	.3136	.6864	−.971,07	.213,17	.698,70	.657,46
.57	.3249	.6751	−1.025,07	.244,13	.745,66	.700,17
.58	.3364	.6636	−1.082,08	.254,80	.795,84	.745,68
.59	.3481	.6519	−1.142,31	.278,34	.849,50	.794,21
.60	.3600	.6400	−1.206,0	.303,91	.906,91	.846,00
.61	.3721	.6279	−1.273,4	.331,69	.968,40	.901,33
.62	.3844	.6156	−1.344,9	.361,88	1.03,431	.960,48
.63	.3969	.6031	−1.42,07	.394,71	1.10,505	1.02,379
.64	.4096	.5904	−1.50,12	.430,42	1.18,102	1.09,160
.65	.4225	.5775	−1.58,68	.469,31	1.26,27	1.16,43
.66	.4356	.5644	−1.67,80	.511,67	1.35,07	1.24,25
.67	.4489	.5511	−1.77,53	.557,87	1.44,56	1.32,64
.68	.4624	.5376	−1.87,93	.60,830	1.54,80	1.41,69
.69	.4761	.5239	−1.99,06	.66,340	1.65,88	1.51,45
.70	.4900	.5100	−2.10,99	.72,369	1.77,87	1.61,98
.71	.5041	.4959	−2.23,80	.78,974	1.90,88	1.73,39
.72	.5184	.4816	−2.37,60	.86,222	2.05,02	1.85,76
.73	.5329	.4671	−2.52,49	.94,187	2.20,43	1.99,20
.74	.5476	4524	−2.68,60	1.02,960	2.37,26	2.13,84
.75	.5625	.4375	−2.86,07	1.12,64	2.55,68	2.29,82
.76	.5776	.4224	−3.05,08	1.23,35	2.75,89	2.47,32
.77	.5929	.4071	−3.25,82	1.35,22	2.98,13	2.66,53
.78	.6084	.3916	−3.48,53	1.48,43	3.22,70	2.87,70
.79	.6241	.3759	−3.73,50	1.63,17	3.49,92	3.11,09
.80	.6400	.3600	−4.01,07	1.79,68	3.80,21	3.37,07
.81	.6561	.3439	−4.31,63	1.98,24	4.14,05	3.66,02
.82	.6724	.3276	−4.65,70	2.19,20	4.5,205	3.98,46
.83	.6889	.3111	−5.0,390	2.43,00	4.9,494	4.3,501
.84	.7056	.2944	−5.4,699	2.70,17	5.4,367	4.7,643
.85	.7225	.2775	−5.9,596	3.0,141	5.9,939	5.2,371
.86	.7396	.2604	−6.5,207	3.3,759	6.6,363	5.7,812
.87	.7569	.2431	−7.1,697	3.7,987	7.3,836	6.4,128
.88	.7744	.2256	−7.9,286	4.2,979	8.2,622	7.1,541
.89	.7921	.2079	−8.8,272	4.8,944	9.3,080	8.0,351

Table 4.8 INFLUENCE COEFFICIENTS (k = 1.4 exactly) (Continued)

M	M^2	$1-M^2$	F_A	F_f	F_{To} / $F_w/2$	F_Q / $-F_W$
.90	.8100	.1900	−9.9,076	5.6,176	10.,571	9.0,976
.91	.8281	.1719	−11.2,304	6.5,099	12.,125	10.4,023
.92	.8464	.1536	−12.,8865	7.6,350	14.,078	12.,0401
.93	.8649	.1351	−15.,0186	9.,0927	16.,602	14.,1538
.94	.8836	.1164	−17.,8651	11.,0499	19.,982	16.,9815
.95	.9025	.0975	−21.,854	13.,806	24.,734	20.,952
.96	.9216	.0784	−27.,844	17.,962	3,1.884	26.,922
.97	.9409	.0591	−3,7.833	2,4.918	4,3.834	3,6.892
.98	.9604	.0396	−5,7.822	3,8.873	,67.784	5,6.861
.99	.9801	.0199	−11,7.811	8,0.827	1,39.732	1,16.831
1.00	1.0000	0	∞	∞	∞	∞
1.01	1.0201	−.0201	12,2.211	−8,7.267	−1,48.373	−1,23.231
1.02	1.0404	−.0404	6,2.222	−4,5.315	−,76.426	−6,3.263
1.03	1.0609	−.0609	4,2.233	−3,1.364	−5,2.480	−4,3.294
1.04	1.0816	−.0816	32.,244	−24.,413	−4,0.535	−33.,326
1.05	1.1025	−.1025	26.,256	−20.,263	−33.,391	−27.,358
1.06	1.1236	−.1236	22.,267	−17.,513	−28.,647	−23.,391
1.07	1.1449	−.1449	19.,421	−15.,565	−25.,275	−20.,566
1.08	1.1664	−.1664	17.,290	−14.1,17	−22.,762	−18.,456
1.09	1.1881	−.1881	15.,634	−13.0,03	−20.8,20	−16.,823
1.10	1.2100	−.2100	14.3,12	−12.1,228	−19.2,79	−15.5,23
1.11	1.2321	−.2321	13.2,33	−11.4,133	−18.0,30	−14.4,65
1.12	1.2544	−.2544	12.3,36	−10.8,318	−17.0,00	−13.5,90
1.13	1.2769	−.2769	11.5,78	−10.3,489	−16.1,38	−12.8,55
1.14	1.2996	−.2996	10.9,30	−9.9,437	−15.4,09	−12.2,30
1.15	1.3225	−.3225	10.3,708	−9.6,008	−14.7,86	−11.6,934
1.16	1.3456	−.3456	9.8,827	−9.30,87	−14.2,50	−11.2,283
1.17	1.3689	−.3689	9.4,534	−9.05,85	−13.7,85	−10.8,223
1.18	1.3924	−.3924	9.07,32	−8.84,34	−13.3,80	−10.46,56
1.19	1.4161	−.4161	8.73,43	−8.65,80	−13.02,5	−10.15,04
1.20	1.4400	−.4400	8.49,05	−8.49,80	−12.71,3	−9.87,06
1.21	1.4641	−.4641	8.15,70	−8.35,98	−12.43,8	−9.62,11
1.22	1.4884	−.4884	7.90,94	−8.24,06	−12.19,5	−9.39,78
1.23	1.5129	−.5129	7.68,44	−8.13,80	−11.98,0	−9.19,73
1.24	1.5376	−.5376	7.47,93	−8.05,01	−11.79,0	−9.01,69
1.25	1.5625	−.5625	7.29,17	−7.97,52	−11.62,1	−8.85,42
1.26	1.5876	−.5876	7.11,95	−7.91,19	−11.47,1	−8.70,71
1.27	1.6129	−.6129	6.96,10	−7.85,91	−11.33,9	−8.57,39
1.28	1.6384	−.6384	6.81,48	−7.81,57	−11.22,3	−8.45,32
1.29	1.6641	−.6641	6.67,96	−7.78,08	−11.12,1	−8.34,37
1.30	1.6900	−.6900	6.55,43	−7.75,37	−11.03,1	−8.24,43
1.31	1.7161	−.7161	6.43,79	−7.73,37	−10.95,3	−8.15,40
1.32	1.7424	−.7424	6.32,97	−7.72,02	−10.88,5	−8.07,21
1.33	1.7689	−.7689	6.22,89	−7.71,28	−10.82,7	−7.99,78
1.34	1.7956	−.7956	6.13,48	−7.71,10	−10.77,8	−7.93,04

Table 4.8 INFLUENCE COEFFICIENTS (k = 1.4 exactly) (Continued)

M	M^2	$1-M^2$	F_A	F_f	F_{T_o} / $F_w/2$	F_Q / $-F_w$
1.35	1.8225	−.8225	6.04,69	−7.71,44	−10.73,8	−7.86,94
1.36	1.8496	−.8496	5.96,47	−7.72,26	−10.70,5	−7.81,43
1.37	1.8769	−.8769	5.88,77	−7.735,4	−10.67,9	−7.76,46
1.38	1.9044	−.9044	5.815,5	−7.752,5	−10.66,0	−7.71,99
1.39	1.9321	−.9321	5.747,7	−7.773,6	−10.64,7	−7.67,98
1.40	1.9600	−.9600	5.684,0	−7.798,4	−10.64,0	−7.644,0
1.41	1.9881	−.9881	5.624,1	−7.826,9	−10.63,9	−7.612,2
1.42	2.0164	−1.0164	5.567,8	−7.858,9	−10.64,3	−7.584,2
1.43	2.0449	−1.0449	5.514,8	−7.894,1	−10.652	−7.559,7
1.44	2.0736	−1.0736	5.464,9	−7.932,4	−10.665	−7.538,5
1.45	2.1025	−1.1025	5.417,9	−7.973,8	−10.683	−7.520,4
1.46	2.1316	−1.1316	5.373,5	−8.018,0	−10.705	−7.505,1
1.47	2.1609	−1.1609	5.331,7	−8.065,0	−10.731	−7.492,6
1.48	2.1904	−1.1904	5.292,3	−8.114,6	−10.761	−7.482,7
1.49	2.2201	−1.2201	5.255,1	−8.166,8	−10.795	−7.475,2
1.50	2.2500	−1.2500	5.220,0	−8.221,5	−10.832	−7.470,0
1.51	2.2801	−1.2801	5.186,9	−8.278,6	−10.872	−7.467,0
1.52	2.3104	−1.3104	5.155,7	−8.338,1	−10.916	−7.466,1
1.53	2.3409	−1.3409	5.126,2	−8.399,9	−10.963	−7.467,1
1.54	2.3716	−1.3716	5.098,4	−8.464,0	−11.013	−7.470,0
1.55	2.4025	−1.4025	5.072,2	−8.530,2	−11.066	−7.474,8
1.56	2.4336	−1.4336	5.047,5	−8.598,6	−11.122	−7.481,2
1.57	2.4649	−1.4649	5.024,3	−8.669,1	−11.181	−7.489,2
1.58	2.4964	−1.4964	5.002,4	−8.741,6	−11.243	−7.498,8
1.59	2.5281	−1.5281	4.981,8	−8.816,2	−11.307	−7.509,9
1.60	2.5600	−1.5600	4.962,5	−8.892,7	−11.374	−7.522,5
1.61	2.5921	−1.5921	4.944,3	−8.971,2	−11.443	−7.536,4
1.62	2.6244	−1.6244	4.927,2	−9.051,7	−11.515	−7.551,7
1.63	2.6569	−1.6569	4.911,2	−9.134,1	−11.590	−7.568,2
1.64	2.6896	−1.6896	4.896,3	−9.218,4	−11.667	−7.585,9
1.65	2.7225	−1.7225	4.882,3	−9.304,5	−11.746	−7.604,8
1.66	2.7556	−1.7556	4.869,3	−9.392,5	−11.827	−7.624,8
1.67	2.7889	−1.7889	4.857,2	−9.482,3	−11.911	−7.646,0
1.68	2.8224	−1.8224	4.845,9	−9.573,9	−11.997	−7.668,3
1.69	2.8561	−1.8561	4.835,5	−9.667,4	−12.085	−7.691,6
1.70	2.8900	−1.8900	4.825,8	−9.762,7	−12.175	−7.715,8
1.71	2.9241	−1.9241	4.816,9	−9.859,8	−12.268	−7.741,9
1.72	2.9584	−1.9584	4.808,8	−9.958,6	−12.363	−7.767,2
1.73	2.9929	−1.9929	4.801,4	−10.059,2	−12.460	−7.794,3
1.74	3.0276	−2.0276	4.794,7	−10.161,5	−12.559	−7.882,3
1.75	3.0625	−2.0625	4.788,6	−10.266	−12.660	−7.851,1
1.76	3.0976	−2.0976	4.783,2	−10.372	−12.763	−7.880,8
1.77	3.1329	−2.1329	4.778,4	−10.479	−12.868	−7.911,3
1.78	3.1684	−2.1684	4.774,2	−10.588	−12.976	−7.942,6
1.79	3.2041	−2.2041	4.770,5	−10.699	−13.085	−7.974,6

Table 4.8 INFLUENCE COEFFICIENTS (k = 1.4 exactly) (Continued)

M	M^2	$1-M^2$	F_A	F_f	F_{T_o} $F_w/2$	F_Q $-F_W$
1.80	3.2400	−2.2400	4.767,4	−10.812	−13.196	−8.007,4
1.81	3.2761	−2.2761	4.764,8	−10.927	−13.310	−8.040,9
1.82	3.3124	−2.3124	4.762,8	−11.044	−13.425	−8.075,2
1.83	3.3489	−2.3489	4.761,3	−11.162	−13.542	−8.110,2
1.84	3.3856	−2.3856	4.760,3	−11.282	−13.662	−8.145,9
1.85	3.4225	−2.4225	4.759,7	−11.403	−13.783	−8.182,2
1.86	3.4596	−2.4596	4.7596	−11.526	−13.906	−8.219,2
1.87	3.4969	−2.4969	4.7599	−11.651	−14.032	−8.256,8
1.88	3.5344	−2.5344	4.7607	−11.778	−14.159	−8.295,1
1.89	3.5721	−2.5721	4.7619	−11.907	−14.288	−8.334,0
1.90	3.6100	−2.6100	4.7635	−12.038	−14.419	−8.373,5
1.91	3.6481	−2.6481	4.7655	−12.170	−14.552	−8.413,7
1.92	3.6864	−2.6864	4.7679	−12.304	−14.688	−8.454,4
1.93	3.7249	−2.7249	4.7707	−12.440	−14.825	−8.495,7
1.94	3.7636	−2.7636	4.7739	−12.577	−14.964	−8.537,5
1.95	3.8025	−2.8025	4.7774	−12.716	−15.105	−8.579,9
1.96	3.8416	−2.8416	4.7812	−12.857	−15.248	−8.622,8
1.97	3.8809	−2.8809	4.7854	−13.000	−15.393	−8.666,3
1.98	3.9204	−2.9204	4.7900	−13.145	−15.540	−8.710,4
1.99	3.9601	−2.9601	4.7948	−13.292	−15.689	−8.755,0
2.00	4.0000	−3.0000	4.8000	−13.440	−15.840	−8.800,0
2.01	4.0401	−3.0401	4.8055	−13.590	−15.993	−8.845,6
2.02	4.0804	−3.0804	4.8113	−13.742	−16.148	−8.891,7
2.03	4.1209	−3.1209	4.8174	−13.896	−16.305	−8.938,3
2.04	4.1616	−3.1616	4.8238	−14.052	−16.464	−8.985,4
2.05	4.2025	−3.2025	4.8305	−14.210	−16.625	−9.032,9
2.06	4.2436	−3.2436	4.8374	−14.369	−16.788	−9.081,0
2.07	4.2849	−3.2849	4.8446	−14.530	−16.953	−9.129,5
2.08	4.3264	−3.3264	4.8521	−14.694	−17.120	−9.178,5
2.09	4.3681	−3.3681	4.8598	−14.860	−17.290	−9.227,9
2.10	4.4100	−3.4100	4.8678	−15.027	−17.461	−9.2778
2.11	4.4521	−3.4521	4.8761	−15.196	−17.634	−9.3282
2.12	4.4944	−3.4944	4.8846	−15.367	−17.810	−9.3790
2.13	4.5369	−3.5369	4.8933	−15.540	−17.987	−9.4302
2.14	4.5796	−3.5796	4.9023	−15.715	−18.166	−9.4819
2.15	4.6225	−3.6225	4.9115	−15.892	−18.348	−9.5340
2.16	4.6656	−3.6656	4.9210	−16.072	−18.532	−9.5865
2.17	4.7089	−3.7089	4.9307	−16.253	−18.718	−9.6395
2.18	4.7524	−3.7524	4.9406	−16.426	−18.906	−9.6930
2.19	4.7961	−3.7961	4.9507	−16.621	−19.096	−9.7468
2.20	4.8400	−3.8400	4.9610	−16.808	−19.288	−9.8010
2.21	4.8841	−3.8841	4.9715	−16.997	−19.483	−9.8556
2.22	4.9284	−3.9284	4.9822	−17.188	−19.679	−9.9107
2.23	4.9729	−3.9729	4.9932	−17.382	−19.878	−9.9662
2.24	5.0176	−4.0176	5.0044	−17.578	−20.079	−10.0220

Table 4.8 INFLUENCE COEFFICIENTS (k = 1.4 exactly) (Continued)

M	M^2	$1-M^2$	F_A	F_f	F_{T_o} $F_w/2$	F_Q $-F_W$
2.25	5.0625	−4.0625	5.0158	−17.775	−20.282	−10.078
2.26	5.1076	−4.1076	5.0274	−17.974	−20.488	−10.135
2.27	5.1529	−4.1529	5.0391	−18.176	−20.696	−10.192
2.28	5.1984	−4.1984	5.0510	−18.380	−20.906	−10.249
2.29	5.2441	−4.2441	5.0631	−18.586	−21.118	−10.307
2.30	5.2900	−4.2900	5.0754	−18.794	−21.332	−10.365
2.31	5.3361	−4.3361	5.0879	−19.004	−21.549	−10.424
2.32	5.3824	−4.3824	5.1006	−19.217	−21.768	−10.483
2.33	5.4289	−4.4289	5.1135	−19.432	−21.989	−10.542
2.34	5.4756	−4.4756	5.1265	−19.649	−22.213	−10.602
2.35	5.5225	−4.5225	5.1397	−19.868	−22.439	−10.662
2.36	5.5696	−4.5696	5.1531	−20.090	−22.667	−10.723
2.37	5.6169	−4.6169	5.1666	−20.314	−22.897	−10.784
2.38	5.6644	−4.6644	5.1803	−20.540	−23.130	−10.845
2.39	5.7121	−4.7121	5.1942	−20.769	−23.366	−10.906
2.40	5.7600	−4.7600	5.2082	−21.000	−23.604	−10.968
2.41	5.8081	−4.8081	5.2224	−21.233	−23.844	−11.030
2.42	5.8564	−4.8564	5.2368	−21.468	−24.086	−11.093
2.43	5.9049	−4.9049	5.2513	−21.706	−24.331	−11.156
2.44	5.9536	−4.9536	5.2659	−21.946	−24.579	−11.220
2.45	6.0025	−5.0025	5.2807	−22.188	−24.829	−11.283
2.46	6.0516	−5.0516	5.2957	−22.433	−25.081	−11.347
2.47	6.1009	−5.1009	5.3109	−22.681	−25.336	−11.412
2.48	6.1504	−5.1504	5.3262	−22.931	−25.594	−11.477
2.49	6.2001	−5.2001	5.3416	−23.183	−25.854	−11.542
2.50	6.2500	−5.2500	5.3571	−23.438	−26.116	−11.607
2.51	6.3001	−5.3001	5.3728	−23.695	−26.381	−11.673
2.52	6.3504	−5.3504	5.3887	−23.955	−26.649	−11.739
2.53	6.4009	−5.4009	5.4047	−24.217	−26.919	−11.806
2.54	6.4516	−5.4516	5.4209	−24.481	−27.192	−11.873
2.55	6.5025	−5.5025	5.4372	−24.748	−27.467	−11.940
2.56	6.5536	−5.5536	5.4536	−25.018	−27.745	−12.007
2.57	6.6049	−5.6049	5.4702	−25.291	−28.026	−12.075
2.58	6.6564	−5.6564	5.4869	−25.566	−28.309	−12.143
2.59	6.7081	−5.7081	5.5037	−25.844	−28.595	−12.212
2.60	6.7600	−5.7600	5.5207	−26.124	−28.884	−12.281
2.61	6.8121	−5.8121	5.5378	−26.407	−29.176	−12.350
2.62	6.8644	−5.8644	5.5550	−26.692	−29.470	−12.419
2.63	6.9169	−5.9169	5.5724	−26.980	−29.767	−12.489
2.64	6.9696	−5.9696	5.5899	−27.271	−30.067	−12.560
2.65	7.0225	−6.0225	5.6075	−27.565	−30.369	−12.630
2.66	7.0756	−6.0756	5.6253	−27.862	−30.674	−12.701
2.67	7.1289	−6.1289	5.6432	−28.161	−30.982	−12.772
2.68	7.1824	−6.1824	5.6612	−28.462	−31.293	−12.843
2.69	7.2361	−6.2361	5.6793	−28.767	−31.607	−12.915

Table 4.8 INFLUENCE COEFFICIENTS (k = 1.4 exactly) (Continued)

M	M^2	$1-M^2$	F_A	F_f	F_{T_o} $F_w/2$	F_Q $-F_w$
2.70	7.2900	−6.2900	5.6975	−29.075	−31.924	−12.987
2.71	7.3441	−6.3441	5.7159	−29.385	−32.244	−13.060
2.72	7.3984	−6.3984	5.7344	−29.698	−32.566	−13.133
2.73	7.4529	−6.4529	5.7530	−30.014	−32.891	−13.206
2.74	7.5076	−6.5076	5.7718	−30.333	−33.219	−13.279
2.75	7.5625	−6.5625	5.7907	−30.655	−33.550	−13.353
2.76	7.6176	−6.6176	5.8097	−30.980	−33.884	−13.427
2.77	7.6729	−6.6729	5.8288	−31.307	−34.221	−13.502
2.78	7.7284	−6.7284	5.8480	−31.637	−34.561	−13.576
2.79	7.7841	−6.7841	5.8674	−31.971	−34.904	−13.651
2.80	7.8400	−6.8400	5.8869	−32.308	−35.250	−13.727
2.81	7.8961	−6.8961	5.9065	−32.647	−35.599	−13.803
2.82	7.9524	−6.9524	5.9262	−32.989	−35.952	−13.879
2.83	8.0089	−7.0089	5.9460	−33.334	−36.308	−13.955
2.84	8.0656	−7.0656	5.9659	−33.683	−36.667	−14.031
2.85	8.1225	−7.1225	5.9859	−34.035	−37.028	−14.108
2.86	8.1796	−7.1796	6.0061	−34.389	−37.392	−14.185
2.87	8.2369	−7.2369	6.0264	−34.747	−37.760	−14.263
2.88	8.2944	−7.2944	6.0468	−35.108	−38.131	−14.341
2.89	8.3521	−7.3521	6.0673	−35.472	−38.506	−14.419
2.90	8.4100	−7.4100	6.0879	−35.839	−38.884	−14.498
2.91	8.4681	−7.4681	6.1086	−36.210	−39.265	−14.577
2.92	8.5264	−7.5264	6.1294	−36.583	−39.649	−14.656
2.93	8.5849	−7.5849	6.1504	−36.960	−40.036	−14.735
2.94	8.6436	−7.6436	6.1715	−37.340	−40.426	−14.815
2.95	8.7025	−7.7025	6.1926	−37.723	−40.820	−14.895
2.96	8.7616	−7.7616	6.2138	−38.110	−41.217	−14.975
2.97	8.8209	−7.8209	6.2352	−38.500	−41.618	−15.056
2.98	8.8804	−7.8804	6.2567	−38.893	−42.022	−15 137
2.99	8.9401	−7.9401	6.2783	−39.290	−42.429	−15.218
3.00	9.00	−8.00	6.3000	−39.690	−42.840	−15.300
3.50	12.25	−11.25	7.5133	−64.427	−68.184	−19.763
4.00	16.00	−15.00	8.9600	−100.352	−104.832	−24.960
4.50	20.25	−19.25	10.6247	−150.605	−155.918	−30.875
5.00	25.00	−24.00	12.5000	−218.750	−225.000	−37.500
6.00	36.00	−35.00	16.869	−425.09	−433.52	−52.869
7.00	49.00	−48.00	22.050	−756.32	−767.34	−71.050
8.00	64.00	−63.00	28.038	−1256.11	−1270.13	−92.038
9.00	81.00	−80.00	34.830	−1974.86	−1992.28	−115.830
10.00	100.00	−99.00	42.424	−2969.69	−2990.91	−142.424
∞	∞	−∞	∞	−∞	−∞	−∞

Table 4.8 INFLUENCE COEFFICIENTS (k = 1.4 exactly) (Concluded)

M	F_A	F_f	F_{T_0} / $F_w/2$,	F_Q / $-F_w$
0	0	0	0	0
.05	−.00,500	.0 ₄104	.00,251	.00,252
.10	−.02,027	.0 ₃169	.01,030	.01,027
.15	−.04,638	.0 ₃872	.02,407	.02,388
.20	−.08,445	.002,82	.04,498	.04,445
.25	−.13,61	.007,10	.07,517	.07,363
.30	−.20,38	.01,531	.11,72	.11,38
.35	−.29,07	.02,973	.17,51	.16,82
.40	−.40,14	.05,362	.25,43	.24,14
.45	−.54,23	.09,170	.36,28	.33,98
.50	−.7,225	.15,08	.5,121	.4,725
.55	−.9,553	.2,413	.7,189	.6,528
.60	−1.2,61	.3,790	1.0,093	.9,007
.65	−1.6,70	.5,893	1.4,24	1.2,48
.70	−2.2,37	.9,153	2.0,34	1.7,47
.75	−3.0,56	1.4,35	2.,963	2.4,93
.80	−4.,318	2.,307	4.,466	3.,678
.85	−6.,468	3.,902	7.,136	5.,745
.90	−1,0.84	,7.332	1,2.75	1,0.03
.95	−2,1.11	1,8.17	3,0.22	2,3.21
1.00	∞	∞	∞	∞
1.05	2,9.46	−2,7.12	−4,1.85	−3,0.56
1.10	1,6.19	−1,6.36	−2,4.46	−1,7.40
1.15	11.,84	−13.,07	−18.,99	−13.,16
1.20	9.,703	−11.,67	−16.,52	−11.,14
1.25	8.4,64	−11.0,4	−15.,27	−10.,03
1.30	7.6,72	−10.8,3	−14.6,6	−9.3,62
1.35	7.1,37	−10.8,6	−14.4,3	−8.9,60
1.40	6.7,64	−11.0,7	−14.4,5	−8.7,24
1.45	6.5,00	−11.4,1	−14.6,6	−8.6,03
1.50	6.3,14	−11.8,6	−15.0,2	−8.564
1.55	6.1,83	−12.4,0	−15.5,0	−8.586
1.60	6.09,7	−13.0,3	−16.0,8	−8.65,7
1.65	6.04,4	−13.7,4	−16.7,6	−8.76,7
1.70	6.01,9	−14.5,2	−17.5,3	−8.90,9

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0 ₃429 signifies .000429. The notation 5370 ₆ signifies 5,370,000.

Table 4.9 INFLUENCE COEFFICIENTS (k = 1.67 exactly)

M	F_A	F_f	F_{T_o} $F_w/2$	F_Q $-F_W$
1.75	6.01,6	−15.3,8	−18.3,9	−9.07,9
1.80	6.03,3	−16.3,2	−19.3,4	−9.27,3
1.85	6.06,5	−17.3,3	−20.3,7	−9.48,8
1.90	6.11,1	−18.4,2	−21.4,8	−9.72,2
1.95	6.17,0	−19.5,9	−22.6,8	−9.97,3
2.00	6.24,0	−20.8,4	−23.9,7	−10.24
2.05	6.32,0	−22.1,8	−25.3,4	−10.52
2.10	6.40,8	−23.6,0	−26.8,0	−10.82
2.15	6.50,4	−25.1,1	−28.3,6	−11.13
2.20	6.60,8	−26.7,1	−30.0,1	−11.45
2.25	6.71,9	−28.4,0	−31.7,6	−11,78
2.30	6.83,6	−30.2,0	−33.6,2	−12.12
2.35	6.96,0	−32.1,0	−35.5,8	−12.48
2.40	7.09,0	−34.1,0	−37.6,5	−12.85
2.45	7.22,5	−36.2,1	−39.8,3	−13.23
2.50	7.36,6	−38.4,4	−42.1,2	−13.62
2.55	7.51,2	−40.7,9	−44.5,4	−14.01
2.60	7.66,3	−43.2,6	−47.0,8	−14.42
2.65	7.81,9	−45.8,5	−49.7,5	−14.84
2.70	7.97,9	−48.5,7	−52.5,6	−15.27
2.75	8.144	−51.4,2	−55.5,0	−15.71
2.80	8.313	−54.4,2	−58.5,8	−16.16
2.85	8.487	−57.5,6	−61.8,0	−16.61
2.90	8.665	−60.8,5	−65.1,8	−17.07
2.95	8.847	−64.2,9	−68.7,1	−17.55
3.00	9.034	−67.89	−72.41	−18.03
3.50	11.11	−113.7	−119.2	−23.36
4.00	13.57	−181.3	−188.0	−29.57
4.50	16.38	−276.9	−285.1	−36.63
5.00	19.53	−407.7	−417.5	−44.53
6.00	26.87	−807.6	−821.0	−62.87
7.00	35.56	−1455.	−1472.	−84.56
8.00	45.59	−2436.	−2459.	−109.6
9.00	56.97	−3853.	−3882.	−137.8
10.00	69.70	−5820.	−5854.	−169.7
∞	∞	−∞	−∞	−∞

Table 4.9 INFLUENCE COEFFICIENTS (k = 1.67 exactly) (Concluded)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
0	0	1.000,0	1.000,0	1.000	∞	∞	∞
.05	.05	.998,9	.998,9	1.000	12.,146	10.,025	12.,136
.10	.10	.995,1	.995,1	1.000	6.,096	5.,050	6.,065
.15	.15	.988,8	.988,8	1.000	4.,089	3.,408	4.,044
.20	.20	.980,2	.980,2	1.000	3.0,94	2.6,00	3.0,33
.25	.25	.969,3	.969,3	1.000	2.5,03	2.1,25	2.4,26
.30	.30	.956,1	.956,1	1.000	2.1,15	1.8,17	2.0,22
.35	.35	.940,6	.940,6	1.000	1.8,42	1.6,04	1.7,33
.40	.40	.923,1	.923,1	1.000	1.6,43	1.45,0	1.5,16
.45	.45	.903,7	.903,7	1.000	1.49,1	1.33,6	1.34,8
.50	.50	.882,5	.882,5	1.000	1.37,5	1.25,0	1.21,31
.55	.55	.859,7	.859,7	1.000	1.28,3	1.18,4	1.10,28
.60	.60	.835,3	.835,3	1.000	1.21,0	1.13,3	1.01,09
.65	.65	.809,6	.809,6	1.000	1.15,3	1.09,42	.93,31
.70	.70	.782,7	.782,7	1.000	1.10,7	1.06,43	.86,65
.75	.75	.754,9	.754,9	1.000	1.07,14	1.04,17	.80,87
.80	.80	.726,2	.726,2	1.000	1.04,41	1.02,50	.75,82
.85	.85	.6968	.6968	1.000	1.02,40	1.013,2	.71,36
.90	.90	.6670	.6670	1.000	1.01,04	1.005,6	.673,9
.95	.95	.6369	.6369	1.000	1.00,25	1.001,3	.638,5
1.00	1.00	.6065	.6065	1.000	1.00,00	1.000,0	.606,5
1.05	1.05	.5762	.5762	1.000	1.00,25	1.001,2	.577,7
1.10	1.10	.5461	.5461	1.000	1.00,97	1.004,5	.551,4
1.15	1.15	.5163	.5163	1.000	1.02,17	1.009,8	.527,4
1.20	1.20	.486,8	.486,8	1.000	1.03,84	1.016,7	.505,4
1.25	1.25	.457,8	.457,8	1.000	1.05,98	1.025,0	.485,2
1.30	1.30	.429,5	.429,5	1.000	1.08,61	1.034,6	.466,6
1.35	1.35	.402,0	.402,0	1.000	1.11,7	1.045,3	.449,3
1.40	1.40	.375,3	.375,3	1.000	1.15,4	1.057,1	.433,2
1.45	1.45	.349,5	.349,5	1.000	1.19,7	1.069,8	.418,3
1.50	1.50	.324,7	.324,7	1.000	1.24,5	1.083,3	.404,4
1.55	1.55	.300,8	.300,8	1.000	1.30,0	1.097,6	.391,3
1.60	1.60	.278,0	.278,0	1.000	1.36,3	1.113	.379,1
1.65	1.65	.256,3	.256,3	1.000	1.43,4	1.128	.367,6
1.70	1.70	.235,7	.235,7	1.000	1.51,4	1.144	.356,8

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_4429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.10 ISENTROPIC FLOW (Perfect Gas, k = 1.0 exactly)

M	M*	p/p₀	ρ/ρ₀	T/T₀	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_0}$
1.75	1.75	.216,3	.216,3	1.000	1.60,3	1.161	.346,6
1.80	1.80	.197,9	.197,9	1.000	1.70,3	1.178	.337,0
1.85	1.85	.180,6	.180,6	1.000	1.81,5	1.195	.327,9
1.90	1.90	.164,5	.164,5	1.000	1.94,1	1.213	.319,2
1.95	1.95	.149,4	.149,4	1.000	2.08,2	1.231	.311,0
2.00	2.00	.135,3	.135,3	1.000	2.24,1	1.250	.3033
2.05	2.05	.122,3	.122,3	1.000	2.41,9	1.269	.2959
2.10	2.10	.110,2	.110,2	1.000	2.62,0	1.288	.2888
2.15	2.15	.099,14	.099,14	1.000	2.84,6	1.307	.2821
2.20	2.20	.088,92	.088,92	1.000	3.10,0	1.327	.2757
2.25	2.25	.079,56	.079,56	1.000	3.38,8	1.347	.2696
2.30	2.30	.071,00	.071,00	1.000	3.71,4	1.367	.2637
2.35	2.35	.063,21	.063,21	1.000	4.0,83	1.387	.2581
2.40	2.40	.056,14	.056,14	1.000	4.5,02	1.408	.2527
2.45	2.45	.049,73	.049,73	1.000	4.9,79	1.429	.2475
2.50	2.50	.043,94	.043,94	1.000	5.5,22	1.450	.2426
2.55	2.55	.038,73	.038,73	1.000	6.1,42	1.471	.2379
2.60	2.60	.034,05	.034,05	1.000	6.8,52	1.492	.2333
2.65	2.65	.029,86	.029,86	1.000	7.6,65	1.513	.2289
2.70	2.70	.0261,2	.0261,2	1.000	8.6,00	1.535	.2247
2.75	2.75	.0227,9	.0227,9	1.000	9.6,76	1.557	.2206
2.80	2.80	.0198,4	.0198,4	1.000	10.9,2	1.579	.2166
2.85	2.85	.0172,3	.0172,3	1.000	12.3,5	1.600	.2128
2.90	2.90	.0149,2	.0149,2	1.000	14.0,2	1.622	.2092
2.95	2.95	.0128,9	.0128,9	1.000	15.9,5	1.644	.2056
3.00	3.00	.01111	.01111	1.000	18.20	1.667	.2022
3.50	3.50	.00219	.00219	1.000	79.22	1.893	.1733
4.00	4.00	$.0_{3}335$	$.0_{3}335$	1.000	452.0	2.125	.1516
4.50	4.50	$.0_{4}401$	$.0_{4}401$	1.000	3364	2.361	.1348
5.00	5.00	$.0_{3}373$	$.0_{3}373$	1.000	32550	2.600	.1213
6.00	6.00	$.0_{7}152$	$.0_{7}152$	1.000	6640_{4}	3.083	.1010
7.00	7.00	$.0_{10}229$	$.0_{10}229$	1.000	3780_{7}	3.571	.08665
8.00	8.00	$.0_{13}127$	$.0_{13}127$	1.000	5990_{10}	4.062	.07578
9.00	9.00	$.0_{17}258$	$.0_{17}258$	1.000	2620_{14}	4.556	.06741
10.00	10.00	$.0_{21}193$	$.0_{21}193$	1.000	3140_{18}	5.050	.06065
∞	∞	0	0	1.000	∞	∞	0

Table 4.10 ISENTROPIC FLOW (Perfect Gas, k = 1.0 exactly) (Concluded)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
0	0	1.000,0	1.000,0	1.0000	∞	∞	∞
.05	.05123	.998,6	.998,8	.9999	11.,999	9.,785	11.,982
.10	.1024	.994,5	.995,0	.9995	6.,023	4.,931	5.,990
.15	.1536	.987,7	.988,8	.9989	4.,042	3.,332	3.,992
.20	.2047	.978,3	.980,2	.9980	3.0,59	2.5,45	2.9,93
.25	.2558	.966,3	.969,3	.9969	2.4,76	2.0,83	2.3,93
.30	.3067	.951,8	.956,1	.9955	2.0,94	1.7,84	1.9,93
.35	.3575	.935,0	.940,8	.9939	1.8,25	1.5,77	1.7,07
.40	.4082	.916,1	.923,4	.9921	1.6,28	1.42,9	1.4,92
.45	.4588	.895,1	.904,2	.9900	1.48,0	1.31,9	1.32,5
.50	.5092	.872,3	.883,2	.9877	1.36,5	1.23,7	1.19,08
.55	.5594	.847,8	.860,6	.9851	1.27,5	1.17,4	1.08,12
.60	.6094	.821,8	.836,6	.9823	1.20,4	1.12,5	.98,97
.65	.6592	.794,5	.811,3	.9793	1.14,8	1.08,82	.91,21
.70	.7087	.766,2	.785,0	.9761	1.10,4	1.05,99	.84,56
.75	.7579	.737,0	.757,8	.9727	1.06,89	1.03,87	.78,78
.80	.8069	.7071	.729,8	.9690	1.04,25	1.02,31	.73,72
.85	.8557	.6768	.7013	.9651	1.02,31	1.012,2	.69,24
.90	.9041	.6462	.6724	.9610	1.01,00	1.005,1	.652,6
.95	.9522	.6154	.6431	.9568	1.00,24	1.001,2	.616,9
1.00	1.0000	.5847	.6139	.9524	1.00,00	1.000,0	.584,7
1.05	1.0474	.5542	.5847	.9478	1.00,23	1.001,1	.555,5
1.10	1.0945	.524,0	.5557	.9430	1.009,2	1.004,1	.528,9
1.15	1.141	.494,4	.5271	.9380	1.020,4	1.008,7	.504,6
1.20	1.188	.465,4	.498,9	.9328	1.036,0	1.014,8	.482,2
1.25	1.234	.437,1	.471,3	.9275	1.055,9	1.022,1	.461,6
1.30	1.279	.409,7	.444,3	.9221	1.08,01	1.030,5	.442,5
1.35	1.324	.383,2	.418,0	.9165	1.10,88	1.039,7	.424,9
1.40	1.369	.357,6	.392,6	.9107	1.14,21	1.049,7	.408,4
1.45	1.413	.333,0	.368,0	.9048	1.18,02	1.060,4	.393,0
1.50	1.457	.309,5	.344,3	.8989	1.22,3	1.071,7	.378,7
1.55	1.501	.287,1	.321,6	.8928	1.27,2	1.0836	.365,2
1.60	1.544	.265,8	.299,9	.8865	1.32,6	1.0958	.352,6
1.65	1.586	.245,6	.279,1	.8801	1.38,7	1.108	.340,7
1.70	1.628	.226,6	.259,3	.8737	1.45,4	1.121	.329,4

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_4429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.11 ISENTROPIC FLOW (Perfect Gas, k = 1.1 exactly)

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M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
1.75	1.670	.208,6	.240,6	.8672	1.52,8	1.134	.318,8
1.80	1.711	.191,7	.222,8	.8606	1.61,0	1.147	.308,8
1.85	1.752	.175,9	.206,0	.8539	1.70,1	1.161	.299,3
1.90	1.792	.161,2	.190,2	.8471	1.80,1	1.175	.290,2
1.95	1.832	.147,4	.175,4	.8402	1.91,1	1.189	.281,6
2.00	1.871	.134,6	.161,5	.8333	2.03,2	1.203	.2735
2.05	1.910	.122,7	.148,5	.8264	2.16,5	1.217	.2657
2.10	1.948	.111,7	.136,3	.8194	2.31,2	1.231	.2582
2.15	1.986	.101,5	.125,0	.8123	2.47,3	1.245	.2511
2.20	2.023	.092,18	.114,5	.8052	2.65,1	1.259	.2444
2.25	2.060	.083,57	.104,73	.7980	2.84,6	1.273	.2379
2.30	2.096	.075,66	.095,68	.7908	3.06,1	1.286	.2317
2.35	2.132	.068,42	.087,31	.7836	3.29,9	1.300	.2257
2.40	2.167	.061,79	.079,59	.7764	3.56,0	1.314	.2200
2.45	2.202	.055,74	.072,47	.7692	3.84,8	1.328	.2145
2.50	2.236	.050,22	.065,92	.7619	4.16,5	1.342	.2092
2.55	2.270	.045,20	.059,90	.7546	4.51,5	1.356	.2041
2.60	2.303	.0406,4	.054,38	.7473	4.90,2	1.369	.1992
2.65	2.336	.0365,0	.0493,2	.7401	5.3,28	1.382	.1945
2.70	2.368	.0327,6	.0447,0	.7329	5.7,99	1.395	.1900
2.75	2.400	.0293,6	.0404,7	.7256	6.3,20	1.408	.1856
2.80	2.432	.0263,0	.0366,1	.7184	6.8,95	1.422	.1814
2.85	2.463	.0235,4	.0331,0	.7112	7.5,32	1.435	.1773
2.90	2.493	.0210,4	.0298,9	.7040	8.2,37	1 448	.1733
2.95	2.523	.0188,0	.0269,8	.6968	9.0,16	1.460	.1695
3.00	2.553	.01679	.02434	.6897	9.880	1.472	.1658
3.50	2.824	.00522	.00841	.6202	25.83	1.589	.1348
4.00	3.055	.00156	.00280	.5556	71.74	1.691	.1116
4.50	3.250	$.0_3456$	$.0_3918$	.4969	205.7	1.779	.09382
5.00	3.416	$.0_3134$	$.0_3301$	.4444	597.3	1.854	.08004
6.00	3.674	$.0_4121$	$.0_4338$	.3571	4911	1.973	.05942
7.00	3.862	$.0_5121$	$.0_5419$	.2899	37920	2.060	.04588
8.00	4.000	$.0_6139$	$.0_6585$	.2381	2630_3	2.125	.03653
9.00	4.104	$.0_7184$	$.0_7927$	.1980	1610_4	2.174	.02971
10.00	4.183	$.0_8275$	$.0_7165$ •	.1667	8890_4	2.211	.02444
∞	4.583	0	0	0	∞	2.400	0

Table 4.11 ISENTROPIC FLOW (Perfect Gas, k = 1.1 exactly) (Concluded)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
0	0	1.000,0	1.000,0	1.000,0	∞	∞	∞
.05	.05243	.998,5	.998,8	.999,8	11.,857	9.,562	11.,839
.10	.1048	.994,0	.995,0	.999,1	5.,953	4.,822	5.,917
.15	.1571	.986,6	.988,8	.997,8	3.,996	3.,260	3.,942
.20	.2093	.976,3	.980,2	.996,0	3.0,26	2.4,93	2.9,54
.25	.2614	.963,3	.969,3	.993,8	2.4,51	2.0,44	2.3,61
.30	.3133	.947,7	.956,2	.991,1	2.0,73	1.7,53	1.9,65
.35	.3649	.929,6	.940,9	.987,9	1.8,09	1.5,53	1.6,81
.40	.4162	.909,2	.923,6	.984,3	1.6,15	1.40,9	1.4,68
.45	.4672	.886,7	.904,6	.980,2	1.46,9	1.30,4	1.30,2
.50	.5179	.862,3	.883,9	.9756	1.35,6	1.22,4	1.17,0
.55	.5683	.836,3	.861,6	.9706	1.26,8	1.16,4	1.06,06
.60	.618,3	.808,8	.837,9	.9653	1.19,9	1.11,8	.96,94
.65	.667,8	.780,1	.813,1	.9595	1.14,4	1.08,26	.89,22
.70	.716,8	.750,5	.787,3	.9533	1.10,0	1.05,59	.82,58
.75	.765,4	.720,1	.760,6	.9467	1.06,66	1.03,60	.76,81
.80	.813,4	.6892	.733,3	.9398	1.04,10	1.021,4	.71,74
.85	.860,9	.6580	.7055	.9326	1.02,22	1.011,2	.67,26
.90	.907,8	.6267	.6774	.9251	1.00,96	1.004,7	.632,7
.95	.954,2	.5954	.6492	.9172	1.00,23	1.001,1	.596,8
1.00	1.000,0	.564,4	.6209	.9091	1.00,00	1.000,0	.564,4
1.05	1.045,1	.533,9	.5928	.9007	1.002,2	1.001,0	.535,1
1.10	1.089,6	.503,9	.5649	.8921	1.008,7	1.003,7	.508,3
1.15	1.134	.474,6	.537,4	.8832	1.019,4	1.007,9	.483,8
1.20	1.177	.446,1	.510,4	.8741	1.034,0	1.013,3	.461,3
1.25	1.219	.418,5	.483,9	.8648	1.052,5	1.019,7	.440,5
1.30	1.261	.391,8	.458,1	.8554	1.074,9	1.027,0	.421,2
1.35	1.302	.366,2	.433,0	.8458	1.101	1.035,0	.403,3
1.40	1.342	.341,7	.408,7	.8361	1.131	1.043,7	.386,7
1.45	1.382	.318,2	.385,2	.8263	1.166	1.0529	.371,2
1.50	1.421	.295,9	.362,5	.8163	1.20,5	1.0625	.356,6
1.55	1.459	.274,7	.340,7	.8063	1.24,8	1.0724	.343,0
1.60	1.497	.254,7	.319,9	.7962	1.29,6	1.0826	.330,2
1.65	1.534	.235,8	.300,0	.7860	1.34,9	1.0930	.318,1
1.70	1.570	.218,0	.281,0	.7758	1.40,7	1.1036	.306,7

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0 ,429 signifies .000429. The notation 5370 , signifies 5,370,000.

Table 4.12 ISENTROPIC FLOW (Perfect Gas, k = 1.2 exactly)

M	M*	p/p₀	ρ/ρ₀	T/T₀	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_0}$
1.75	1.606	.201,3	.262,9	.7656	1.47,0	1.114	.296,0
1.80	1.641	.185,6	.245,8	.7553	1.53,9	1.125	.285,8
1.85	1.675	.171,0	.229,5	.7450	1.61,5	1.136	.276,2
1.90	1.708	.157,3	.214,1	.7347	1.69,8	1.147	.267,1
1.95	1.741	.144,6	.199,6	.7245	1.78,7	1.158	.258,4
2.00	1.773	.132,8	.185.9	.7143	1.88,4	1.168	.2502
2.05	1.804	.121,8	.173,0	.7041	1.98,9	1.179	.2423
2.10	1.835	.111,7	.160,9	.6940	2.10,3	1.190	.2348
2.15	1.865	.102,3	.149,6	.6839	2.22,6	1.201	.2277
2.20	1.894	.093,62	.139,0	.6739	2.35,9	1.212	.2209
2.25	1.923	.085,63	.129,0	.6639	2.50,4	1.222	.2144
2.30	1.951	.078,26	.119,7	.6540	2.66,0	1.232	.2082
2.35	1.978	.071,48	.111,0	.6442	2.82,9	1.242	.2022
2.40	2.005	.065,26	.102,9	.6345	3.01,1	1.252	.1965
2.45	2.031	.059,55	.095,29	.6249	3.20,8	1.262	.1910
2.50	2.057	.0543,1	.088,25	.6154	3.42,1	1.272	.1858
2.55	2.082	.0495,1	.081,70	.6060	3.65,0	1.282	.1808
2.60	2.106	.0451,2	.0756,2	.5967	3.89,8	1.291	.1759
2.65	2.130	.0411,0	.0699,7	.5875	4.16,6	1.300	.1712
2.70	2.154	.0374,3	.0647,2	.5784	4.45,5	1.309	.1667
2.75	2.177	.0340,8	.0598,5	.5694	4.76,7	1.318	.1624
2.80	2.199	.0310,2	.0553,4	.5605	5.10,3	1.327	.1583
2.85	2.220	.0282,3	.0511,6	.5518	5.46,6	1.335	.1543
2.90	2.241	.0256,9	.0472,9	.5432	5.85,8	1.343	.1505
2.95	2.262	.0233,7	.0437,0	.5347	6.28,0	1.352	.1467
3.00	2.283	.02126	.04039	.5263	6.735	1.360	.1432
3.50	2.461	.00824	.01834	.4494	13.76	1.434	.1134
4.00	2.602	.00324	.00842	.3846	28.35	1.493	.09178
4.50	2.714	.00130	.00395	.3306	57.96	1.541	.07563
5.00	2.803	$.0_3544$	.00190	.2857	116.3	1.580	.06327
6.00	2.934	$.0_3106$	$.0_3486$	.2174	434.7	1.637	.04608
7.00	3.023	$.0_4237$	$.0_3140$	.1695	1458	1.677	.03456
8.00	3.084	$.0_5609$	$.0_4451$	.1351	4451	1.704	.02711
9.00	3.129	$.0_5176$	$.0_4160$	.1099	12411	1.724	.02184
10.00	3.162	$.0_6564$	$.0_5621$	.09091	31659	1.739	.01789
∞	3.317	0	0	0	∞	1.809	0

Table 4.12 ISENTROPIC FLOW (Perfect Gas, k = 1.2 exactly) (Concluded)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A^*	F/F^*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
0	0	1.000,0	1.000,0	1.000,0	∞	∞	∞
.05	.05361	.998,4	.998,8	.999,6	11.,721	9.,354	11.,702
.10	.1072	.993,6	.995,1	.998,5	5.,885	4.,720	5.,848
.15	.1606	.985,5	.988,9	.996,6	3.,952	3.,194	3.,895
.20	.2138	.974,4	.980,3	.994,0	2.9,94	2.4,45	2.9,17
.25	.2668	.960,3	.969,4	.990,7	2.4,26	2.0,07	2.3,30
.30	.3195	.943,5	.956,3	.986,7	2.0,54	1.7,24	1.9,38
.35	.3719	.924,1	.941,1	.982,0	1.7,93	1.5,30	1.6,57
.40	.423,9	.902,3	.924,0	.976,6	1.6,02	1.39,1	1.4,46
.45	.475,4	.878,4	.905,1	.970,5	1.45,9	1.28,9	1.28,1
.50	.526,4	.852,6	.884,5	.963,8	1.34,8	1.21,3	1.14,91
.55	.576,9	.825,1	.862,5	.956,6	1.26,1	1.15,5	1.04,07
.60	.626,7	.796,2	.839,2	.948,8	1.19,3	1.11,1	.95,01
.65	.675,9	.766,2	.814,8	.940,4	1.13,9	1.07,77	.87,31
.70	.724,5	.735,4	.789,5	.931,5	1.09,72	1.05,24	.80,69
.75	.772,4	.7040	.763,4	.922,2	1.06,44	1.03,36	.74,93
.80	.819,5	.6723	.7367	.9124	1.03,95	1.019,9	.69,88
.85	.865,8	.6403	.7096	.9022	1.02,14	1.010,4	.65,40
.90	.911,3	.6084	.6823	.8917	1.00,92	1.004,3	.614,0
.95	.956,1	.576,8	.6549	.8808	1.00,22	1.001,0	.578,1
1.00	1.000,0	.545,7	.6276	.8696	1.000,0	1.000,0	.545,7
1.05	1.043,0	.515,2	.6004	.8581	1.002,1	1.000,9	.516,3
1.10	1.085,2	.485,4	.5735	.8464	1.008,3	1.003,4	.489,5
1.15	1.127	.456,5	.547,0	.8345	1.018,3	1.007,2	.464,9
1.20	1.167	.428,5	.521,0	.8224	1.032,1	1.012,0	.442,3
1.25	1.206	.401,5	.495,6	.8102	1.049,5	1.017,7	.421,4
1.30	1.245	.375,6	.470,9	.7978	1.070,4	1.024,1	.402,1
1.35	1.283	.350,9	.446,8	.7853	1.094,8	1.031,2	.384,2
1.40	1.320	.327,3	.423,5	.7728	1.123	1.0388	.367,5
1.45	1.356	.304,9	.401,0	.7603	1.154	1.0467	.351,9
1.50	1.391	.283,6	.379,3	.7477	1.189	1.0549	.337,4
1.55	1.425	.263,5	.358,5	.7351	1.228	1.0634	.323,7
1.60	1.458	.244,6	.338,5	.7225	1.271	1.0720	.310,9
1.65	1.491	.226,8	.319,4	.7100	1.318	1.0808	.298,9
1.70	1.523	.210,1	.301,1	.6976	1.369	1.0897	.287,5

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_{3}429$ signifies .000429. The notation 5370_{4} signifies 5,370,000.

Table 4.13 ISENTROPIC FLOW (Perfect Gas, k= 1.3 exactly)

M	M*	p/p₀	ρ/ρ₀	T/T₀	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_0}$
1.75	1.554	.194,4	.283,6	.6852	1.42,4	1.0986	.276,8
1.80	1.584	.179,7	.267,0	.6729	1.48,4	1.108	.266,7
1.85	1.613	.166,0	.251,3	.6607	1.54,9	1.116	.257,1
1.90	1.641	.153,3	.236,4	.6487	1.61,8	1.125	.2481
1.95	1.669	.141,5	.222,2	.6368	1.69,3	1.134	.2395
2.00	1.696	.130,5	.208,7	.6250	1.77,3	1.143	.2313
2.05	1.722	.120,3	.196,0	.6134	1.85,9	1.152	.2236
2.10	1.747	.110,8	.184,1	.6019	1.95,1	1.160	.2162
2.15	1.772	.102,0	.172,8	.5905	2.05,0	1.168	.2092
2.20	1.796	.093,93	.162,1	.5793	2.15,6	1.176	.2025
2.25	1.819	.086,45	.152,1	.5684	2.26,8	1.184	.1961
2.30	1.842	.079,55	.142,7	.5576	2.38,8	1.192	.1900
2.35	1.864	.073,18	.133,8	.5470	2.51,7	1.200	.1842
2.40	1.885	.067,31	.125,4	.5365	2.65,4	1.208	.1786
2.45	1.906	.0619,0	.117,6	.5262	2.79,9	1.216	.1733
2.50	1.926	.0569,2	.1103	.5161	2.95,4	1.223	.1682
2.55	1.946	.0523,4	.1034	.5062	3.11,9	1.230	.1633
2.60	1.965	.0481,3	.0969,3	.4965	3.29,5	1.237	.1586
2.65	1.983	.0442,6	.0908,7	.4870	3.48,2	1.244	.1541
2.70	2.001	.0407,0	.0852,0	.4777	3.68,1	1.250	.1498
2.75	2.019	.0374,3	.0798,8	.4686	3.89,2	1.257	.1457
2.80	2.036	.0344,2	.0749,0	.4596	4.11,6	1.264	.1417
2.85	2.052	.0316,6	.0702,4	.4508	4.35,4	1.270	.1379
2.90	2.068	.0291,3	.0658,7	.4422	4.60,7	1.276	.1342
2.95	2.084	.0268,0	.0617,8	.4338	4.87,5	1.282	.1307
3.00	2.099	.02466	.05796	.4255	5.160	1.288	.12726
3.50	2.228	.01090	.03092	.3524	9.110	1.338	.09926
4.00	2.326	.00498	.01692	.2941	15.94	1.378	.07934
4.50	2.402	.00236	.00954	.2477	27.39	1.409	.06471
5.00	2.460	.00117	.00555	.2105	45.95	1.433	.05372
6.00	2.543	$.0_3321$	.00206	.15625	120.1	1.468	.03856
7.00	2.598	$.0_3101$	$.0_3847$	.11976	285.3	1.491	.02882
8.00	2.635	$.0_4360$	$.0_3382$	.09434	625.2	1.507	.02251
9.00	2.662	$.0_4141$	$.0_3186$	.07605	1275	1.519	.01798
10.00	2.681	$.0_5605$	$.0_4963$	.06250	2438	1.527	.01475
∞	2.769	0	0	0	∞	1.565	0

ble 4.13 ISENTROPIC FLOW (Perfect Gas, k = 1.3 exactly) (Concluded)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
0	0	1.0000,0	1.0000,0	1.00000	∞	∞	∞
.01	.01096	.9999,3	.9999,5	.99998	5,7.874	4,5.650	5,7.870
.02	.02191	.9997,2	.9998,0	.99992	2,8.942	2,2.834	2,8.934
.03	.03286	.9993,7	.9995,5	.99982	1,9.300	15.,232	1,9.288
.04	.04381	.9988,8	.9992,0	.99968	14.,482	11.,435	14.,465
.05	.05476	.9982,5	.9987,5	.99950	11.5,915	9.,1584	11.,5712
.06	.06570	.9974,8	.9982,0	.99928	9.6,659	7.,6428	9.,6415
.07	.07664	.9965,8	.9975,5	.99902	8.2,915	6.5,620	8.2,631
.08	.08758	.9955,3	.9968,0	.99872	7.2,616	5.7,529	7.2,291
.09	.09851	.9943,5	.9959,6	.99838	6.4,613	5.1,249	6.4,248
.10	.10943	.9930,3	.9950,2	.99800	5.8,218	4.6,236	5.7,812
.11	.12035	.9915,7	.9939,8	.99758	5.2,992	4.2,146	5.2,546
.12	.13126	.9899,8	.9928,4	.99714	4.8,643	3.8,747	4.8,157
.13	.14216	.9882,6	.9916,0	.99664	4.4,968	3.58,80	4.4,440
.14	.15306	.9864,0	.9902,7	.99610	4.18,24	3.34,32	4.12,55
.15	.16395	.9844,1	.9888,4	.99552	3.91.03	3.13,17	3.84,93
.16	.17483	.9822,8	.9873,1	.99490	3.67,27	2.94,74	3.60,76
.17	.18569	.9800,3	.9856,9	.99425	3.46,35	2.78,55	3.39,43
.18	.19654	.9776,5	.9839,8	.99356	3.27,79	2.64,22	3.20,46
.19	.20738	.9751,4	.9821,7	.99283	3.11,22	2.51,46	3.03,48
.20	.21822	.9725,0	.9802,7	.99206	2.96,35	2.40,04	2.88,20
.21	.22904	.9697,3	.9782,8	.99125	2.82,93	2.29,76	2.74,37
.22	.23984	.9668,5	.9762,1	.99041	2.70,76	2.20,46	2.61,78
.23	.25063	.9638,3	.9740,3	.98953	2.59,68	2.12,03	2.50,29
.24	.26141	.9607,0	.9717,7	.98861	2.49,56	2.04,34	2.39,75
.25	.27216	.9574,5	.9694,2	.98765	2.40,27	1.97,32	2.30,05
.26	.28291	.9540,8	.9669,9	.98666	2.31,73	1.90,88	2.21,09
.27	.29364	.9506,0	.9644,6	.98563	2.23,85	1.84,96	2.12,79
.28	.30435	.9470,0	.9618,5	.98456	2.16,56	1.795,0	2.05,08
.29	.31504	.9432,9	.9591,6	.98346	2.09,79	1.744,6	1.97,89
.30	.32572	.9394,7	.9563,8	.98232	2.035,1	1.697,9	1.911,9
.31	.33638	.9355,4	.9535,2	.98114	1.976,5	1.654,6	1.849,1
.32	.34701	.9315,0	.9505,8	.97993	1.921,8	1.614,4	1.790,2
.33	.35762	.9273,6	.9475,6	.97868	1.870,7	1.576,9	1.734,8
.34	.36821	.9231,2	.9444,6	.97740	1.822,9	1.542,0	1.682,8
.35	.37879	.9187,7	.9412,8	.97608	1.778,0	1.509,4	1.633,6
.36	.38935	.9143,3	.9380,3	.97473	1.735,8	1.478,9	1.587,1
.37	.39988	.9097,9	.9347,0	.97335	1.696,1	1.450,3	1.543,1
.38	.41039	.9051,6	.9312,9	.97193	1.658,7	1.423,6	1.501,4
.39	.42087	.9004,4	.9278,2	.97048	1.623,4	1.398,5	1.461,8
.40	.43133	.8956,2	.9242,8	.96899	1.590,1	1.374,9	1.424,1
.41	.44177	.8907,1	.9206,6	.96747	1.558,7	1.352,7	1.388,3
.42	.45218	.8857,2	.9169,7	.96592	1.528,9	1.331,8	1.354,2
.43	.46256	.8806,5	.9132,2	.96434	1.500,7	1.312,2	1.321,6
.44	.47292	.8755,0	.9094,0	.96272	1.474,0	1.293,7	1.290,5

Notes: (1) For values of M from 0 to 5.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.
(2) The notation $.0_3429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.14 ISENTROPIC FLOW (Perfact Gas, k = 1.4 exactly)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
.45	.48326	.8702,7	.9055,2	.96108	1.448,7	1.276,3	1.260,7
.46	.49357	.8649,6	.9015,7	.95940	1.424,6	1.259,8	1.232,2
.47	.50385	.8595,8	.8975,6	.95769	1.401,8	1.244,3	1.205,0
.48	.51410	.8541,3	.8934,9	.95595	1.380,1	1.229,6	1.178,8
.49	.52432	.8486,1	.8893,6	.95418	1.359,4	1.215,8	1.153,7
.50	.53452	.8430,2	.8851,7	.95238	1.339,8	1.202,7	1.129,51
.51	.54469	.8373,7	.8809,2	.95055	1.321,2	1.190,3	1.106,31
.52	.55482	.8316,6	.8766,2	.94869	1.303,4	1.178,6	1.083,97
.53	.56493	.8258,9	.8722,7	.94681	1.286,4	1.167,5	1.062,45
.54	.57501	.8200,5	.8678,8	.94489	1.270,3	1.157,1	1.041,73
.55	.58506	.8141,6	.86342	.94295	1.255,0	1.147,2	1.021,74
.56	.59508	.8082,2	.85892	.94098	1.240,3	1.137,8	1.002,44
.57	.60506	.8022,4	.85437	.93898	1.226,3	1.128,9	.983,81
.58	.61500	.7962,1	.84977	.93696	1.213,0	1.120,5	.965,81
.59	.62491	.7901,2	.84513	.93491	1.200,3	1.112,6	.948,39
.60	.63480	.78400	.84045	.93284	1.188,2	1.1050,4	.931,55
.61	.64466	.77784	.83573	.93074	1.176,6	1.0979,3	.915,25
.62	.65448	.77164	.83096	.92861	1.165,6	1.0912,0	.899,46
.63	.66427	.76540	.82616	.92646	1.155,1	1.0848,5	.884,16
.64	.67402	.75913	.82132	.92428	1.145,1	1.0788,3	.869,32
.65	.68374	.75283	.81644	.92208	1.1356	1.0731,4	.8549,3
.66	.69342	.74650	.81153	.91986	1.1265	1.0677,7	.8409,6
.67	.70307	.74014	.80659	.91762	1.1178	1.0627,1	.8274,0
.68	.71268	.73376	.80162	.91535	1.1096	1.0579,2	.8142,1
.69	.72225	.72735	.79662	.91306	1.1018	1.0534,0	.8014,1
.70	.73179	.72092	.79158	.91075	1.0943,7	1.0491,5	.7889,6
.71	.74129	.71448	.78652	.90842	1.0872,9	1.0451,4	.7768,5
.72	.75076	.70802	.78143	.90606	1.0805,7	1.0413,7	.7650,7
.73	.76019	.70155	.77632	.90368	1.0741,9	1.0378,3	.7536,0
.74	.76958	.69507	.77119	.90129	1.0681,4	1.0345,0	.7424,3
.75	.77893	.68857	.76603	.89888	1.0624,2	1.0313,7	.7315,5
.76	.78825	.68207	.76086	.89644	1.0570,0	1.0284,4	.7209,5
.77	.79753	.67556	.75567	.89399	1.0518,8	1.0257,0	.7106,2
.78	.80677	.66905	.75046	.89152	1.0470,5	1.0231,4	.7005,4
.79	.81597	.66254	.74524	.88903	1.0425,0	1.0207,5	.6907,0
.80	.82514	.65602	.74000	.88652	1.0382,3	1.0185,3	.6811,0
.81	.83426	.64951	.73474	.88400	1.0342,2	1.0164,6	.6717,3
.82	.84334	.64300	.72947	.88146	1.0304,6	1.0145,5	.6625,9
.83	.85239	.63650	.72419	.87890	1.0269,6	1.0127,8	.6536,6
.84	.86140	.63000	.71890	.87633	1.0237,0	1.0111,5	.6449,3
.85	.87037	.62351	.71361	.87374	1.0206,7	1.0096,6	.6364,0
.86	.87929	.61703	.70831	.87114	1.0178,7	1.0082,9	.6280,6
.87	.88817	.61057	.70300	.86852	1.0153,0	1.0070,4	.6199,1
.88	.89702	.60412	.69769	.86589	1.0129,4	1.0059,1	.6119,3
.89	.90583	.59768	.69237	.86324	1.0108,0	1.0049,0	.6041,3

Table 4.14 ISENTROPIC FLOW (Perfect Gas, k = 1.4 exactly) (Continued)

(This page contains a correction of an error which appeared in the data of the corresponding table of the Meteor Report No. 14, dated Dec. 1, 1947.)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
.90	.91460	.59126	.68704	.86058	1.0088,6	1.0039,9	.5965,0
.91	.92333	.58486	.68171	.85791	1.0071,3	1.0031,8	.5890,3
.92	.93201	.57848	.67639	.85523	1.0056,0	1.0024,8	.5817,1
.93	.94065	.57212	.67107	.85253	1.0042,6	1.0018,8	.5745,5
.94	.94925	.56578	.66575	.84982	1.0031,1	1.0013,6	.5675,4
.95	.95781	.55946	.66044	.84710	1.0021,4	1.0009,3	.5606,6
.96	.96633	.55317	.65513	.84437	1.0013,6	1.0005,9	.5539,2
.97	.97481	.54691	.64982	.84162	1.0007,6	1.0003,3	.5473,2
.98	.98325	.54067	.64452	.83887	1.0003,3	1.0001,4	.5408,5
.99	.99165	.53446	.63923	.83611	1.0000,8	1.0000,3	.5345,0
1.00	1.00000	.52828	.63394	.83333	1.0000,0	1.0000,0	.5282,8
1.01	1.00831	.52213	.62866	.83055	1.0000,8	1.0000,3	.5221,8
1.02	1.01658	.51602	.62339	.82776	1.0003,3	1.0001,3	.5161,9
1.03	1.02481	.50994	.61813	.82496	1.0007,4	1.0003,0	.5103,1
1.04	1.03300	.50389	.61288	.82215	1.0013,0	1.0005,3	.5045,4
1.05	1.04114	.49787	.60765	.81933	1.0020,2	1.0008,2	.4988,8
1.06	1.04924	.49189	.60243	.81651	1.0029,0	1.0011,6	.4933,2
1.07	1.05730	.48595	.59722	.81368	1.0039,4	1.0015,5	.4878,7
1.08	1.06532	.48005	.59203	.81084	1.0051,2	1.0020,0	.4825,1
1.09	1.07330	.47418	.58685	.80800	1.0064,5	1.0025,0	.4772,4
1.10	1.08124	.46835	.58169	.80515	1.0079,3	1.00305	.4720,6
1.11	1.08914	.46256	.57655	.80230	1.0095,5	1.00365	.4669,8
1.12	1.09699	.45682	.57143	.79944	1.0113,1	1.00429	.4619,9
1.13	1.10480	.45112	.56632	.79657	1.0132,2	1.00497	.4570,8
1.14	1.11256	.44545	.56123	.79370	1.0152,7	1.00569	.4522,5
1.15	1.1203	.43983	.55616	.79083	1.0174,6	1.00646	.4475,1
1.16	1.1280	.43425	.55112	.78795	1.0197,8	1.00726	.4428,4
1.17	1.1356	.42872	.54609	.78507	1.0222,4	1.00810	.4382,5
1.18	1.1432	.42323	.54108	.78218	1.0248,4	1.00897	.4337,4
1.19	1.1508	.41778	.53610	.77929	1.0275,7	1.00988	.4293,0
1.20	1.1583	.4123,8	.53114	.77640	1.0304,4	1.01082	.4249,3
1.21	1.1658	.4070,2	.52620	.77350	1.0334,4	1.01178	.4206,3
1.22	1.1732	.4017,1	.52129	.77061	1.0365,7	1.01278	.4164,0
1.23	1.1806	.3964,5	.51640	.76771	1.0398,3	1.01381	.4122,4
1.24	1.1879	.3912,3	.51154	.76481	1.0432,3	1.01486	.4081,4
1.25	1.1952	.3860,6	.50670	.76190	1.0467,6	1.01594	.4041,1
1.26	1.2025	.3809,4	.50189	.75900	1.0504,1	1.01705	.4001,4
1.27	1.2097	.3758,6	.49710	.75610	1.0541,9	1.01818	.3962,2
1.28	1.2169	.3708,3	.49234	.75319	1.0581,0	1.01933	.3923,7
1.29	1.2240	.3658,5	.48761	.75029	1.0621,4	1.02050	.3885,8
1.30	1.2311	.3609,2	.48291	.74738	1.0663,1	1.02170	.3848,4
1.31	1.2382	.3560,3	.47823	.74448	1.0706,0	1.02292	.3811,6
1.32	1.2452	.3511,9	.47358	.74158	1.0750,2	1.02415	.3775,4
1.33	1.2522	.3464,0	.46895	.73867	1.0795,7	1.02540	.3739,7
1.34	1.2591	.3416,6	.46436	.73577	1.0842,4	1.02666	.3704,4

Table 4.14 ISENTROPIC FLOW (Perfect Gas, k = 1.4 exactly) (Continued)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
1.35	1.2660	.3369,7	.45980	.73287	1.0890,4	1.02794	.3669,7
1.36	1.2729	.3323,3	.45527	.72997	1.0939,7	1.02924	.3635,5
1.37	1.2797	.3277,4	.45076	.72707	1.0990,2	1.03056	.3601,8
1.38	1.2865	.3231,9	.44628	.72418	1.1042,0	1.03189	.3568,6
1.39	1.2932	.3186,9	.44183	.72128	1.1095,0	1.03323	.3535,9
1.40	1.2999	.3142,4	.43742	.71839	1.1149	1.03458	.35036
1.41	1.3065	.3098,4	.43304	.71550	1.1205	1.03595	.34717
1.42	1.3131	.3054,9	.42869	.71261	1.1262	1.03733	.34403
1.43	1.3197	.3011,9	.42436	.70973	1.1320	1.03872	.34093
1.44	1.3262	.2969,3	.42007	.70685	1.1379	1.04012	.33787
1.45	1.3327	.2927,2	.41581	.70397	1.1440	1.04153	.33486
1.46	1.3392	.2885,6	.41158	.70110	1.1502	1.04295	.33189
1.47	1.3456	.2844,5	.40738	.69823	1.1565	1.04438	.32896
1.48	1.3520	.2803,9	.40322	.69537	1.1629	1.04581	.32607
1.49	1.3583	.2763,7	.39909	.69251	1.1695	1.04725	.32321
1.50	1.3646	.2724,0	.39498	.68965	1.1762	1.04870	.32039
1.51	1.3708	.2684,8	.39091	.68680	1.1830	1.05016	.31761
1.52	1.3770	.2646,1	.38687	.68396	1.1899	1.05162	.31487
1.53	1.3832	.2607,8	.38287	.68112	1.1970	1.05309	.31216
1.54	1.3894	.2570,0	.37890	.67828	1.2042	1.05456	.30948
1.55	1.3955	.2532,6	.37496	.67545	1.2115	1.05604	.30685
1.56	1.4016	.2495,7	.37105	.67262	1.2190	1.05752	.30424
1.57	1.4076	.2459,3	.36717	.66980	1.2266	1.05900	.30167
1.58	1.4135	.2423,3	.36332	.66699	1.2343	1.06049	.29913
1.59	1.4195	.2387,8	.35951	.66418	1.2422	1.06198	.29662
1.60	1.4254	.23527	.35573	.66138	1.2502	1.06348	.29414
1.61	1.4313	.23181	.35198	.65858	1.2583	1.06498	.29169
1.62	1.4371	.22839	.34826	.65579	1.2666	1.06648	.28928
1.63	1.4429	.22501	.34458	.65301	1.2750	1.06798	.28690
1.64	1.4487	.22168	.34093	.65023	1.2835	1.06948	.28454
1.65	1.4544	.21839	.33731	.64746	1.2922	1.07098	.28221
1.66	1.4601	.21515	.33372	.64470	1.3010	1.07249	.27991
1.67	1.4657	.21195	.33016	.64194	1.3099	1.07399	.27764
1.68	1.4713	.20879	.32664	.63919	1.3190	1.07550	.27540
1.69	1.4769	.20567	.32315	.63645	1.3282	1.07701	.27318
1.70	1.4825	.20259	.31969	.63372	1.3376	1.07851	.27099
1.71	1.4880	.19955	.31626	.63099	1.3471	1.08002	.26882
1.72	1.4935	.19656	.31286	.62827	1.3567	1.08152	.26668
1.73	1.4989	.19361	.30950	.62556	1.3665	1.08302	.26457
1.74	1.5043	.19070	.30617	.62286	1.3764	1.08453	.26248
1.75	1.5097	.18782	.30287	.62016	1.3865	1.08603	.26042
1.76	1.5150	.18499	.29959	.61747	1.3967	1.08753	.25838
1.77	1.5203	.18220	.29635	.61479	1.4071	1.08903	.25636
1.78	1.5256	.17944	.29314	.61211	1.4176	1.09053	.25436
1.79	1.5308	.17672	.28997	.60945	1.4282	1.09202	.25239

Table 4.14 ISENTROPIC FLOW (Perfect Gas, k = 1.4 exactly) (Continued)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
1.80	1.5360	.17404	.28682	.60680	1.4390	1.09352	.25044
1.81	1.5412	.17140	.28370	.60415	1.4499	1.09500	.24851
1.82	1.5463	.16879	.28061	.60151	1.4610	1.09649	.24660
1.83	1.5514	.16622	.27756	.59888	1.4723	1.09798	.24472
1.84	1.5564	.16369	.27453	.59626	1.4837	1.09946	.24286
1.85	1.5614	.16120	.27153	.59365	1.4952	1.1009	.24102
1.86	1.5664	.15874	.26857	.59105	1.5069	1.1024	.23919
1.87	1.5714	.15631	.26563	.58845	1.5188	1.1039	.23739
1.88	1.5763	.15392	.26272	.58586	1.5308	1.1054	.23561
1.89	1.5812	.15156	.25984	.58329	1.5429	1.1068	.23385
1.90	1.5861	.14924	.25699	.58072	1.5552	1.1083	.23211
1.91	1.5909	.14695	.25417	.57816	1.5677	1.1097	.23039
1.92	1.5957	.14469	.25138	.57561	1.5804	1.1112	.22868
1.93	1.6005	.14247	.24862	.57307	1.5932	1.1126	.22699
1.94	1.6052	.14028	.24588	.57054	1.6062	1.1141	.22532
1.95	1.6099	.13813	.24317	.56802	1.6193	1.1155	.22367
1.96	1.6146	.13600	.24049	.56551	1.6326	1.1170	.22204
1.97	1.6193	.13390	.23784	.56301	1.6461	1.1184	.22042
1.98	1.6239	.13184	.23522	.56051	1.6597	1.1198	.21882
1.99	1.6285	.12981	.23262	.55803	1.6735	1.1213	.21724
2.00	1.6330	.12780	.23005	.55556	1.6875	1.1227	.21567
2.01	1.6375	.12583	.22751	.55310	1.7017	1.1241	.21412
2.02	1.6420	.12389	.22499	.55064	1.7160	1.1255	.21259
2.03	1.6465	.12198	.22250	.54819	1.7305	1.1269	.21107
2.04	1.6509	.12009	.22004	.54576	1.7452	1.1283	.20957
2.05	1.6553	.11823	.21760	.54333	1.7600	1.1297	.20808
2.06	1.6597	.11640	.21519	.54091	1.7750	1.1311	.20661
2.07	1.6640	.11460	.21281	.53850	1.7902	1.1325	.20515
2.08	1.6683	.11282	.21045	.53611	1.8056	1.1339	.20371
2.09	1.6726	.11107	.20811	.53373	1.8212	1.1352	.20228
2.10	1.6769	.10935	.20580	.53135	1.8369	1.1366	.20087
2.11	1.6811	.10766	.20352	.52898	1.8529	1.1380	.19947
2.12	1.6853	.10599	.20126	.52663	1.8690	1.1393	.19809
2.13	1.6895	.10434	.19902	.52428	1.8853	1.1407	.19672
2.14	1.6936	.10272	.19681	.52194	1.9018	1.1420	.19537
2.15	1.6977	.10113	.19463	.51962	1.9185	1.1434	.19403
2.16	1.7018	.09956	.19247	.51730	1.9354	1.1447	.19270
2.17	1.7059	.09802	.19033	.51499	1.9525	1.1460	.19138
2.18	1.7099	.09650	.18821	.51269	1.9698	1.1474	.19008
2.19	1.7139	.09500	.18612	.51041	1.9873	1.1487	.18879
2.20	1.7179	.09352	.18405	.50813	2.0050	1.1500	.18751
2.21	1.7219	.09207	.18200	.50586	2.0229	1.1513	.18624
2.22	1.7258	.09064	.17998	.50361	2.0409	1.1526	.18499
2.23	1.7297	.08923	.17798	.50136	2.0592	1.1539	.18375
2.24	1.7336	.08784	.17600	.49912	2.0777	1.1552	.18252

Table 4.14 ISENTROPIC FLOW (Perfect Gas, k = 1.4 exactly) (Continued

(This page contains a correction of an error which appeared in the data of the corresponding table of the Meteor Report No. 14, dated Dec. 1, 1947.)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*} \cdot \frac{p}{p_o}$
2.25	1.7374	.08648	.17404	.49689	2.0964	1.1565	.18130
2.26	1.7412	.08514	.17211	.49468	2.1154	1.1578	.18009
2.27	1.7450	.08382	.17020	.49247	2.1345	1.1590	.17890
2.28	1.7488	.08252	.16830	.49027	2.1538	1.1603	.17772
2.29	1.7526	.08123	.16643	.48809	2.1734	1.1616	.17655
2.30	1.7563	.07997	.16458	.48591	2.1931	1.1629	.17539
2.31	1.7600	.07873	.16275	.48374	2.2131	1.1641	.17424
2.32	1.7637	.07751	.16095	.48158	2.2333	1.1653	.17310
2.33	1.7673	.07631	.15916	.47944	2.2537	1.1666	.17197
2.34	1.7709	.07513	.15739	.47730	2.2744	1.1678	.17085
2.35	1.7745	.07396	.15564	.47517	2.2953	1.1690	.16975
2.36	1.7781	.07281	.15391	.47305	2.3164	1.1703	.16866
2.37	1.7817	.07168	.15220	.47095	2.3377	1.1715	.16757
2.38	1.7852	.07057	.15052	.46885	2.3593	1.1727	.16649
2.39	1.7887	.06948	.14885	.46676	2.3811	1.1739	.16543
2.40	1.7922	.06840	.14720	.46468	2.4031	1.1751	.16437
2.41	1.7957	.06734	.14557	.46262	2.4254	1.1763	.16332
2.42	1.7991	.06630	.14395	.46056	2.4479	1.1775	.16229
2.43	1.8025	.06527	.14235	.45851	2.4706	1.1786	.16126
2.44	1.8059	.06426	.14078	.45647	2.4936	1.1798	.16024
2.45	1.8093	.06327	.13922	.45444	2.5168	1.1810	.15923
2.46	1.8126	.06229	.13768	.45242	2.5403	1.1821	.15823
2.47	1.8159	.06133	.13616	.45041	2.5640	1.1833	.15724
2.48	1.8192	.06038	.13465	.44841	2.5880	1.1844	.15626
2.49	1.8225	.05945	.13316	.44642	2.6122	1.1856	.15528
2.50	1.8258	.05853	.13169	.44444	2.6367	1.1867	.15432
2.51	1.8290	.05763	.13023	.44247	2.6615	1.1879	.15337
2.52	1.8322	.05674	.12879	.44051	2.6865	1.1890	.15242
2.53	1.8354	.05586	.12737	.43856	2.7117	1.1901	.15148
2.54	1.8386	.05500	.12597	.43662	2.7372	1.1912	.15055
2.55	1.8417	.05415	.12458	.43469	2.7630	1.1923	.14963
2.56	1.8448	.05332	.12321	.43277	2.7891	1.1934	.14871
2.57	1.8479	.05250	.12185	.43085	2.8154	1.1945	.14780
2.58	1.8510	.05169	.12051	.42894	2.8420	1.1956	.14691
2.59	1.8541	.05090	.11418	.42705	2.8689	1.1967	.14601
2.60	1.8572	.05012	.11787	.42517	2.8960	1.1978	.14513
2.61	1.8602	.04935	.11658	.42330	2.9234	1.1989	.14426
2.62	1.8632	.04859	.11530	.42143	2.9511	1.2000	.14339
2.63	1.8662	.04784	.11403	.41957	2.9791	1.2011	.14253
2.64	1.8692	.04711	.11278	.41772	3.0074	1.2021	.14168
2.65	1.8721	.04639	.11154	.41589	3.0359	1.2031	.14083
2.66	1.8750	.04568	.11032	.41406	3.0647	1.2042	.13999
2.67	1.8779	.04498	.10911	.41224	3.0938	1.2052	.13916
2.68	1.8808	.04429	.10792	.41043	3.1233	1.2062	.13834
2.69	1.8837	.04361	.10674	.40863	3.1530	1.2073	.13752

Table 4.14 ISENTROPIC FLOW (Perfect Gas, k = 1.4 exactly) (Continued)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
2.70	1.8865	.04295	.10557	.40684	3.1830	1.2083	.13671
2.71	1.8894	.04230	.10442	.40505	3.2133	1.2093	.13591
2.72	1.8922	.04166	.10328	.40327	3.2440	1.2103	.13511
2.73	1.8950	.04102	.10215	.40151	3.2749	1.2113	.13432
2.74	1.8978	.04039	.10104	.39976	3.3061	1.2123	.13354
2.75	1.9005	.03977	.09994	.39801	3.3376	1.2133	.13276
2.76	1.9032	.03917	.09885	.39627	3.3695	1.2143	.13199
2.77	1.9060	.03858	.09777	.39454	3.4017	1.2153	.13123
2.78	1.9087	.03800	.09671	.39282	3.4342	1.2163	.13047
2.79	1.9114	.03742	.09566	.39111	3.4670	1.2173	.12972
2.80	1.9140	.03685	.09462	.38941	3.5001	1.2182	.12897
2.81	1.9167	.03629	.09360	.38771	3.5336	1.2192	.12823
2.82	1.9193	.03574	.09259	.38603	3.5674	1.2202	.12750
2.83	1.9220	.03520	.09158	.38435	3.6015	1.2211	.12678
2.84	1.9246	.03467	.09059	.38268	3.6359	1.2221	.12605
2.85	1.9271	.03415	.08962	.38102	3.6707	1.2230	.12534
2.86	1.9297	.03363	.08865	.37937	3.7058	1.2240	.12463
2.87	1.9322	.03312	.08769	.37773	3.7413	1.2249	.12393
2.88	1.9348	.03262	.08674	.37610	3.7771	1.2258	.12323
2.89	1.9373	.03213	.08581	.37448	3.8133	1.2268	.12254
2.90	1.9398	.03165	.08489	.37286	3.8498	1.2277	.12185
2.91	1.9423	.03118	.08398	.37125	3.8866	1.2286	.12117
2.92	1.9448	.03071	.08308	.36965	3.9238	1.2295	.12049
2.93	1.9472	.03025	.08218	.36806	3.9614	1.2304	.11982
2.94	1.9497	.02980	.08130	.36648	3.9993	1.2313	.11916
2.95	1.9521	.02935	.08043	.36490	4.0376	1.2322	.11850
2.96	1.9545	.02891	.07957	.36333	4.0763	1.2331	.11785
2.97	1.9569	.02848	.07872	.36177	4.1153	1.2340	.11720
2.98	1.9593	.02805	.07788	.36022	4.1547	1.2348	.11656
2.99	1.9616	.02764	.07705	.35868	4.1944	1.2357	.11591

Table 4.14 ISENTROPIC FLOW (Perfect Gas, k = 1.4 exactly) (Continued)

M	M*	p/p₀	ρ/ρ₀	T/T₀	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_0}$
3.00	1.964,0	.027,22	.076,23	.357,14	4.23,46	1.2366	.115,28
3.10	1.986,6	.023,45	.068,52	.342,23	4.65,73	1.2450	.109,21
3.20	2.007,9	.020,23	.061,65	.328,08	5.12,10	1.2530	.1035,9
3.30	2.027,9	.0174,8	.055,54	.314,66	5.6,287	1.2605	.0983,7
3.40	2.046,6	.0151,2	.050,09	.301,93	6.1,837	1.2676	.0935,3
3.50	2.064,2	.0131,1	.045,23	.289,86	6.7,896	1.2743	.0890,2
3.60	2.080,8	.0113,8	.040,89	.278,40	7.4,501	1.2807	.0848,2
3.70	2.096,4	.0099,0	.0370,2	.267,52	8.1,691	1.2867	.0809,0
3.80	2.111,1	.0086,3	.0335,5	.257,20	8.9,506	1.2924	.0772,3
3.90	2.125,0	.0075,3	.0304,4	.247,40	9.7,990	1.2978	.0738,0
4.00	2.138,1	.0065,8	.0276,6	.238,10	10.7,19	1.3029	.0705,9
4.10	2.150,5	.0057,7	.0251,6	.229,25	11.7,15	1.3077	.0675,8
4.20	2.162,2	.0050.6	.0229,2	.2208,5	12.7,92	1.3123	.0647,5
4.30	2.173,2	.0044,5	.0209,0	.2128,6	13.9,55	1.3167	.0620,9
4.40	2.183,7	.0039,2	.0190,9	.2052,5	15.2,10	1.3208	.0595,9
4.50	2.193,6	.0034,6	.0174,5	.1980,2	16.5,62	1.3247	.0572,3
4.60	2.203,0	.0030,5	.0159,7	.1911,3	18.0,18	1.3284	.0550,0
4.70	2.211,9	.0027,0	.0146,3	.1845,7	19.5,83	1.3320	.0528,9
4.80	2.220,4	.0024,0	.0134,3	.1783,2	21.2,64	1.3354	.0509,1
4.90	2.228,4	.0021,3	.0123,3	.1723,5	23.0,67	1.3386	.0490,4
5.00	2.2361	.00189	.01134	.16667	25.000	1.3416	.04725
6.00	2.2953	.0 ₃633	.00519	.12195	53.180	1.3655	.03368
7.00	2.3333	.0 ₃242	.00261	.09259	104.143	1.3810	.02516
8.00	2.3591	.0 ₃102	.00141	.07246	190.109	1.3915	.01947
9.00	2.3772	.0 ₄474	.0 ₃815	.05814	327.189	1.3989	.01550
10.00	2.3904	.0 ₄236	.0 ₃495	.04762	535.938	1.4044	.01263
∞	2.4495	0	0	0	∞	1.4289	0

Table 4.14 ISENTROPIC FLOW (Perfect Gas, k = 1.4 exactly) (Concluded)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
0	0	1.000,0	1.000,0	1.000,0	∞	∞	∞
.05	.05775	.997,9	.998,8	.999,2	11.,265	8.,687	11.,242
.10	.1154	.991,7	.995,0	.996,7	5.,661	4.,392	5.,614
.15	.1727	.981,5	.988,8	.992,5	3.,805	2.,982	3.,735
.20	.229,6	.967,4	.980,3	.986,8	2.8,87	2.2,93	2.7,93
.25	.285,9	.949,7	.969,5	.979,5	2.3,44	1.8,92	2.2,26
.30	.341,5	.928,6	.956,6	.970,8	1.9,89	1.6,35	1.8,47
.35	.396,3	.904,6	.941,7	.960,6	1.7,41	1.4,60	1.5,75
.40	.450,2	.878,0	.925,0	.949,1	1.5,60	1.33,6	1.37,0
.45	.503,1	.849,1	.906,7	.936,4	1.42,4	1.24,5	1.20,9
.50	.554,9	.818,4	.886,9	.922,7	1.32,0	1.17,8	1.08,03
.55	.605,5	.786,2	.865,8	.908,0	1.23,9	1.12,8	.97,42
.60	.654,8	.752,9	.843,7	.892,4	1.17,6	1.09,09	.88,53
.65	.702,9	.7190	.820,7	.876,0	1.12,6	1.06,28	.80,97
.70	.749,6	.6847	.797,0	.859,0	1.08,74	1.04,22	.74,45
.75	.794,9	.6503	.7728	.8414	1.05,76	1.02,65	.68,77
.80	.838,8	.616,2	.7483	.8234	1.03,51	1.015,5	.63,78
.85	.881,2	.582,6	.7236	.8051	1.01,89	1.008,0	.59,36
.90	.922,2	.549,7	.6988	.7866	1.00,80	1.003,3	.554,1
.95	.961,8	.517,7	.6742	.7679	1.001,9	1.000,8	.518,7
1.00	1.000,0	.486,7	.6497	.7491	1.000,0	1.000,0	.486,7
1.05	1.036,8	.456,8	.6255	.7303	1.001,8	1.000,7	.457,6
1.10	1.072,1	.428,2	.601,7	.7116	1.007,1	1.002,4	.431,2
1.15	1.106	.400,9	.578,4	.6930	1.015,4	1.005,1	.407,0
1.20	1.139	.374,9	.555,7	.6746	1.026,6	1.008,5	.384,9
1.25	1.170	.350,2	.533,5	.6564	1.040,6	1.0124	.364,6
1.30	1.200	.326,9	.511,9	.6385	1.057,3	1.0167	.345,7
1.35	1.229	.304,9	.491,0	.6209	1.076,5	1.0213	.328,2
1.40	1.257	.284,2	.470,7	.6036	1.098,1	1.0262	.312,1
1.45	1.283	.264,7	.451,1	.5867	1.122	1.0313	.297,2
1.50	1.309	.246,5	.432,3	.5702	1.148	1.0364	.283,0
1.55	1.333	.229,5	.414,2	.5541	1.176	1.0416	.270,0
1.60	1.356	.213,6	.396,8	.5383	1.207	1.0468	.257,9
1.65	1.379	.198,8	.380,1	.5230	1.240	1.0520	.246,5
1.70	1.400	.185,0	.364,0	.5081	1.275	1.0572	.235,8

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_3429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.15 ISENTROPIC FLOW (Perfect Gas, k = 1.67 exactly)

M	M*	p/p_o	ρ/ρ_o	T/T_o	A/A*	F/F*	$\frac{A}{A^*}\cdot\frac{p}{p_o}$
1.75	1.420	.172,1	.348,6	.4936	1.312	1.0623	.225,7
1.80	1.440	.160,1	.333,9	.4795	1.351	1.0673	.216,3
1.85	1.459	.149,0	.319,8	.4658	1.392	1.0722	.207,5
1.90	1.477	.138,6	.306,3	.4526	1.436	1.0770	.199,1
1.95	1.494	.129,0	.293,4	.4398	1.482	1.0817	.191,2
2.00	1.511	.120,1	.281,1	.4274	1.530	1.0863	.1838
2.05	1.527	.111,9	.269,4	.4153	1.580	1.0908	.1768
2.10	1.542	.104,2	.258,2	.4036	1.632	1.0952	.1701
2.15	1.556	.097,12	.247,5	.3923	1.687	1.0994	.1638
2.20	1.570	.090,53	.237,3	.3814	1.744	1.1035	.1579
2.25	1.583	.0844,2	.2276	.3709	1.803	1.107	.1522
2.30	1.596	.0787,5	.2183	.3607	1.865	1.111	.1468
2.35	1.608	.0734,9	.2094	.3508	1.929	1.115	.1417
2.40	1.620	.0686,2	.2010	.3413	1.995	1.119	.1369
2.45	1.631	.0641,0	.1930	.3321	2.064	1.123	.1323
2.50	1.642	.0599,0	.1853	.3232	2.135	1.126	.1279
2.55	1.653	.0560,1	.1780	.3146	2.209	1.129	.1237
2.60	1.663	.0523,9	.1710	.3063	2.285	1.132	.1197
2.65	1.673	.0490,3	.1644	.2983	2.364	1.135	.1159
2.70	1.682	.0459,1	.1581	.2905	2.445	1.138	.1123
2.75	1.691	.0430,1	.1520	.2830	2.529	1.141	.1088
2.80	1.699	.0403,2	.1462	.2757	2.616	1.144	.1055
2.85	1.707	.0378,1	.1407	.2687	2.705	1.146	.1023
2.90	1.715	.0354,7	.1354	.2620	2.797	1.149	.09924
2.95	1.723	.0333,0	.1304	.2554	2.892	1.152	.09633
3.00	1.730	.03128	.12560	.2491	2.990	1.154	.09354
3.50	1.790	.01720	.08779	.1959	4.134	1.174	.07111
4.00	1.833	.00994	.06321	.1572	5.608	1.189	.0557 4
4.50	1.864	.00601	.04676	.1285	7.456	1.200	.04479
5.00	1.887	.00378	.03542	.1067	9.721	1.208	.03672
6.00	1.918	.00165	.02160	.07657	15.68	1.220	.02594
7.00	1.938	$.0_3807$	.01406	.05742	23.85	1.227	.01925
8.00	1.951	$.0_3429$	.00963	.04456	34.58	1.232	.01484
9.00	1.960	$.0_3244$	.00687	.03554	48.24	1.235	.01177
10.00	1.967	$.0_3147$	.00507	.02898	65.18	1.238	.00958
∞	1.996	0	0	0	∞	1.249	0

Table 4.15 ISENTROPIC FLOW (Perfect Gas, k = 1.67 exactly) (Concluded)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
0	0	0	2.00,0	1.213	0
.05	.00,995	.00,995	1.99,5	1.212	.00,499
.10	.03,921	.03,921	1.98,0	1.207	.01,980
.15	.08,608	.08,608	1.95,6	1.200	.04,401
.20	.14,793	.14,793	1.92,3	1.190	.07,692
.25	.22,15	.22,15	1.88,2	1.178	.11,76
.30	.30,30	.30,30	1.83,5	1.164	.16,51
.35	.38,89	.38,89	1.78,2	1.149	21,83
.40	.47,56	.47,56	1.724	1.133	275,8
.45	.56,02	.56,02	1.663	1.116	.336,8
.50	.64,00	.64,00	1.600	1.099,7	.400,0
.55	.71,32	.71,32	1.536	1.083,4	.464,5
.60	.77,85	.77,85	1.471	1.067,9	.529,4
.65	.83,52	.83,52	1.406	1.053,4	.594,0
.70	.88,28	.88,28	1.342	1.040,2	.657,7
.75	.92,16	.92,16	1.280	1.028,5	.720,0
.80	.95,18	.95,18	1.220	1.018,6	.780,5
.85	.97,40	.97,40	1.161	1.010,7	.838,9
.90	.98,90	.98,90	1.105	1.004,8	.895,0
.95	.99,74	.99,74	1.051,2	1.001,2	.948,8
1.00	1.00,00	1.00,00	1.000,0	1.000,0	1.000,0
1.05	.997,6	.997,6	.951,2	1.001,3	1.048,8
1.10	.991,0	.991,0	.904,9	1.005,2	1.095,1
1.15	.980,7	.980,7	.861,1	1.011,8	1.138,9
1.20	.967,5	.967,5	.819,7	1.021,4	1.180,2
1.25	.951,8	.951,8	.780,5	1.034,0	1.220
1.30	.934,2	.934,2	.743,5	1.049,8	1.257
1.35	.915,1	.915,1	.708,6	1.069,0	1.291
1.40	.894,8	.894,8	.675,7	1.091,9	1.324
1.45	.873,7	.873,7	.644,7	1.11,87	1.355
1.50	.8521	.8521	.615,4	1.15,0	1.384
1.55	.8301	.8301	.587,8	1.18,6	1.412
1.60	.8080	.8080,	.561,8	1.22,6	1.438
1.65	.7859	.7859	.537,3	1.27,1	1.463
1.70	.7639	.7639	.514,1	1.32,3	1.486

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_4429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.16 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.0 exactly)

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M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
1.75	.7422	.7422	.492,3	1.38,1	1.508
1.80	.7209	.7209	.471,7	1.44,6	1.528
1.85	.7000	.7000	.452,2	1.51,9	1.547
1.90	.679,5	.679,5	.433,8	1.60,0	1.566
1.95	.659,5	.659,5	.416,4	1.69,1	1.584
2.00	.640,0	.640,0	.400,0	1.79,3	1.601
2.05	.621,1	.621,1	.384,4	1.90,7	1.616
2.10	.602,7	.602,7	.369,7	2.03,4	1.630
2.15	.584,9	.584,9	.355,7	2.17,6	1.644
2.20	.567,7	.567,7	.342,5	2.33,6	1.657
2.25	.551,0	.551,0	.329,9	2.51,5	1.670
2.30	.534,8	.534,8	.317,9	2.71,6	1.682
2.35	.519,2	.519,2	.306,6	2.94,2	1.693
2.40	.504,2	.504,2	.295,9	3.19,7	1.704
2.45	.489,7	.489,7	.285,7	3.48,4	1.714
2.50	.475,7	.475,7	.275,9	3.80,8	1.724
2.55	.462,1	.462,1	.266,6	4.1,75	1.733
2.60	.449,0	.449,0	.257,7	4.5,91	1.742
2.65	.436,4	.436,4	.2493	5.0,64	1.751
2.70	.4243	.4243	.2413	5.6,02	1.759
2.75	.4126	.4126	.2336	6.2,15	1.766
2.80	.4013	.4013	.2262	6.9,16	1.774
2.85	.3904	.3904	.2192	7.7,19	1.781
2.90	.3799	.3799	.2125	8.6,40	1.787
2.95	.3698	.3698	.2061	9.6,99	1.794
3.00	.3600	.3600	.2000	10.92	1.800
3.50	.2791	.2791	.1509	41.85	1.849
4.00	.2215	.2215	.1176	212.7	1.882
4.50	.1794	.1794	.09412	1425	1.906
5.00	.1479	.1479	.07692	12519	1.923
6.00	.10519	.10519	.05405	2150_4	1.946
7.00	.07840	.07840	.04000	1060_7	1.960
8.00	.06059	.06059	.03077	1470_{10}	1.969
9.00	.04818	.04818	.02439	5740_{13}	1.976
10.00	.03921	.03921	.01980	6230_{17}	1.980
∞	0	0	0	∞	2.000

Table 4.16 FRICTIONLESS. CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.0 exactly) (Concluded)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
0	0	0	2.10,0	1.228	0
.05	.01,044	.01,097	2.09,4	1.226	.00,524
.10	.04,111	.04,315	2.07,7	1.221	.02,077
.15	.09,009	.09,449	2.04,9	1.213	.04,611
.20	.15,444	.16,184	2.01,1	1.203	.08,046
.25	.23,05	.24,13	1.96,5	1.190	.12,28
.30	.31,44	.32,86	1.91,1	1.174	.17,20
.35	.40,20	.41,95	1.85,1	1.157	.226,7
.40	.48,98	.51,02	1.786	1.140	.285,7
.45	.57,46	.59,73	1.717	1.122	.347,8
.50	.65,40	.67,82	1.647	1.104,0	.411,8
.55	.72,61	.75,10	1.576	1.086,7	.476,6
.60	.78,98	.81,47	1.504	1.070,2	.541,6
.65	.84,46	.86,84	1.434	1.055,0	.605,7
.70	.89,02	.91,23	1.365	1.041,2	.668,6
.75	.92,70	.94,67	1.297	1.029,1	.729,7
.80	.95,54	.97,20	1.232	1.018,9	.788,7
.85	.97,61	.98,92	1.170	1.010,9	.845,3
.90	.98,99	.99,89	1.111	1.005,0	.899,5
.95	.99,76	1.00,23	1.053,8	1.001,3	.951,1
1.00	1.00,00	1.00,00	1.000,0	1.000,0	1.000,0
1.05	.997,9	.993,0	.949,0	1.001,3	1.046,3
1.10	.991,9	.982,1	.900,9	1.005,1	1.090,1
1.15	.982,7	.967,9	.855,5	1.011,6	1.131,4
1.20	.971,0	.951,1	.812,7	1.020,9	1.170,3
1.25	.957,2	.932,2	.772,4	1.033,1	1.207
1.30	.941,8	.911,8	.734,5	1.048,3	1.241
1.35	.925,1	.890,2	.698,9	1.066,5	1.273
1.40	.907,4	.867,8	.665,4	1.088,0	1.304
1.45	.8892	.8449	.633,9	1.113,0	1.333
1.50	.8706	.8217	.604,3	1.141	1.360
1.55	.8518	.7984	.576,5	1.173	1.385
1.60	.8329	.7753	.550,3	1.210	1.409
1.65	.8141	.7524	.525,7	1.251	1.431
1.70	.7955	.7298	.502,5	1.297	1.452

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_3429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.17 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.1 exactly)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
1.75	.7771	.707,6	.480,7	1.34,7	1.472
1.80	.7591	.685,9	.460,1	1.40,3	1.491
1.85	.7415	.664,8	.440,7	1.46,5	1.508
1.90	.724,3	.644,3	.422,4	1.53,2	1.525
1.95	.707,6	.624,3	.405,2	1.60,7	1.541
2.00	.691,4	.604,9	.388,9	1.68,9	1.556
2.05	.675,6	.586,2	.373,5	1.78,0	1.570
2.10	.660,3	.568,1	.358,9	1.87,9	1.583
2.15	.645,6	.550,6	.345,1	1.98,7	1.595
2.20	.631,3	.533,7	.332,1	2.10,6	1.607
2.25	.617,5	.517,4	.319,7	2.23,7	1.618
2.30	.604,2	.501,7	.307,9	2.38,0	1.629
2.35	.591,4	.486,6	.296,8	2.53,7	1.639
2.40	.579,0	.472,0	.286,3	2.70,9	1.649
2.45	.5671	.458,0	.276,3	2.89,7	1.658
2.50	.5556	.444,4	.266,7	3.10,4	1.667
2.55	.5445	.431,4	.2576	3.33,2	1.675
2.60	.5338	.4189	.2489	3.58,1	1.683
2.65	.5235	.4068	.2406	3.85,5	1.690
2.70	.5136	.3952	.2328	4.15,6	1.697
2.75	.5041	.3840	.2253	4.48,7	1.704
2.80	.4949	.3733	.2182	4.85,1	1.711
2.85	.4860	.3629	.2114	5.25,1	1.717
2.90	.4775	.3529	.2049	5.69,2	1.723
2.95	.4693	.3433	.1986	6.1,76	1.729
3.00	.4613	.3341	.1927	6.710	1.734
3.50	.3960	.2578	.1451	16.26	1.777
4.00	.3496	.2040	.1129	42.42	1.806
4.50	.3160	.1648	.09023	115.70	1.827
5.00	.2909	.1357	.07368	322.33	1.842
6.00	.2568	.09631	.05172	2508.	1.862
7.00	.2356	.07169	.03825	18430.	1.874
8.00	.2215	.05536	.02941	1230_3	1.882
9.00	.2116	.04400	.02331	7430_3	1.888
10.00	.2045	.03579	.01892	4010_4	1.892
∞	.1736	0	0	∞	1.909

Table 4.17 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.1 exactly) (Concluded)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
0	0	0	2.20,0	1.242	0
.05	.01,094	.01,203	2.19,3	1.239	.00,548
.10	.04,301	.04,726	2.17,3	1.234	.02,174
.15	.09,408	.10,325	2.14,1	1.226	.04,820
.20	.16,089	.17,627	2.09,9	1.214	.08,397
.25	.23,95	.26,18	2.04,7	1.199	.12,79
.30	.32,55	.35,48	1.98,6	1.183	.17,87
.35	.41,47	.45,07	1.918	1.165	.235,0
.40	.50,34	.54,50	1.846	1.146	.295,3
.45	.58,84	.63,43	1.770	1.127	.358,4
.50	.66,72	.71,60	1.692	1.107,8	.423,1
.55	.73,81	.78,81	1.614	1.089,5	.488,4
.60	.80,03	.84,97	1.536	1.072,2	.553,1
.65	.85,31	.90,04	1.460	1.056,3	.616,8
.70	.89,69	.94,05	1.385	1.042,0	.678,8
.75	.93,18	.97,04	1.313	1.029,6	.738,8
.80	.95,85	.99,10	1.244	1.019,1	.796,4
85	.97,79	1.00,32	1.178	1.010,9	.851,4
.90	.99,07	1.00,81	1.115	1.004,9	.903,7
.95	.99,78	1.00,67	1.056,2	1.001,2	.953,2
1.00	1.000,0	1.00,00	1.000,0	1.000,0	1.000,0
1.05	.998,1	.988,8	.947,1	1.001,3	1.044,1
1.10	.992,7	.974,1	.897,2	1.005,0	1.085,6
1.15	.984,5	.956,4	.850,4	1.011,4	1.124,7
1.20	.974,0	.936,5	.806,5	1.020,4	1.161,3
1.25	.961,7	.914,9	.765,3	1.032,2	1.196
1.30	.948,1	.892,1	.726,6	1.046,7	1.228
1.35	.933,4	.868,5	.690,3	1.064,0	1.258
1.40	.918,0	.8443	.656,3	1.084,3	1.286
1.45	.9021	.8199	.624,5	1.107,7	1.313
1.50	.8859	.7955	.594,6	1.134	1.338
1.55	.8695	.7712	.566,6	1.164	1.361
1.60	.8532	.7473	.540,3	1.197	1.383
1.65	.8370	.723,7	.515,6	1.234	1.404
1.70	.8211	.700,7	.492,4	1.275	1.423

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0 ,429 signifies .000429. The notation 5370 , signifies 5,370,000.

Table 4.18 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.2 exactly)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
1.75	.8054	.678,2	.470,6	1.320	1.441
1.80	.7900	.656,3	.450,1	1.369	1.458
1.85	.7750	.635,1	.430,8	1.42,2	1.474
1.90	.7604	.614,6	.412,6	1.48,0	1.490
1.95	.7462	.594,7	.395,5	1.54,3	1.504
2.00	.7325	.575,5	.379,3	1.61,2	1.517
2.05	.7192	.557,0	.364,1	1.68,7	1.530
2.10	.7063	.539,1	.349,7	1.76,7	1.542
2.15	.6939	.521,9	.336,0	1.85,4	1.553
2.20	.6819	.505,4	.323,1	1.94,8	1.564
2.25	.6703	.489,5	.310,9	2.05,0	1.574
2.30	.6591	.474,2	.299,4	2.15,9	1.584
2.35	.6484	.459,5	.288,4	2.27,7	1.593
2.40	.6381	.445,3	.278,0	2.40,5	1.602
2.45	.6281	.431,7	.268,2	2.54,2	1.610
2.50	.6185	.418,7	.258,8	2.69,0	1.618
2.55	.6093	.406,2	.2499	2.84,9	1.625
2.60	.6004	.394,1	.2414	3.02,1	1.632
2.65	.5918	.382,5	.2334	3.20,5	1.639
2.70	.5836	.371,3	.2257	3.40,3	1.645
2.75	.5757	.3606	.2184	3.61,7	1.651
2.80	.5681	.3503	.2114	3.84,7	1.657
2.85	.5608	.3404	.2047	4.09,4	1.663
2.90	.5537	.3309	.1983	4.35,9	1.668
2.95	.5469	.3217	.1923	4.64,4	1.673
3.00	.5404	.3128	.1864	4.951	1.678
3.50	.4865	.2405	.1401	9.597	1.717
4.00	.4486	.1898	.1089	18.99	1.743
4.50	.4211	.1531	.08696	37.61	1.761
5.00	.4006	.1259	.07097	73.64	1.774
6.00	.3730	.08919	.04977	266.2	1.792
7.00	.3557	.06632	.03679	875.9	1.803
8.00	.3443	.05118	.02828	2621	1.810
9.00	.3363	.04065	.02240	7181	1.815
10.00	.3306	.03306	.01818	18182	1.818
∞	.3056	0	0	∞	1.833

Table 4.18 FRICTIONLESS. CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.2 exactly) (Concluded)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
0	0	0	2.30,0	1.255	0
.05	.01,143	.01,314	2.29,3	1.253	.00,573
.10	.04,489	.05,155	2.27,0	1.247	.02,270
.15	.09,803	.11,236	2.23,4	1.237	.05,028
.20	.16,726	.191,20	2.18,6	1.224	.08,745
.25	.24,82	.28,28	2.12,7	1.209	.13,29
.30	.33,63	.38,16	2.05,9	1.191	.18,53
.35	.42,70	.48,22	1.98,4	1.172	.243,0
.40	.51,65	.58,00	1.904	1.152	.304,6
.45	.60,15	.67,13	1.821	1.131	.368,7
.50	.67,96	.75,33	1.736	1.111,2	.434,0
.55	.74,94	.82,44	1.651	1.091,9	.499,4
.60	.80,99	.88,37	1.567	1.073,9	.564,0
.65	.86,11	.93,12	1.485	1.057,4	.627,2
.70	.90,29	.96,73	1.405	1.042,6	.688,5.
.75	.93,61	.99,28	1.328	1.029,9	.747,3
.80	.96,14	1.00,88	1.255	1.019,3	.803,5
.85	.97,95	1.01,63	1.186	1.010,9	.856,9
.90	.99,14	1.01,66	1.120	1.004,9	.907,5
.95	.99,80	1.01,08	1.0583	1.001,2	.955,2
1.00	1.000,0	1.000,0	1.000,0	1.000,0	1.000,0
1.05	.998,2	.985,1	.945,2	1.001,2	1.042,1
1.10	.993,3	.966,9	.893,9	1.004,9	1.081,6
1.15	.985,9	.946,1	.845,8	1.011,1	1.118,6
1.20	.976,5	.923,5	.800,8	1.019,9	1.153,2
1.25	.965,6	.899,6	.758,8	1.031,2	1.186
1.30	.953,4	.874,7	.719,4	1.045,1	1.216
1.35	.940,4	.8493	.682,6	1.061,7	1.244
1.40	.9268	.8237	.648,3	1.080,9	1.270
1.45	.9128	.7980	.616,1	1.102,8	1.295
1.50	.8986	.7726	.586,0	1.128	1.318
1.55	.8843	.747,5	.557,8	1.155	1.340
1.60	.8701	.723,0	.531,4	1.185	1.360
1.65	.8560	.699,0	.506,7	1.219	1.379
1.70	.8421	.675,6	.483,5	1.256	1.397

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_4429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.19 FRICTIONLESS CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.3 exactly)

M	T_o T_o^*	T, T^*	p p^*	p_o p_o^*	ρ^*/ρ V/V^*
1.75	.8285	.652,9	.461,7	1.296	1.414
1.80	.8153	.630,9	.441,3	1.340	1.430
1.85	.8024	.609,7	.422,1	1.387	1.445
1.90	.7898	.589,2	.404,0	1.438	1.459
1.95	.7776	.569,5	.387,0	1.493	1.472
2.00	.7659	.550,5	.371,0	1.552	1.484
2.05	.7545	.532,2	.355,9	1.61,5	1.495
2.10	.7435	.514,6	.341,6	1.68,3	1.506
2.15	.7329	.497,7	.328,1	1.75,5	1.517
2.20	.7227	.481,5	.315,4	1.83,2	1.527
2.25	.7129	.465,9	.303,4	1.91,5	1.536
2.30	.7034	.451,0	.292,0	2.00,3	1.545
2.35	.6943	.436,7	.281,2	2.09,7	1.553
2.40	.6855	.422,9	.271,0	2.19,7	1.561
2.45	.6771	.409,7	.261,3	2.30,3	1.568
2.50	.6690	.397,1	.252,1	2.41,6	1.575
2.55	.6612	.385,0	.243,3	2.53,6	1.582
2.60	.6537	.373,3	.2350	2.66,4	1.588
2.65	.6465	.362,1	.2271	2.80,0	1.594
2.70	.6396	.351,3	.2195	2.94,4	1.600
2.75	.6329	.3410	.2123	3.09,6	1.606
2.80	.6265	.3311	.2055	3.25,8	1.611
2.85	.6203	.3216	.1990	3.42,9	1.616
2.90	.6144	.3124	.1928	3.61,1	1.621
2.95	.6087	.3036	.1868	3.80,4	1.626
3.00	.6032	.2952	.1811	4.007	1.630
3.50	.5582	.2262	.1359	6.806	1.665
4.00	.5265	.1781	.1055	11.57	1.688
4.50	.5037	.1435	.08417	19.44	1.704
5.00	.4867	.1178	.06866	32.06	1.716
6.00	.4639	.08335	.04812	76.97	1.732
7.00	.4496	.06192	.03555	191.3	1.742
8.00	.4402	.04775	.02732	413.4	1.748
9.00	.4336	.03792	.02164	833.4	1.753
10.00	.4289	.03082	.01756	1582	1.756
∞	.4083	0	0	∞	1.769

Table 4.19 FRICTIONLESS CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.3 exactly) (Concluded)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
0	0	0	2.400,0	1.2679	0
.01	.0$_3$4,80	.0$_3$5,76	2.399,7	1.2678	.0$_3$2,40
.02	.001,92	.002,30	2.398,7	1.2675	.0$_3$9,59
.03	.004,31	.005,16	2.397,0	1.2671	.002,16
.04	.007,65	.009,17	2.394,6	1.2665	.003,83
.05	.011,92	.014,30	2.391,6	1.2657	.005,98
.06	.017,12	.020,53	2.388,0	1.2647	.008,60
.07	.023,22	.027,84	2.383,7	1.2636	.011,68
.08	.030,21	.036,21	2.378,7	1.2623	.015,22
.09	.038,07	.045,62	2.373,1	1.2608	.019,22
.10	.046,78	.056,02	2.366,9	1.2591	.023,67
.11	.056,30	.067,39	2.360,0	1.2573	.028,56
.12	.066,61	.079,70	2.352,6	1.2554	.033,88
.13	.077,68	.092,90	2.344,5	1.2533	.039,62
.14	.089,47	.106,95	2.335,9	1.2510	.0457,8
.15	.101,96	.121,81	2.326,7	1.2486	.0523,5
.16	.115,11	.137,43	2.317,0	1.2461	.0593,1
.17	.128,88	.153,77	2.306,7	1.2434	.0666,6
.18	.143,24	.170,78	2.295,9	1.2406	.0743,8
.19	.158,14	.188,41	2.284,5	1.2377	.0824,7
.20	.173,55	.206,61	2.2727	1.2346	.0909,1
.21	.1894,3	.225,33	2.2604	1.2314	.0996,9
.22	.2057,4	.2445,2	2.2477	1.2281	.1087,9
.23	.2224,4	.2641,3	2.2345	1.2248	.1182,0
.24	.2394,8	.2841,1	2.2209	1.2213	.1279,2
.25	.2568,4	.3044,0	2.2069	1.2177	.1379,3
.26	.2744,6	.3249,6	2.1925	1.2140	.1482,1
.27	.2923,1	.3457,3	2.1777	1.2102	.1587,6
.28	.3103,5	.3666,7	2.1626	1.2064	.1695,5
.29	.3285,5	.3877,3	2.1472	1.2025	.1805,8
.30	.3468,6	.4088,7	2.1314	1.1985	.1918,3
.31	.3652,5	.4300,4	2.1154	1.1945	.2032,9
.32	.3836,9	.4511,9	2.0991	1.1904	.2149,4
.33	.4021,4	.4722,8	2.0825	1.1863	.2267,8
.34	.4205,7	.4932,7	2.0657	1.1821	.2387,9
.35	.4389,4	.5141,3	2.0487	1.1779	.2509,6
.36	.4572,3	.5348,2	2.0314	1.1737	.2632,7
.37	.4754,1	.5553,0	2.0140	1.1695	.2757,2
.38	.4934,6	.5755,3	1.9964	1.1652	.2882,8
.39	.5113,4	.5954,9	1.9787	1.1609	.3009,5
.40	.5290,3	.6151,5	1.9608	1.1566	.3137,2
.41	.5465,1	.6344,8	1.9428	1.1523	.3265,8
.42	.5637,6	.6534,5	1.9247	1.1480	.3395,1
.43	.5807,5	.6720,5	1.9065	1.1437	.3525,1
.44	.5974,8	.690,25	1.8882	1.1394	.36556

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are vaild for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0$_3$429 signifies .000429. The notation 5370$_4$ signifies 5,370,000.

Table 4.20 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.4 exactly)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
.45	.6139,3	.708,03	1.8699	1.1351	.37865
.46	.6300,7	.725,38	1.8515	1.1308	.39178
.47	.6458,9	.742,28	1.8331	1.1266	.40493
.48	.6613,9	.758,71	1.8147	1.1224	.41810
.49	.6765,5	.774,66	1.7962	1.1182	.43127
.50	.6913,6	.790,12	1.7778	1.1140	.44445
.51	.7058,1	.805,09	1.7594	1.1099	.45761
.52	.7199,0	.819,55	1.7410	1.1059	.47075
.53	.7336,1	.833,51	1.7226	1.1019	.48387
.54	.7469,5	.846,95	1.7043	1.0979	.49696
.55	.7599,1	.859,87	1.6860	1.09397	.5100,1
.56	.7724,8	.872,27	1.6678	1.09010	.5230,2
.57	.7846,7	.884,15	1.6496	1.08630	.5359,7
.58	.7964,7	.895,52	1.6316	1.08255	.5488,7
.59	.8078,9	.906,37	1.6136	1.07887	.5617,0
.60	.8189,2	.916,70	1.5957	1.0752,5	.5744,7
.61	.8295,6	.926,53	1.5780	1.0717,0	.5871,6
.62	.8398,2	.935,85	1.5603	1.068,21	.5997,8
.63	.8497,0	.944,66	1.5427	1.0648,0	.6123,2
.64	.8592,0	.952,98	1.5253	1.0614,6	.6247,7
.65	.8683,3	.960,81	1.5080	1.0582,0	.6371,3
.66	.8770,9	.968,16	1.4908	1.0550,2	.6494,1
.67	.8854,8	.975,03	1.4738	1.0519,2	.6615,9
.68	.8935,0	.981,44	1.4569	1.0489,0	.6736,7
.69	.9011,7	.987,39	1.4401	1.0459,6	.6856,4
.70	.9085,0	.992,89	1.4235	1.0431,0	.6975,1
.71	.9154,8	.997,96	1.4070	1.0403,3	.7092,7
.72	.9221,2	1.002,60	1.3907	1.0376,4	.7209,3
.73	.9284,3	1.0068,2	1.3745	1.0350,4	.7324,8
.74	.9344,2	1.0106,2	1.3585	1.0325,3	.7439,2
.75	.9400,9	1.0140,3	1.3427	1.0301,0	.7552,5
.76	.9454,6	1.0170,6	1.3270	1.0277,6	.7664,6
.77	.9505,2	1.0197,1	1.3115	1.0255,2	.7775,5
.78	.9552,8	1.0219,8	1.2961	1.0233,7	.7885,2
.79	.9597,5	1.0239,0	1.2809	1.0213,1	.7993,8
.80	.9639,4	1.0254,8	1.2658	1.0193,4	.8101,2
.81	.9678,6	1.0267,2	1.2509	1.0174,6	.8207,5
.82	.9715,2	1.0276,3	1.2362	1.0156,9	.8312,6
.83	.9749,2	1.0282,3	1.2217	1.0139,9	.8416,4
.84	.9780,7	1.0285,3	1.2073	1.0124,0	.8519,0
.85	.9809,7	1.0285,4	1.1931	1.0109,1	.8620,4
.86	.9836,3	1.0282,6	1.1791	1.00951	.8720,6
.87	.9860,7	1.0277,1	1.1652	1.00819	.8819,6
.88	.9882,8	1.0269,0	1.1515	1.00698	.8917,5
.89	.9902,8	1.0258,3	1.1380	1.00587	.9014,2

Table 4.20 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.4 exactly) (Continued)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
.90	.9920,7	1.0245,1	1.1246	1.0048,5	.9109,7
.91	.9936,6	1.0229,7	1.1114	1.0039,3	.9203,9
.92	.9950,6	1.0212,0	1.0984,2	1.0031,0	.9297,0
.93	.9962,7	1.0192,1	1.0855,5	1.0023,7	.9388,9
.94	.9972,9	1.0170,2	1.0728,5	1.0017,4	.9479,6
.95	.9981,4	1.0146,3	1.0603,0	1.0012,1	.9569,2
.96	.9988,3	1.0120,5	1.0479,2	1.0007,7	.9657,6
.97	.9993,5	1.0092,9	1.0357,0	1.0004,3	.9744,9
.98	.9997,2	1.0063,6	1.0236,4	1.0001,9	.9831,1
.99	.9999,3	1.0032,6	1.0117,4	1.0000,4	.9916,1
1.00	1.0000,0	1.0000,0	1.0000,0	1.0000,0	1.0000,0
1.01	.9999,3	.9965,9	.9884,1	1.0000,4	1.0082,8
1.02	.9997,3	.9930,4	.9769,7	1.0001,9	1.0164,4
1.03	.9994,0	.9893,6	.9656,9	1.0004,3	1.0245,0
1.04	.9989,5	.9855,5	.9545,6	1.0007,7	1.0324,6
1.05	.9983,8	.9816,1	.9435,8	1.0012,1	1.0403,0
1.06	.9976,9	.9775,5	.9327,5	1.0017,5	1.0480,4
1.07	.9969,0	.9733,9	.9220,6	1.0023,8	1.0556,7
1.08	.9960,0	.9691,3	.9115,2	1.0031,1	1.0632,0
1.09	.9950,1	.9647,7	.9011,2	1.0039,4	1.0706,2
1.10	.9939,2	.9603,1	.8908,6	1.0048,6	1.0779,5
1.11	.9927,4	.9557,7	.8807,5	1.0058,8	1.0851,8
1.12	.9914,8	.9511,5	.8707,8	1.0069,9	1.0923,0
1.13	.9901,3	.9464,6	.8609,4	1.0082,0	1.0993,3
1.14	.9887,1	.9416,9	.8512,3	1.0095,1	1.1062,6
1.15	.9872,1	.9368,5	.8416,6	1.0109,2	1.1131
1.16	.9856,4	.9319,5	.8322,2	1.0124,3	1.1198
1.17	.9840,0	.9270,0	.8229,2	1.0140,3	1.1264
1.18	.9823,0	.9220,0	.8137,4	1.0157,2	1.1330
1.19	.9805,4	.9169,5	.8046,8	1.0175,2	1.1395
1.20	.9787,2	.91185	.7957,6	1.0194,1	1.1459
1.21	.9768,5	.90671	.7869,5	1.0214,0	1.1522
1.22	.9749,2	.90153	.7782,7	1.0234,8	1.1584
1.23	.97294	.89632	.7697,1	1.0256,6	1.1645
1.24	.97092	.89108	.7612,7	1.0279,4	1.1705
1.25	.96886	.88581	.7529,4	1.0303,2	1.1764
1.26	.96675	.88052	.7447,3	1.0328,0	1.1823
1.27	.96461	.87521	.7366,3	1.0353,6	1.1881
1.28	.96243	.86988	.7286,5	1.0380,3	1.1938
1.29	.96022	.86453	.7207,8	1.0408,0	1.1994
1.30	.95798	.85917	.7130,1	1.0436,5	1.2050
1.31	.95571	.85380	.7053,5	1.0466,1	1.2105
1.32	.95341	.84843	.6978,0	1.0496,7	1.2159
1.33	.95108	.84305	.6903,5	1.0528,3	1.2212
1.34	.94873	.83766	.6830,1	1.0560,8	1.2264

Table 4.20 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.4 exactly) (Continued)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
1.35	.94636	.83227	.6757,7	1.0594,3	1.2316
1.36	.94397	.82689	.6686,3	1.0628,8	1.2367
1.37	.94157	.82151	.6615,9	1.0664,2	1.2417
1.38	.93915	.81613	.6546,4	1.0700,6	1.2467
1.39	.93671	.81076	.6477,8	1.0738,0	1.2516
1.40	.93425	.80540	.6410,2	1.0776,5	1.2564
1.41	.93178	.80004	.6343,6	1.0815,9	1.2612
1.42	.92931	.79469	.6277,9	1.0856,3	1.2659
1.43	.92683	.78936	.6213,1	1.0897,7	1.2705
1.44	.92434	.78405	.6149,1	1.0940,0	1.2751
1.45	.92184	.77875	.6086,0	1.0983	1.2796
1.46	.91933	.77346	.6023,7	1.1028	1.2840
1.47	.91682	.76819	.5962,3	1.1073	1.2884
1.48	.91431	.76294	.5901,8	1.1120	1.2927
1.49	.91179	.75771	.5842,1	1.1167	1.2970
1.50	.90928	.75250	.5783,1	1.1215	1.3012
1.51	.90676	.74731	.5725,0	1.1264	1.3054
1.52	.90424	.74215	.5667,7	1.1315	1.3095
1.53	.90172	.73701	.5611,1	1.1367	1.3135
1.54	.89920	.73189	.5555,3	1.1420	1.3175
1.55	.89669	.72680	.5500,2	1.1473	1.3214
1.56	.89418	.72173	.5445,8	1.1527	1.3253
1.57	.89167	.71669	.5392,2	1.1582	1.3291
1.58	.88917	.71168	.5339,3	1.1639	1.3329
1.59	.88668	.70669	.5287,1	1.1697	1.3366
1.60	.88419	.70173	.5235,6	1.1756	1.3403
1.61	.88170	.69680	.5184,8	1.1816	1.3439
1.62	.87922	.69190	.5134,6	1.1877	1.3475
1.63	.87675	.68703	.5085,1	1.1939	1.3511
1.64	.87429	.68219	.5036,3	1.2002	1.3546
1.65	.87184	.67738	.4988,1	1.2066	1.3580
1.66	.86940	.67259	.4940,5	1.2131	1.3614
1.67	.86696	.66784	.4893,5	1.2197	1.3648
1.68	.86453	.66312	.4847,1	1.2264	1.3681
1.69	.86211	.65843	.4801,4	1.2332	1.3713
1.70	.85970	.65377	.4756,3	1.2402	1.3745
1.71	.85731	.64914	.4711,7	1.2473	1.3777
1.72	.85493	.64455	.4667,7	1.2545	1.3809
1.73	.85256	.63999	.4624,2	1.2618	1.3840
1.74	.85020	.63546	.4581,3	1.2692	1.3871
1.75	.84785	.63096	.4539,0	1.2767	1.3901
1.76	.84551	.62649	.4497,2	1.2843	1.3931
1.77	.84318	.62205	.4455,9	1.2920	1.3960
1.78	.84087	.61765	.4415,2	1.2998	1.3989
1.79	.83857	.61328	.4375.0	1.3078	1.4018

Table 4.20 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.4 exactly) (Continued)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
1.80	.83628	.60894	.4335,3	1.3159	1.4046
1.81	.83400	.60463	.4296,0	1.3241	1.4074
1.82	.83174	.60036	.4257,3	1.3324	1.4102
1.83	.82949	.59612	.4219,1	1.3408	1.4129
1.84	.82726	.59191	.4181,3	1.3494	1.4156
1.85	.82504	.58773	.4144,0	1.3581	1.4183
1.86	.82283	.58359	.41072	1.3669	1.4209
1.87	.82064	.57948	.40708	1.3758	1.4235
1.88	.81846	.57540	.40349	1.3848	1.4261
1.89	.81629	.57135	.39994	1.3940	1.4286
1.90	.81414	.56734	.39643	1.4033	1.4311
1.91	.81200	.56336	.39297	1.4127	1.4336
1.92	.80987	.55941	.38955	1.4222	1.4360
1.93	.80776	.55549	.38617	1.4319	1.4384
1.94	.80567	.55160	.38283	1.4417	1.4408
1.95	.80359	.54774	.37954	1.4516	1.4432
1.96	.80152	.54391	.37628	1.4616	1.4455
1.97	.79946	.54012	.37306	1.4718	1.4478
1.98	.79742	.53636	.36988	1.4821	1.4501
1.99	.79540	.53263	.36674	1.4925	1.4523
2.00	.79339	.52893	.36364	1.5031	1.4545
2.01	.79139	.52526	.36057	1.5138	1.4567
2.02	.78941	.52161	.35754	1.5246	1.4589
2.03	.78744	.51800	.35454	1.5356	1.4610
2.04	.78549	.51442	.35158	1.5467	1.4631
2.05	.78355	.51087	.34866	1.5579	1.4652
2.06	.78162	.50735	.34577	1.5693	1.4673
2.07	.77971	.50386	.34291	1.5808	1.4694
2.08	.77781	.50040	.34009	1.5924	1.4714
2.09	.77593	.49697	.33730	1.6042	1.4734
2.10	.77406	.49356	.33454	1.6161	1.4753
2.11	.77221	.49018	.33181	1.6282	1.4773
2.12	.77037	.48683	.32912	1.6404	1.4792
2.13	.76854	.48351	.32646	1.6528	1.4811
2.14	.76673	.48022	.32383	1.6653	1.4830
2.15	.76493	.47696	.32122	1.6780	1.4849
2.16	.76314	.47373	.31864	1.6908	1.4867
2.17	.76137	.47052	.31610	1.7037	1.4885
2.18	.75961	.46734	.31359	1.7168	1.4903
2.19	.75787	.46419	.31110	1.7300	1.4921
2.20	.75614	.46106	.30864	1.7434	1.4939
2.21	.75442	.45796	.30621	1.7570	1.4956
2.22	.75271	.45489	.30381	1.7707	1.4973
2.23	.75102	.45184	.30143	1.7846	1.4990
2.24	.74934	.44882	.29908	1.7986	1.5007

Table 4.20 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.4 exactly) (Continued)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
2.25	.74767	.44582	.29675	1.8128	1.5024
2.26	.74602	.44285	.29445	1.8271	1.5040
2.27	.74438	.43990	.29218	1.8416	1.5056
2.28	.74275	.43698	.28993	1.8562	1.5072
2.29	.74114	.43409	.28771	1.8710	1.5088
2.30	.73954	.43122	.28551	1.8860	1.5104
2.31	.73795	.42837	.28333	1.9012	1.5119
2.32	.73638	.42555	.28118	1.9165	1.5134
2.33	.73482	.42276	.27905	1.9320	1.5150
2.34	.73327	.41999	.27695	1.9476	1.5165
2.35	.73173	.41724	.27487	1.9634	1.5180
2.36	.73020	.41451	.27281	1.9794	1.5195
2.37	.72868	.41181	.27077	1.9955	1.5209
2.38	.72718	.40913	.26875	2.0118	1.5223
2.39	.72569	.40647	.26675	2.0283	1.5237
2.40	.72421	.40383	.26478	2.0450	1.5252
2.41	.72274	.40122	.26283	2.0619	1.5266
2.42	.72129	.39863	.26090	2.0789	1.5279
2.43	.71985	.39606	.25899	2.0961	1.5293
2.44	.71842	.39352	.25710	2.1135	1.5306
2.45	.71700	.39100	.25523	2.1311	1.5320
2.46	.71559	.38850	.25337	2.1489	1.5333
2.47	.71419	.38602	.25153	2.1669	1.5346
2.48	.71280	.38356	.24972	2.1850	1.5359
2.49	.71142	.38112	.24793	2.2033	1.5372
2.50	.71005	.37870	.24616	2.2218	1.5385
2.51	.70870	.37630	.24440	2.2405	1.5398
2.52	.70736	.37392	.24266	2.2594	1.5410
2.53	.70603	.37157	.24094	2.2785	1.5422
2.54	.70471	.36923	.23923	2.2978	1.5434
2.55	.70340	.36691	.23754	2.3173	1.5446
2.56	.70210	.36461	.23587	2.3370	1.5458
2.57	.70081	.36233	.23422	2.3569	1.5470
2.58	.69953	.36007	.23258	2.3770	1.5482
2.59	.69825	.35783	.23096	2.3972	1.5494
2.60	.69699	.35561	.22936	2.4177	1.5505
2.61	.69574	.35341	.22777	2.4384	1.5516
2.62	.69450	.35123	.22620	2.4593	1.5527
2.63	.69327	.34906	.22464	2.4804	1.5538
2.64	.69205	.34691	.22310	2.5017	1.5549
2.65	.69084	.34478	.22158	2.5233	1.5560
2.66	.68964	.34267	.22007	2.5451	1.5571
2.67	.68845	.34057	.21857	2.5671	1.5582
2.68	.68727	.33849	.21709	2.5892	1.5593
2.69	.68610	.33643	.21562	2.6116	1.5603

Table 4.20 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.4 exactly) (Continued)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
2.70	.68494	.33439	.21417	2.6342	1.5613
2.71	.68378	.33236	.21273	2.6571	1.5623
2.72	.68263	.33035	.21131	2.6802	1.5633
2.73	.68150	.32836	.20990	2.7035	1.5644
2.74	.68038	.32638	.20850	2.7270	1.5654
2.75	.67926	.32442	.20712	2.7508	1.5663
2.76	.67815	.32248	.20575	2.7748	1.5673
2.77	.67704	.32055	.20439	2.7990	1.5683
2.78	.67595	.31864	.20305	2.8235	1.5692
2.79	.67487	.31674	.20172	2.8482	1.5702
2.80	.67380	.31486	.20040	2.8731	1.5711
2.81	.67273	.31299	.19909	2.8982	1.5721
2.82	.67167	.31114	.19780	2.9236	1.5730
2.83	.67062	.30931	.19652	2.9493	1.5739
2.84	.66958	.30749	.19525	2.9752	1.5748
2.85	.66855	.30568	.19399	3.0013	1.5757
2.86	.66752	.30389	.19274	3.0277	1.5766
2.87	.66650	.30211	.19151	3.0544	1.5775
2.88	.66549	.30035	.19029	3.0813	1.5784
2.89	.66449	.29860	.18908	3.1084	1.5792
2.90	.66350	.29687	.18788	3.1358	1.5801
2.91	.66252	.29515	.18669	3.1635	1.5809
2.92	.66154	.29344	.18551	3.1914	1.5818
2.93	.66057	.29175	.18435	3.2196	1.5826
2.94	.65961	.29007	.18320	3.2481	1.5834
2.95	.65865	.28841	.18205	3.2768	1.5843
2.96	.65770	.28676	.18091	3.3058	1.5851
2.97	.65676	.28512	.17978	3.3351	1.5859
2.98	.65583	.28349	.17867	3.3646	1.5867
2.99	.65490	.28188	.17757	3.3944	1.5875
3.00	.65398	.28028	.17647	3.4244	1.5882
3.50	.61580	.21419	.13223	5.3280	1.6198
4.00	.58909	.16831	.10256	8.2268	1.6410
4.50	.56983	.13540	.08177	12.502	1.6559
5.00	.55555	.11111	.06667	18.634	1.6667
6.00	.53633	.07849	.04669	38.946	1.6809
7.00	.52437	.05826	.03448	75.414	1.6896
8.00	.51646	.04491	.02649	136.62	1.6954
9.00	.51098	.03565	.02098	233.88	1.6993
10.00	.50702	.02897	.01702	381.62	1.7021
∞	.48980	0	0	∞	1.7143

Table 4.20 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.4 exactly) (Concluded)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
0	0	0	2.67,0	1.29,9	0
.05	.01,325	.01,767	2.65,9	1.29,7	.00,665
.10	.05,183	.06,896	2.62,6	1.28,9	.02,626
.15	.11,243	.14,90	2.57,3	1.276	.05,790
.20	.19,020	.25,06	2.50,3	1.259	.10,011
.25	.27,94	.36,53	2.41,8	1.239	.15,11
.30	.37,42	.48,49	2.32,1	1.216	.20,89
.35	.46,93	.60,18	2.216	1.192	.271,5
.40	.56,06	.71,03	2.107	1.168	.337,1
.45	.64,48	.80,62	1.995	1.144	.404,0
.50	.72,01	.88,70	1.884	1.120,2	.470,9
.55	.78,53	.95,19	1.774	1.098,1	.536,6
.60	.84,02	1.00,10	1.66,7	1.077,8	.600,3
.65	.88,53	1.03,54	1.56,5	1.059,7	.661,4
.70	.92,13	1.05,65	1.46,8	1.043,8	.719,5
.75	.94,91	1.06,62	1.37,7	1.030,3	.774,4
.80	.96,97	1.06,60	1.29,1	1.019,3	.826,0
.85	.98,42	1.05,78	1.21,0	1.010,8	.874,2
.90	.993,5	1.04,32	1.13,5	1.004,8	.919,2
.95	.998,5	1.023,5	1.06,49	1.001,2	.961,1
1.00	1.000,0	1.000,0	1.00,00	1.000,0	1.000,0
1.05	.998,7	.973,6	.939,8	1.001,2	1.036,1
1.10	.995,2	.945,4	.883,9	1.004,6	1.069,5
1.15	.989,9	.915,8	.832,1	1.010,3	1.100,5
1.20	.983,3	.8855	.784,2	1.018,1	1.129,2
1.25	.975,7	.8550	.739,7	1.028,0	1.156
1.30	.967,4	.8246	.698,5	1.040,0	1.181
1.35	.9586	.794,6	.660,3	1.054,0	1.204
1.40	.9495	.765,2	.624,9	1.070,0	1.225
1.45	.9403	.736,5	.591,9	1.088,0	1.245
1.50	.9310	.708,7	.561,2	1.108	1.263
1.55	.9217	.681,8	.532,7	1.130	1.280
1.60	.9125	.655,9	.506,2	1.154	1.296
1.65	.9035	.630,9	.481,4	1.179	1.311
1.70	.8947	.606,9	.458,3	1.206	1.324

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0 ,429 signifies .000429. The notation 5370 , signifies 5,370,000.

Table 4.21 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.67 exactly)

M	T_o/T_o^*	T/T^*	p/p^*	p_o/p_o^*	ρ^*/ρ V/V^*
1.75	.8862	.584,0	.436,7	1.235	1.337
1.80	.8779	.562,0	.416,5	1.266	1.349
1.85	.8699	.541,0	.397,6	1.299	1.360
1.90	.8621	.520,9	.379,9	1.334	1.371
1.95	.8546	.501,8	.363,3	1.370	1.381
2.00	.8474	.483,5	.347,7	1.408	1.391
2.05	.8405	.466,0	.333,0	1.448	1.400
2.10	.8338	.449,3	.319,2	1.490	1.408
2.15	.8274	.433,4	.306,2	1.534	1.415
2.20	.8213	.418,3	.294,0	1.580	1.423
2.25	.8154	.403,8	.282,4	1.628	1.430
2.30	.8097	.389,9	.271,5	1.678	1.436
2.35	.8043	.376,7	.261,2	1.729	1.442
2.40	.7991	.364,1	.251,4	1.783	1.448
2.45	.7941	.352,1	.242,2	1.839	1.454
2.50	.7893	.340,6	.233,4	1.897	1.459
2.55	.7847	.329,6	.225,1	1.956	1.464
2.60	.7803	.319,1	.2173	2.018	1.469
2.65	.7761	.309,0	.2098	2.082	1.473
2.70	.7721	.2994	.2027	2.148	1.477
2.75	.7682	.2902	.1959	2.216	1.481
2.80	.7644	.2814	.1895	2.287	1.485
2.85	.7608	.2730	.1834	2.360	1.489
2.90	.7574	.2649	.1775	2.435	1.493
2.95	.7541	.2571	.1719	2.512	1.496
3.00	.7509	.2497	.1666	2.587	1.499
3.50	.7251	.1897	.1244	3.521	1.524
4.00	.7072	.1484	.09632	4.716	1.541
4.50	.6943	.1191	.07669	6.213	1.553
5.00	.6848	.0975	.06246	8.044	1.561
6.00	.6721	.06870	.04368	12.86	1.573
7.00	.6642	.05092	.03224	19.44	1.580
8.00	.6590	.03920	.02475	28.07	1.584
9.00	.6553	.03110	.01959	39.05	1.587
10.00	.6528	.02526	.01589	52.66	1.589
∞	.6414	0	0	∞	1.599

Table 4.21 FRICTIONLESS, CONSTANT-AREA FLOW WITH CHANGE IN STAGNATION TEMPERATURE (Perfect Gas, k = 1.67 exactly) (Concluded)

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M	T/T*	p/p*	p_o/p_o^*	V/V^* ρ^*/ρ	F/F*	$4fL_{max}/D$
0	1.000	∞	∞	0	∞	∞
.05	1.000	2,0.000	1,2.146	.0500	10.,025	3,93.01
.10	1.000	1,0.000	,6.096	.1000	5.,050	,94.39
.15	1.000	6.,667	4.,089	.1500	3.,408	3,9.65
.20	1.000	5.,000	3.,094	.2000	2.6,00	2,0.78
.25	1.000	4.0,00	2.5,03	.2500	2.1,25	1,2.23
.30	1.000	3.3,33	2.1,15	.3000	1.8,17	7.,703
.35	1.000	2.8,57	1.8,42	.3500	1.6,04	5.,064
.40	1.000	2.5,00	1.6,43	.4000	1.45,0	3.,417
.45	1.000	2.2,22	1.49,2	.4500	1.33,6	2.3,41
.50	1.000	2.00,0	1.37,5	.5000	1.25,0	1.6,14
.55	1.000	1.81,8	1.28,3	.5500	1.18,4	1.1,10
.60	1.000	1.66,7	1.21,0	.6000	1.13,3	.7,561
.65	1.000	1.53,9	1.15,3	.6500	1.09,42	.5,053
.70	1.000	1.42,9	1.10,7	.7000	1.06,43	.3,275
.75	1.000	1.33,3	1.07,14	.7500	1.04,17	.20,24
.80	1.000	1.25,0	1.04,41	.8000	1.02,50	.11,62
.85	1.000	1.17,6	1.02,40	.8500	1.01,32	.05,904
.90	1.000	1.11,1	1.01,04	.9000	1.005,6	.02,385
.95	1.000	1.05,26	1.00,26	.9500	1.001,3	.00,545
1.00	1.000	1.00,00	1.00,00	1.0000	1.000,0	0
1.05	1.000	.952,4	1.00,25	1.0500	1.001,2	.00,461
1.10	1.000	.909,1	1.00,97	1.100	1.004,5	.01,707
1.15	1.000	.869,5	1.02,17	1.150	1.009,8	.03,567
1.20	1.000	.833,3	1.03,84	1.200	1.016,7	.059,09
1.25	1.000	.800,0	1.05,98	1.250	1.025,0	.086,29
1.30	1.000	.769,2	1.08,62	1.300	1.034,6	.116,4
1.35	1.000	.740,7	1.11,8	1.350	1.045,3	.148,9
1.40	1.000	.714,3	1.15,4	1.400	1.057,1	.183,1
1.45	1.000	.689,7	1.19,6	1.450	1.069,8	.218,8
1.50	1.000	.666,7	1.24,5	1.500	1.083,3	.255,4
1.55	1.000	.645,2	1.30,0	1.550	1.097,6	.292,7
1.60	1.000	.625,0	1.36,3	1.600	1.112	.3306
1.65	1.000	.606,1	1.43,4	1.650	1.128	.3689
1.70	1.000	.588,2	1.51,4	1.700	1.144	.4073

Notes: (1) For values of M from 0 to 3.00. all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_{,}429$ signifies .000429. The notation $5370_{,}$ signifies 5,370,000.

Table 4.22 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.0 exactly)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
1.75	1.000	.571,4	1.60,3	1.750	1.161	.4458
1.80	1.000	.555,6	1.70,3	1.800	1.178	.4842
1.85	1.000	.540,6	1.81,5	1.850	1.195	.5225
1.90	1.000	.526,3	1.94,1	1.900	1.213	.5607
1.95	1.000	.512,8	2.08,2	1.950	1.231	.5986
2.00	1.000	.500,0	2.24,1	2.000	1.250	.6363
2.05	1.000	.487,8	2.41,9	2.050	1.269	.6736
2.10	1.000	.476,2	2.62,0	2.100	1.288	.7106
2.15	1.000	.465,1	2.84,6	2.150	1.308	.7472
2.20	1.000	.454,5	3.10,0	2.200	1.327	.7835
2.25	1.000	.444,4	3.38,8	2.250	1.347	.8194
2.30	1.000	.4348	3.71,4	2.300	1.367	.8549
2.35	1.000	.4256	4.0,83	2.350	1.388	.8900
2.40	1.000	.4167	4.5,02	2.400	1.408	.9246
2.45	1.000	.4082	4.9.79	2.450	1.429	.9588
2.50	1.000	.4000	5.5,22	2.500	1.450	.9926
2.55	1.000	.3922	6.1,42	2.550	1.471	1.0260
2.60	1.000	.3847	6.8,52	2.600	1.492	1.0590
2.65	1.000	.3774	7.6,65	2.650	1.514	1.0916
2.70	1.000	.3704	8.6,00	2.700	1.535	1.1237
2.75	1.000	.3636	9.6,76	2.750	1.557	1.155
2.80	1.000	.3571	10.9,2	2.800	1.579	1.187
2.85	1.000	.3509	12.3,5	2.850	1.600	1.218
2.90	1.000	.3449	14.0,2	2.900	1.622	1.248
2.95	1.000	.3390	15.9,5	2.950	1.644	1.279
3.00	1.000	.3333	18.20	3.000	1.667	1.308
3.50	1.000	.2857	79.22	3.500	1.893	1.587
4.00	1.000	.2500	452.01	4.000	2.125	1.835
4.50	1.000	.2222	3364	4.500	2.361	2.058
5.00	1.000	.2000	32550	5.000	2.600	2.259
6.00	1.000	.1667	6640_4	6.000	3.083	2.611
7.00	1.000	.1429	3780_7	7.000	3.571	2.912
8.00	1.000	.1250	5990_{10}	8.000	4.062	3.174
9.00	1.000	.1111	2620_{14}	9.000	4.556	3.407
10.00	1.000	.1000	3140_{18}	10.000	5.050	3.615
∞	1.000	0	∞	∞	∞	∞

Table 4.22 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW
(Perfect Gas, k = 1.0 exactly) (Concluded)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
0	1.0500	∞	∞	0	∞	∞
.05	1.0499	2,0.493	11.,999	.05123	9.,785	3,57.05
.10	1.0495	1,0.244	6.,023	.1024	4.,932	,85.65
.15	1.0488	6.,828	4.,042	.1536	3.,332	3,5.92
.20	1.0479	5.,118	3.0,59	.2047	2.5,45	1,8.79
.25	1.0467	4.0,92	2.4,76	.2558	2.0,83	11.,03
.30	1.0453	3.4,08	2.0,94	.3067	1.7,84	6.,936
.35	1.0436	2.9,19	1.8,25	.3575	1.5,77	4.,549
.40	1.0417	2.5,52	1.6,28	.4082	1.42,9	3.,062
.45	1.0395	2.2,66	1.48,0	.4588	1.31,9	2.0,93
.50	1.0370	2.03,7	1.36,5	.5092	1.23,7	1.4,39
.55	1.0343	1.84,9	1.27,5	.5594	1.17,4	.9,871
.60	1.0314	1.69,3	1.20,4	.6094	1.12,5	.6,705
.65	1.0283	1.56,0	1.14,8	.6591	1.08,82	.4,468
.70	1.0249	1.44,6	1.10,4	.7086	1.05,99	.2,887
.75	1.0213	1.34,7	1.06,89	.7579	1.03,86	.17,80
.80	1.0174	1.26,1	1.04,25	.8069	1.02,31	.10,19
.85	1.0133	1.18,4	1.02,31	.8557	1.012,2	.05,160
.90	1.0091	1.11,6	1.01,00	.9041	1.005,1	.02,078
.95	1.0047	1.05,51	1.00,24	.9522	1.001,2	.00,472
1.00	1.0000	1.00,00	1.00,00	1.0000	1.000,0	0
1.05	.9951	.950,1	1.00,23	1.0474	1.001,1	.00,398
1.10	.9901	.904,6	1.009,2	1.0945	1.004,1	.01,468
1.15	.9849	.863,0	1.020,4	1.1412	1.008,7	.03,058
1.20	.9795	.824,7	1.036,0	1.1876	1.014,8	.050,50
1.25	.9739	.789,5	1.055,9	1.234	1.022,1	.073,50
1.30	.9682	.756,9	1.080,1	1.279	1.030,4	.098,85
1.35	.9623	.726,6	1.10,9	1.324	1.039,7	.126,0
1.40	.9563	.698,5	1.14,2	1.369	1.049,8	.154,4
1.45	.9501	.672,2	1.18,0	1.413	1.060,5	.183,8
1.50	.9438	.647,6	1.22,3	1.457	1.0717	.2138
1.55	.9374	.624,6	1.27,2	1.501	1.0835	.2443
1.60	.9309	.603,0	1.32,6	1.544	1.0958	.2749
1.65	.9242	.582,6	1.38,7	1.586	1.108	.3056
1.70	.9174	.563,4	1.45,4	1.628	1.121	.3362

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_{4}429$ signifies .000429. The notation 5370_{4} signifies 5,370,000.

Table 4.23 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.1 exactly)

M	T/T*	p/p*	p_o/p_o^*	V/V^* ρ^*/ρ	F/F*	$4fL_{max}/D$
1.75	.9105	.545,3	1.52,8	1.670	1.134	.3667
1.80	.9036	.528,1	1.61,0	1.711	1.148	.3969
1.85	.8966	.511,8	1.70,1	1.752	1.161	.4268
1.90	.8895	.496,4	1.80,1	1.792	1.175	.4563
1.95	.8823	.481,7	1.91,1	1.832	1.189	.4854
2.00	.8750	.467,7	2.03,2	1.871	1.203	.514,0
2.05	.8677	.454,4	2.16,5	1.910	1.217	.542,2
2.10	.8603	.441,7	2.31,2	1.948	1.231	.569,8
2.15	.8529	.429,5	2.47,3	1.986	1.245	.597,0
2.20	.8454	.417,9	2.65,1	2.023	1.259	.623,7
2.25	.8379	.4068	2.84,6	2.060	1.273	.649,8
2.30	.8304	.3962	3.06,1	2.096	1.286	.675,4
2.35	.8228	.3860	3.29,9	2.132	1.300	.700,5
2.40	.8152	.3762	3.56,0	2.167	1.314	.725,1
2.45	.8076	.3668	3.84,8	2.202	1.328	.749,1
2.50	.8000	.3578	4.16,5	2.236	1.342	.772,6
2.55	.7924	.3491	4.51,5	2.270	1.355	.795,7
2.60	.7848	.3407	4.90,2	2.303	1.369	.818,2
2.65	.7771	.3327	5.32,8	2.336	1.382	.840,2
2.70	.7695	.3249	5.7,99	2.368	1.395	.861,7
2.75	.7619	.3174	6.3,20	2.400	1.409	.882,8
2.80	.7543	.3102	6.8,95	2.432	1.422	.903,4
2.85	.7467	.3032	7.5,32	2.463	1.434	.923,5
2.90	.7392	.2965	8.2,37	2.493	1.447	.943,2
2.95	.7316	.2900	9.0,16	2.523	1.460	.962,4
3.00	.7241	.2837	9.880	2.553	1.472	.9812
3.50	.6512	.2305	25.83	2.824	1.589	1.147
4.00	.5833	.1909	71.74	3.055	1.691	1.280
4.50	.5217	.1605	205.7	3.250	1.779	1.386
5.00	.4667	1366	597.3	3.416	1.854	1.472
6.00	.3750	.1021	4911	3.674	1.973	1.601
7.00	.3043	.07881	37919	3.862	2.060	1.689
8.00	.2500	.06250	2630_2	4.000	2.125	1.752
9.00	.2079	.05067	1610_4	4.104	2.174	1.798
10.00	.1750	.04183	8890_4	4.183	2.211	1.832
∞	0	0	∞	4.583	2.400	1.997

Table 4.23 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.1 exactly) (Concluded)

M	T/T*	p/p*	p_o/p_o^*	V/V^* ρ^*/ρ	F/F*	$4fL_{max}/D$
0	1.100,0	∞	∞	0	∞	∞
.05	1.099,7	2,0.974	11.,857	.05243	,9.562	3,27.09
.10	1.098,9	1,0.483	5.,953	.1048	,4.822	,78.36
.15	1.097,5	6.,984	3.,996	.1571	3.,260	3,2.81
.20	1.095,6	5.,234	3.0,26	.2093	2.4,93	1,7.13
.25	1.093,2	4.1,82	2.4,51	.2614	2.0,44	10.,04
.30	1.090,2	3.4,80	2.0,73	.3133	1.7,53	6.,298
.35	1.086,7	2.9,78	1.8,09	.3649	1.5,53	4.,121
.40	1.082,7	2.6,01	1.6,15	.4162	1.40,9	2.,768
.45	1.078,2	2.3,07	1.46,9	.4672	1.30,4	1.8,87
.50	1.073,2	2.07,2	1.35,6	.5179	1.22,4	1.2,94
.55	1.067,7	1.87,9	1.26,8	.5683	1.16,4	.8,855
.60	1.061,8	1.71,7	1.19,9	.618,3	1.11,8	.5,999
.65	1.0554	1.58,1	1.14,4	.667,8	1.08,26	.3,987
.70	1.0486	1.46,3	1.10,0	.716,8	1.05,61	.2,570
.75	1.0414	1.36,1	1.06,66	.765,4	1.03,60	.15,79
.80	1.0338	1.27,1	1.04,10	.813,4	1.02,14	.09,016
.85	1.0259	1.19,2	1.02,22	.860,9	1.011,2	.04,554
.90	1.0176	1.12,1	1.00,96	.907,8	1.004,7	.01,829
.95	1.0089	1.05,73	1.00,23	.954,2	1.001,1	.00,414
1.00	1.0000	1.00,00	1.00,00	1.000,0	1.000,0	0
1.05	.9908	.94,80	1.002,2	1.045,1	1.001,0	.00,347
1.10	.9813	.900,5	1.008,7	1.089,6	1.003,7	.01,277
1.15	.9715	.857,1	1.019,4	1.134	1.007,9	.026,57
1.20	.9615	.817,2	1.034,0	1.177	1.013,4	.043,68
1.25	.9514	.780,3	1.052,5	1.219	1.019,7	.063,38
1.30	.9410	.746,2	1.074,9	1.261	1.027,0	.085,00
1.35	.9304	.714,5	1.101	1.302	1.035,1	.108,0
1.40	.9197	.685,0	1.132	1.342	1.043,7	.132,0
1.45	.9089	.657,5	1.166	1.382	1.0529	.1567
1.50	.8980	.631,7	1.205	1.421	1.0625	.1817
1.55	.8869	.607,6	1.24,8	1.459	1.0724	.2069
1.60	.8758	.584,9	1.29,6	1.497	1.0826	.2323
1.65	.8646	.563,5	1.34,9	1.534	1.0930	.2575
1.70	.8534	.543,4	1.40,7	1.570	1.1036	.2825

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_3429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.24 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.2 exactly)

M	T/T*	p/p*	p_o/p_o^*	V/V^* ρ^*/ρ	F/F*	$4fL_{max}/D$
1.75	.8421	.524,4	1.47,1	1.606	1.114	.3072
1.80	.8308	.506,4	1.54,0	1.641	1.125	.3316
1.85	.8195	.489,4	1.61,5	1.675	1.136	.355,6
1.90	.8082	.473,2	1.69,7	1.708	1.147	.379,1
1.95	.7970	.457,8	1.78,7	1.741	1.158	.402,1
2.00	.7857	.443,2	1.88,4	1.773	1.168	.424,7
2.05	.7745	.429,3	1.98,9	1.804	1.179	.446,8
2.10	.7634	.416,0	2.10,3	1.835	1.190	.468,4
2.15	.7523	.403,4	2.22,6	1.865	1.201	.489,4
2.20	.7413	.391,3	2.35,9	1.894	1.211	.509,9
2.25	.7303	.379,8	2.50,4	1.923	1.221	.529,9
2.30	.7194	.3688	2.66,0	1.951	1.232	.549,3
2.35	.7086	.3582	2.82,9	1.978	1.242	.568,3
2.40	.6980	.3481	3.01,1	2.005	1.252	.586,8
2.45	.6874	.3384	3.20,8	2.031	1.262	.604,7
2.50	.6769	.3291	3.42,0	2.057	1.272	.622,2
2.55	.6665	.3202	3.65,0	2.082	1.281	.639,2
2.60	.6563	.3116	3.89,8	2.106	1.291	.655,7
2.65	.6462	.3033	4.16,6	2.130	1.300	.671,8
2.70	.6362	.2954	4.45,5	2.154	1.309	.687,4
2.75	.6263	.2878	4.76,7	2.176	1.318	.7026
2.80	.6166	.2804	5.10,3	2.199	1.327	.7173
2.85	.6070	.2733	5.46,6	2.220	1.335	.7316
2.90	.5975	.2665	5.85,8	2.242	1.344	.7456
2.95	.5882	.2600	6.28,0	2.263	1.352	.7592
3.00	.5789	.2536	6.735	2.283	1.360	.7724
3.50	.4944	.2009	13.76	2.461	1.434	.8857
4.00	.4231	.1626	28.35	2.602	1.493	.9718
4.50	.3636	.1340	57.96	2.714	1.541	1.0380
5.00	.3143	.1121	116.31	2.803	1.580	1.0896
6.00	.2391	.08150	434.7	2.934	1.637	1.163
7.00	.1864	.06168	1458	3.023	1.677	1.212
8.00	.1486	.04819	4353	3.084	1.704	1.245
9.00	.1209	.03863	13156	3.129	1.724	1.268
10.00	.1000	.03162	29601	3.162	1.739	1.286
∞	0	0	∞	3.317	1.809	1.365

Table 4.24 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.2 exactly) (Concluded)

M	T/T*	p/p*	p_o/p_o^*	V/V^* ρ^*/ρ	F/F*	$4fL_{max}/D$
0	1.150	∞	∞	0	∞	∞
.05	1.149	2,1.444	11.,721	.05361	9.,354	3,01.74
.10	1.148	1,0.716	5.,885	.1072	4.,720	,72.20
.15	1.146	7.,137	3.,952	.1606	3.,194	3,0.18
.20	1.143	5..346	2.9,94	.2138	2.4,45	1,5.73
.25	1.139	4.2,70	2.4,26	.2668	2.0,07	9.,201
.30	1.134	3.5,51	2.0,54	.3195	1.7,24	5.,759
.35	1.129	3.0,36	1.7,93	.3719	1.5,30	3.,760
.40	1.123	2.6,49	1.6,02	.423,9	1.39,1	2.,520
.45	1.116	2.3,48	1.45,9	.475,4	1.28,9	1.7,14
.50	1.1084	2.10,6	1.34,8	.526,4	1.21,3	1.1,72
.55	1.1001	1.90,7	1.26,1	.576,9	1.15,5	.8,004
.60	1.0911	1.74,1	1.19,3	.626,7	1.11,1	.5,409
.65	1.0815	1.60,0	1.14,0	.675,9	1.07,77	.3,586
.70	1.0713	1.47,9	1.09,72	.724,5	1.05,24	.23,05
.75	1.0605	1.37,3	1.06,44	.772,4	1.03,36	.14,13
.80	1.0493	1.28,0	1.03,95	.819,5	1.019,9	.08,044
.85	1.0376	1.19,8	1.02,14	.865,8	1.010,4	.04,053
.90	1.0254	1.12,5	1.00,92	.911,3	1.004,3	.01,623
.95	1.0129	1.05,94	1.00,22	.956,1	1.001,0	.00,367
1.00	1.0000	1.00,00	1.000,0	1.000,0	1.000,0	0
1.05	.9868	.94,61	1.002,1	1.043,0	1.000,9	.00,305
1.10	.9733	.896,9	1.008,3	1.085,2	1.003,3	.011,22
1.15	.9596	.851,8	1.018,3	1.126,6	1.007,1	.023,24
1.20	.9457	.810,4	1.032,1	1.167,0	1.012,0	.038,20
1.25	.9316	.772,2	1.049,5	1.206	1.017,7	.055,24
1.30	.9174	.736,8	1.070,4	1.245	1.024,1	.073,88
1.35	.9031	.703,9	1.094,8	1.283	1.031,2	.093,65
1.40	.8887	.673,4	1.122,7	1.320	1.0388	.114,17
1.45	.8743	.644,8	1.154,3	1.356	1.0467	.1351,3
1.50	.8598	.618,2	1.189	1.391	1.0549	.1564
1.55	.8454	.593,2	1.228	1.425	1.0634	.1777
1.60	.8309	.569,7	1.271	1.458	1.0721	.1989
1.65	.8165	.547,7	1.318	1.491	1.0808	.2200
1.70	.8022	.526,9	1.369	1.523	1.0897	.2408

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_3429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.25 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.3 exactly)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
1.75	.7880	.507,3	1.424	1.554	1.0986	.2613
1.80	.7739	.488,7	1.484	1.584	1.108	.2814
1.85	.7599	.471,2	1.549	1.613	1.116	.3010
1.90	.7460	.454,6	1.61,8	1.641	1.125	.3202
1.95	.7323	.438,8	1.69,3	1.669	1.134	.339,0
2.00	.7188	.423,9	1.77,3	1.696	1.143	.357,3
2.05	.7054	.409,7	1.85,9	1.722	1.151	.375,1
2.10	.6922	.396,2	1.95,1	1.747	1.160	.392,4
2.15	.6791	.383,3	2.05,0	1.772	1.168	.409,2
2.20	.6662	.371,0	2.15,6	1.796	1.176	.425,5
2.25	.6536	.359,3	2.26,8	1.819	1.184	.441,3
2.30	.6412	.3482	2.38,8	1.842	1.192	.4566
2.35	.6290	.3375	2.51,7	1.864	1.200	.4715
2.40	.6170	.3273	2.65,4	1.885	1.208	.4860
2.45	.6051	.3175	2.80,0	1.906	1.215	.5000
2.50	.5935	.3082	2.95,4	1.926	1.223	.5136
2.55	.5822	.2992	3.11,9	1.946	1.230	.5267
2.60	.5711	.2906	3.29,5	1.965	1.237	.5394
2.65	.5601	.2824	3.48,2	1.983	1.244	.5517
2.70	.5493	.2745	3.68,1	2.001	1.250	.5636
2.75	.5388	.2669	3.89,2	2.019	1.257	.5752
2.80	.5285	.2596	4.11,6	2.036	1.263	.5864
2.85	.5184	.2526	4.35,4	2.052	1.270	.5972
2.90	.5085	.2459	4.60,7	2.068	1.276	.6077
2.95	.4988	.2394	4.87,5	2.084	1.282	.6179
3.00	.4894	.2332	5.160	2.099	1.288	.6277
3.50	.4053	.1819	9.110	2.228	1.338	.7110
4.00	.3382	.1454	15.94	2.326	1.378	.7726
4.50	.2848	.1186	27.39	2.402	1.409	.8189
5.00	.2421	.09841	45.95	2.460	1.433	.8543
6.00	.1797	.07065	120.1	2.543	1.468	.9037
7.00	.1377	.05302	285.3	2.598	1.491	.9355
8.00	.1085	.04117	625.2	2.635	1.507	.9570
9.00	.08745	.03286	1275	2.662	1.519	.9722
10.00	.07188	.02769	2438	2.681	1.527	.9832
∞	0	0	∞	2.769	1.565	1.0326

Table 4.25 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.3 exactly) (Concluded)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
0	1.2000	∞	∞	0	∞	∞
.01	1.2000	10,9.544	5,7.874	.01095	4,5.650	7,134.40
.02	1.1999	5,4.770	2,8.942	.02191	22.,834	1,778.45
.03	1.1998	3,6.511	1,9.300	.03286	15.,232	7,87.08
.04	1.1996	27.,382	14.,482	.04381	11.,435	4,40.35
.05	1.1994	21.,903	11.,5914	.05476	9.,1584	2,80.02
.06	1.1991	18.,251	9.,6659	.06570	7.6,428	19,3.03
.07	1.1988	15.6,42	8.2,915	.07664	6.5,620	14,0.66
.08	1.1985	13.6,84	7.2,616	.08758	5.7,529	10,6.72
.09	1.1981	12.1,62	6.4,614	.09851	5.1,249	8,3.496
.10	1.1976	10.9,435	5.8,218	.10943	4.6,236	66.,922
.11	1.1971	9.9,465	5.2,992	.12035	4.2,146	54.,688
.12	1.1966	9.1,156	4.8,643	.13126	3.8,747	45.,408
.13	1.1960	8.4,123	4.4,968	.14216	3.58,80	38.,207
.14	1.1953	7.8,093	4.1,824	.15306	3.34,32	32.,511
.15	1.1946	7.2,866	3.91,03	.16395	3.13,17	27.,932
.16	1.1939	6.82,91	3.67,27	.17482	2.94,74	24.,198
.17	1.1931	6.42,52	3.46,35	.18568	2.78,55	21.,115
.18	1.1923	6.06,62	3.27,79	.19654	2.64,22	18.5,43
.19	1.1914	5.74,48	3.11,23	.20739	2.51,46	16.3,75
.20	1.1905	5.45,55	2.96,35	.21822	2.40,04	14.5,33
.21	1.1895	5.19,36	2.82,93	.22904	2.29,76	12.9,56
.22	1.1885	4.95,54	2.70,76	.23984	2.20,46	11.5,96
.23	1.1874	4.73,78	2.59,68	.25063	2.12,03	10.4,16
.24	1.1863	4.53,83	2.49,56	.26141	2.04,34	9.3,865
.25	1.1852	4.35,46	2.40,27	.27217	1.97,32	8.4,834
.26	1.1840	4.18,50	2.31,73	.28291	1.90,88	7.6,876
.27	1.1828	4.02,80	2.23,85	.29364	1.84,96	6.9,832
.28	1.1815	3.88,20	2.16,56	.30435	1.795,0	6.3,572
.29	1.1802	3.74,60	2.09,79	.31504	1.744,6	5.7,989
.30	1.1788	3.61,90	2.035,1	.32572	1.697,9	5.2,992
.31	1.1774	3.50,02	1.976,5	.33637	1.654,6	4.8,507
.32	1.1759	3.38,88	1.921,9	.34700	1.614,4	4.44,68
.33	1.1744	3.28,40	1.870,8	.35762	1.576,9	4.08,21
.34	1.1729	3.18,53	1.822,9	.36822	1.542,0	3.75,20
.35	1.1713	3.09,22	1.778,0	.37880	1.509,4	3.45,25
.36	1.1697	3.004,2	1.735,8	.38935	1.478,9	3.18,01
.37	1.1680	2.920,9	1.696,1	.39988	1.450,3	2.93,20
.38	1.1663	2.842,0	1.658,7	.41039	1.423,6	2.70,55
.39	1.1646	2.767,1	1.623,4	.42087	1.398,5	2.49,83
.40	1.1628	2.695,8	1.590,1	.43133	1.374,9	2.30,85
.41	1.1610	2.628,0	1.558,7	.44177	1.352,7	2.13,44
.42	1.1591	2.563,4	1.528,9	.45218	1.331,8	1.97,44
.43	1.1572	2.501,7	1.506,7	.46257	1.312,2	1.82,72
.44	1.1553	2.442,8	1.473,9	.47293	1.293,7	1.69,15

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_3429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.26 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.4 exactly)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
.45	1.1533	2.386,5	1.448,6	.48326	1.276,3	1.56,64
.46	1.1513	2.332,6	1.424,6	.49357	1.259,8	1.45,09
.47	1.1492	2.280.9	1.401,8	.50385	1.244,3	1.34,42
.48	1.1471	2.231,4	1.380,1	.51410	1.229,6	1.24,53
.49	1.1450	2.183,8	1.359,5	.52433	1.215,8	1.15,39
.50	1.1429	2.138,1	1.339,9	.53453	1.202,7	1.06,908
.51	1.1407	2.094,2	1.321,2	.54469	1.190,3	.99,042
.52	1.1384	2.051,9	1.303,4	.55482	1.178,6	.91,741
.53	1.1362	2.011,2	1.286,4	.56493	1.167,5	.84,963
.54	1.1339	1.971,9	1.270,2	.57501	1.157,1	.786,62
.55	1.1315	1.934,1	1.254,9	.58506	1.147,2	.728,05
.56	1.1292	1.897,6	1.240,3	.59507	1.137,8	.673,57
.57	1.1268	1.862,3	1.226,3	.60505	1.128,9	.622,86
.58	1.1244	1.828,2	1.213,0	.61500	1.120,5	.575,68
.59	1.1219	1.795,2	1.200,3	.62492	1.112,6	.531,74
.60	1.1194	1.763,4	1.188,2	.63481	1.1050,4	.490,81
.61	1.1169	1.732,5	1.176,6	.64467	1.0979,3	.452,70
.62	1.1144	1.702,6	1.165,6	.65449	1.0912,0	.417,20
.63	1.1118	1.673.7	1.155,1	.66427	1.0848,5	.384,11
.64	1.1091	1.645,6	1.145,1	.67402	1.0788,3	.353,30
.65	1.10650	1.618,3	1.135,6	.68374	1.0731,4	.324,60
.66	1.10383	1.591,9	1.126,5	.69342	1.0677,7	.297,85
.67	1.10114	1.566,2	1.117,9	.70306	1.0627,1	.272,95
.68	1.09842	1.541,3	1.109,7	.71267	1.0579,2	.249,78
.69	1.09567	1.517,0	1.101,8	.72225	1.0534,0	.228,21
.70	1.09290	1.493,4	1.0943,6	.73179	1.0491,5	.208,14
.71	1.09010	1.470,5	1.0872,9	.74129	1.0451,4	.189,49
.72	1.08727	1.448,2	1.0805,7	.75076	1.0413,7	.172,15
.73	1.08442	1.426,5	1.0741,9	.76019	1.0378,3	.156,06
.74	1.08155	1.405,4	1.0681,5	.76958	1.0345,0	.141,13
.75	1.07865	1.384,8	1.0624,2	.77893	1.0313,7	.127,28
.76	1.07573	1.364,7	1.0570,0	.78825	1.0284,4	.114,46
.77	1.07279	1.345,1	1.0518,8	.79753	1.0257,0	.102,62
.78	1.06982	1.326,0	1.0470,5	.80677	1.0231,4	.091,67
.79	1.06684	1.3074	1.0425,0	.81598	1.0207,5	.081,59
.80	1.06383	1.2892	1.0382,3	.82514	1.0185,3	.072,29
.81	1.06080	1.2715	1.0342,2	.83426	1.0164,6	.063,75
.82	1.05775	1.2542	1.0304,7	.84334	1.0145,5	.055,93
.83	1.05468	1.2373	1.0269,6	.85239	1.0127,8	.048,78
.84	1.05160	1.2208	1.0237,0	.86140	1.0111,5	.042,26
.85	1.04849	1.2047	1.0206,7	.87037	1.0096,6	.036,32
.86	1.04537	1.1889	1.0178,7	.87929	1.0082,9	.030,97
.87	1.04223	1.1735	1.0152,9	.88818	1.0070,4	.026,13
.88	1.03907	1.1584	1.0129,4	.89703	1.0059,1	.021,80
.89	1.03589	1.1436	1.0108,0	.90583	1.0049,0	.017,93

Table 4.26 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.4 exactly) (Continued)

(This page contains a correction of an error which appeared in the data of the corresponding table of the Meteor Report No. 14, dated Dec. 1, 1947.)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
.90	1.03270	1.1291,3	1.0088,7	.91459	1.0039,9	.0145,13
.91	1.02950	1.1150,0	1.0071,4	.92332	1.0031,8	.0115,19
.92	1.02627	1.1011,4	1.0056,0	.93201	1.0024,8	.0089,16
.93	1.02304	1.0875,8	1.0042,6	.94065	1.0018,8	.0066,94
.94	1.01978	1.0743,0	1.0031,1	.94925	1.0013,6	.0048,15
.95	1.01652	1.0612,9	1.0021,5	.95782	1.0009,3	.0032,80
.96	1.01324	1.0485,4	1.0013,7	.96634	1.0005,9	.0020,56
.97	1.00995	1.0360,5	1.0007,6	.97481	1.0003,3	.0011,35
.98	1.00664	1.0237,9	1.0003,3	.98324	1.0001,4	.0004,93
.99	1.00333	1.0117,8	1.0000,8	.99164	1.0000,3	.0001,20
1.00	1.00000	1.0000,0	1.0000,0	1.00000	1.0000,0	0
1.01	.99666	.9884,4	1.0000,8	1.00831	1.0000,3	.0001,14
1.02	.99331	.9771,1	1.0003,3	1.01658	1.0001,3	.0004,58
1.03	.98995	.9659,8	1.0007,3	1.02481	1.0003,0	.0010,13
1.04	.98658	.9550,6	1.0013,0	1.03300	1.0005,3	.0017,71
1.05	.98320	.9443,5	1.0020,3	1.04115	1.0008,2	.0027,12
1.06	.97982	.9338,3	1.0029,1	1.04925	1.0011,6	.0038,37
1.07	.97642	.9235,0	1.0039,4	1.05731	1.0015,5	.0051,29
1.08	.97302	.9133,5	1.0051,2	1.06533	1.0020,0	.0065,82
1.09	.96960	.9033,8	1.0064,5	1.07331	1.0025,0	.0081,85
1.10	.96618	.8935,9	1.0079,3	1.08124	1.00305	.0099,33
1.11	.96276	.8839,7	1.0095,5	1.08913	1.00365	.0118,13
1.12	.95933	.8745,1	1.0113,1	1.09698	1.00429	.0138,24
1.13	.95589	.8652,2	1.0132,2	1.10479	1.00497	.0159,49
1.14	.95244	.8560,8	1.0152,7	1.11256	1.00569	.0181,87
1.15	.94899	.8471,0	1.0174,6	1.1203	1.00646	.0205,3
1.16	.94554	.8382,7	1.0197,8	1.1280	1.00726	.0229,8
1.17	.94208	.8295,8	1.0222,4	1.1356	1.00810	.0255,2
1.18	.93862	.8210,4	1.0248,4	1.1432	1.00897	.0281,4
1.19	.93515	.8126,3	1.0275,7	1.1508	1.00988	.0308,5
1.20	.93168	.8043,6	1.0304,4	1.1583	1.01082	.0336,4
1.21	.92820	.7962,3	1.0334,4	1.1658	1.01178	.0365,0
1.22	.92473	.7882,2	1.0365,7	1.1732	1.01278	.0394,2
1.23	.92125	.7803,4	1.0398,3	1.1806	1.01381	.0424,1
1.24	.91777	.7725,8	1.0432,3	1.1879	1.01486	.0454,7
1.25	.91429	.7649,5	1.0467,6	1.1952	1.01594	.04858
1.26	.91080	.7574,3	1.0504,1	1.2025	1.01705	.05174
1.27	.90732	.7500,3	1.0541,9	1.2097	1.01818	.05494
1.28	.90383	.7427,4	1.0580,9	1.2169	1.01933	.05820
1.29	.90035	.7355,6	1.0621,3	1.2240	1.02050	.06150
1.30	.89686	.7284,8	1.0663,0	1.2311	1.02169	.06483
1.31	.89338	.7215,2	1.0706,0	1.2382	1.02291	.06820
1.32	.88989	.7146,5	1.0750,2	1.2452	1.02415	.07161
1.33	.88641	.7078,9	1.0795,7	1.2522	1.02540	.07504
1.34	.88292	.7012,3	1.0842,4	1.2591	1.02666	.07850

Table 4.26 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.4 exactly) (Continued)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
1.35	.87944	.6946,6	1.0890,4	1.2660	1.02794	.08199
1.36	.87596	.6881,8	1.0939,7	1.2729	1.02924	.08550
1.37	.87249	.6818,0	1.0990,2	1.2797	1.03056	.08904
1.38	.86901	.6755,1	1.1041,9	1.2864	1.03189	.09259
1.39	.86554	.6693,1	1.1094,8	1.2932	1.03323	.09616
1.40	.86207	.6632,0	1.1149	1.2999	1.03458	.09974
1.41	.85860	.6571,7	1.1205	1.3065	1.03595	.10333
1.42	.85514	.6512,2	1.1262	1.3131	1.03733	.10694
1.43	.85168	.6453,6	1.1320	1.3197	1.03872	.11056
1.44	.84822	.6395,8	1.1379	1.3262	1.04012	.11419
1.45	.84477	.6338,7	1.1440	1.3327	1.04153	.11782
1.46	.84133	.6282,4	1.1502	1.3392	1.04295	.12146
1.47	.83788	.6226,9	1.1565	1.3456	1.04438	.12510
1.48	.83445	.6172,2	1.1629	1.3520	1.04581	.12875
1.49	.83101	.6118,1	1.1695	1.3583	1.04725	.13240
1.50	.82759	.6064,8	1.1762	1.3646	1.04870	.13605
1.51	.82416	.6012,2	1.1830	1.3708	1.05016	.13970
1.52	.82075	.5960,2	1.1899	1.3770	1.05162	.14335
1.53	.81734	.5908.9	1.1970	1.3832	1.05309	.14699
1.54	.81394	.5858,3	1.2043	1.3894	1.05456	.15063
1.55	.81054	.5808,4	1.2116	1.3955	1.05604	.15427
1.56	.80715	.5759,1	1.2190	1.4015	1.05752	.15790
1.57	.80376	.5710,4	1.2266	1.4075	1.05900	.16152
1.58	.80038	.5662,3	1.2343	1.4135	1.06049	.16514
1.59	.79701	.5614,8	1.2422	1.4195	1.06198	.16876
1.60	.79365	.5567,9	1.2502	1.4254	1.06348	.17236
1.61	.79030	.5521,6	1.2583	1.4313	1.06498	.17595
1.62	.78695	.5475,9	1.2666	1.4371	1.06648	.17953
1.63	.78361	.5430,8	1.2750	1.4429	1.06798	.18311
1.64	.78028	.5386,2	1.2835	1.4487	1.06948	.18667
1.65	.77695	.5342,1	1.2922	1.4544	1.07098	.19022
1.66	.77363	.5298,6	1.3010	1.4601	1.07249	.19376
1.67	.77033	.5255,6	1.3099	1.4657	1.07399	.19729
1.68	.76703	.5213,1	1.3190	1.4713	1.07550	.20081
1.69	.76374	.5171,1	1.3282	1.4769	1.07701	.20431
1.70	.76046	.5129,7	1.3376	1.4825	1.07851	.20780
1.71	.75718	.5088,7	1.3471	1.4880	1.08002	.21128
1.72	.75392	.5048,2	1.3567	1.4935	1.08152	.21474
1.73	.75067	.5008,2	1.3665	1.4989	1.08302	.21819
1.74	.74742	.4968,6	1.3764	1.5043	1.08453	.22162
1.75	.74419	.4929,5	1.3865	1.5097	1.08603	.22504
1.76	.74096	.4890,9	1.3967	1.5150	1.08753	.22844
1.77	.73774	.4852,7	1.4070	1.5203	1.08903	.23183
1.78	.73453	.4814,9	1.4175	1.5256	1.09053	.23520
1.79	.73134	.4777,6	1.4282	1.5308	1.09202	.23855

Table 4.26 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.4 exactly) (Continued)

M	T/T*	p/p*	p_o/p_o^*	V/V^* ρ^*/ρ	F/F*	$4fL_{max}/D$
1.80	.72816	.47407	1.4390	1.5360	1.09352	.24189
1.81	.72498	.47042	1.4499	1.5412	1.09500	.24521
1.82	.72181	.46681	1.4610	1.5463	1.09649	.24851
1.83	.71865	.46324	1.4723	1.5514	1.09798	.25180
1.84	.71551	.45972	1.4837	1.5564	1.09946	.25507
1.85	.71238	.45623	1.4952	1.5614	1.1009	.25832
1.86	.70925	.45278	1.5069	1.5664	1.1024	.26156
1.87	.70614	.44937	1.5188	1.5714	1.1039	.26478
1.88	.70304	.44600	1.5308	1.5763	1.1054	.26798
1.89	.69995	.44266	1.5429	1.5812	1.1068	.27116
1.90	.69686	.43936	1.5552	1.5861	1.1083	.27433
1.91	.69379	.43610	1.5677	1.5909	1.1097	.27748
1.92	.69074	.43287	1.5804	1.5957	1.1112	.28061
1.93	.68769	.42967	1.5932	1.6005	1.1126	.28372
1.94	.68465	.42651	1.6062	1.6052	1.1141	.28681
1.95	.68162	.42339	1.6193	1.6099	1.1155	.28989
1.96	.67861	.42030	1.6326	1.6146	1.1170	.29295
1.97	.67561	.41724	1.6461	1.6193	1.1184	.29599
1.98	.67262	.41421	1.6597	1.6239	1.1198	.29901
1.99	.66964	.41121	1.6735	1.6284	1.1213	.30201
2.00	.66667	.40825	1.6875	1.6330	1.1227	.30499
2.01	.66371	.40532	1.7017	1.6375	1.1241	.30796
2.02	.66076	.40241	1.7160	1.6420	1.1255	.31091
2.03	.65783	.39954	1.7305	1.6465	1.1269	.31384
2.04	.65491	.39670	1.7452	1.6509	1.1283	.31675
2.05	.65200	.39389	1.7600	1.6553	1.1297	.31965
2.06	.64910	.39110	1.7750	1.6597	1.1311	.32253
2.07	.64621	.38834	1.7902	1.6640	1.1325	.32538
2.08	.64333	.38562	1.8056	1.6683	1.1339	.32822
2.09	.64047	.38292	1.8212	1.6726	1.1352	.33104
2.10	.63762	.38024	1.8369	1.6769	1.1366	.33385
2.11	.63478	.37760	1.8528	1.6811	1.1380	.33664
2.12	.63195	.37498	1.8690	1.6853	1.1393	.33940
2.13	.62914	.37239	1.8853	1.6895	1.1407	.34215
2.14	.62633	.36982	1.9018	1.6936	1.1420	.34488
2.15	.62354	.36728	1.9185	1.6977	1.1434	.34760
2.16	.62076	.36476	1.9354	1.7018	1.1447	.35030
2.17	.61799	.36227	1.9525	1.7059	1.1460	.35298
2.18	.61523	.35980	1.9698	1.7099	1.1474	.35564
2.19	.61249	.35736	1.9873	1.7139	1.1487	.35828
2.20	.60976	.35494	2.0050	1.7179	1.1500	.36091
2.21	.60704	.35254	2.0228	1.7219	1.1513	.36352
2.22	.60433	.35017	2.0409	1.7258	1.1526	.36611
2.23	.60163	.34782	2.0592	1.7297	1.1539	.36868
2.24	.59895	.34550	2.0777	1.7336	1.1552	.37124

Table 4.26 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW
(Perfect Gas, k = 1.4 exactly) (Continued)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
2.25	.59627	.34319	2.0964	1.7374	1.1565	.37378
2.26	.59361	.34091	2.1154	1.7412	1.1578	.37630
2.27	.59096	.33865	2.1345	1.7450	1.1590	.37881
2.28	.58833	.33641	2.1538	1.7488	1.1603	.38130
2.29	.58570	.33420	2.1733	1.7526	1.1616	.38377
2.30	.58309	.33200	2.1931	1.7563	1.1629	.38623
2.31	.58049	.32983	2.2131	1.7600	1.1641	.38867
2.32	.57790	.32767	2.2333	1.7637	1.1653	.39109
2.33	.57532	.32554	2.2537	1.7673	1.1666	.39350
2.34	.57276	.32342	2.2744	1.7709	1.1678	.39589
2.35	.57021	.32133	2.2953	1.7745	1.1690	.39826
2.36	.56767	.31925	2.3164	1.7781	1.1703	.40062
2.37	.56514	.31720	2.3377	1.7817	1.1715	.40296
2.38	.56262	.31516	2.3593	1.7852	1.1727	.40528
2.39	.56011	.31314	2.3811	1.7887	1.1739	.40760
2.40	.55762	.31114	2.4031	1.7922	1.1751	.40989
2.41	.55514	.30916	2.4254	1.7956	1.1763	.41216
2.42	.55267	.30720	2.4479	1.7991	1.1775	.41442
2.43	.55021	.30525	2.4706	1.8025	1.1786	.41667
2.44	.54776	.30332	2.4936	1.8059	1.1798	.41891
2.45	.54533	.30141	2.5168	1.8092	1.1810	.42113
2.46	.54291	.29952	2.5403	1.8126	1.1821	.42333
2.47	.54050	.29765	2.5640	1.8159	1.1833	.42551
2.48	.53810	.29579	2.5880	1.8192	1.1844	.42768
2.49	.53571	.29395	2.6122	1.8225	1.1856	.42983
2.50	.53333	.29212	2.6367	1.8257	1.1867	.43197
2.51	.53097	.29031	2.6615	1.8290	1.1879	.43410
2.52	.52862	.28852	2.6865	1.8322	1.1890	.43621
2.53	.52627	.28674	2.7117	1.8354	1.1901	.43831
2.54	.52394	.28498	2.7372	1.8386	1.1912	.44040
2.55	.52163	.28323	2.7630	1.8417	1.1923	.44247
2.56	.51932	.28150	2.7891	1.8448	1.1934	.44452
2.57	.51702	.27978	2.8154	1.8479	1.1945	.44655
2.58	.51474	.27808	2.8420	1.8510	1.1956	.44857
2.59	.51247	.27640	2.8689	1.8541	1.1967	.45059
2.60	.51020	.27473	2.8960	1.8571	1.1978	.45259
2.61	.50795	.27307	2.9234	1.8602	1.1989	.45457
2.62	.50571	.27143	2.9511	1.8632	1.2000	.45654
2.63	.50349	.26980	2.9791	1.8662	1.2011	.45850
2.64	.50127	.26818	3.0074	1.8691	1.2021	.46044
2.65	.49906	.26658	3.0359	1.8721	1.2031	.46237
2.66	.49687	.26499	3.0647	1.8750	1.2042	.46429
2.67	.49469	.26342	3.0938	1.8779	1.2052	.46619
2.68	.49251	.26186	3.1234	1.8808	1.2062	.46807
2.69	.49035	.26032	3.1530	1.8837	1.2073	.46996

Table 4.26 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.4 exactly) (Continued)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
2.70	.48820	.25878	3.1830	1.8865	1.2083	.47182
2.71	.48606	.25726	3.2133	1.8894	1.2093	.47367
2.72	.48393	.25575	3.2440	1.8922	1.2103	.47551
2.73	.48182	.25426	3.2749	1.8950	1.2113	.47734
2.74	.47971	.25278	3.3061	1.8978	1.2123	.47915
2.75	.47761	.25131	3.3376	1.9005	1.2133	.48095
2.76	.47553	.24985	3.3695	1.9032	1.2143	.48274
2.77	.47346	.24840	3.4017	1.9060	1.2153	.48452
2.78	.47139	.24697	3.4342	1.9087	1.2163	.48628
2.79	.46933	.24555	3.4670	1.9114	1.2173	.48803
2.80	.46729	.24414	3.5001	1.9140	1.2182	.48976
2.81	.46526	.24274	3.5336	1.9167	1.2192	.49148
2.82	.46324	.24135	3.5674	1.9193	1.2202	.49321
2.83	.46122	.23997	3.6015	1.9220	1.2211	.49491
2.84	.45922	.23861	3.6359	1.9246	1.2221	.49660
2.85	.45723	.23726	3.6707	1.9271	1.2230	.49828
2.86	.45525	.23592	3.7058	1.9297	1.2240	.49995
2.87	.45328	.23458	3.7413	1.9322	1.2249	.50161
2.88	.45132	.23326	3.7771	1.9348	1.2258	.50326
2.89	.44937	.23196	3.8133	1.9373	1.2268	.50489
2.90	.44743	.23066	3.8498	1.9398	1.2277	.50651
2.91	.44550	.22937	3.8866	1.9423	1.2286	.50812
2.92	.44358	.22809	3.9238	1.9448	1.2295	.50973
2.93	.44167	.22682	3.9614	1.9472	1.2304	.51133
2.94	.43977	.22556	3.9993	1.9497	1.2313	.51291
2.95	.43788	.22431	4.0376	1.9521	1.2322	.51447
2.96	.43600	.22307	4.0763	1.9545	1.2331	.51603
2.97	.43413	.22185	4.1153	1.9569	1.2340	.51758
2.98	.43226	.22063	4.1547	1.9592	1.2348	.51912
2.99	.43041	.21942	4.1944	1.9616	1.2357	.52064
3.00	.42857	.21822	4.2346	1.9640	1.2366	.52216
3.50	.34783	.16850	6.7896	2.0642	1.2743	.58643
4.00	.28571	.13363	10.719	2.1381	1.3029	.63306
4.50	.23762	.10833	16.562	2.1936	1.3247	.66764
5.00	.20000	.08944	25.000	2.2361	1.3416	.69381
6.00	.14634	.06376	53.180	2.2953	1.3655	.72987
7.00	.11111	.04762	104.14	2.3333	1.3810	.75281
8.00	.08696	.03686	190.11	2.3591	1.3915	.76820
9.00	.06977	.02935	327.19	2.3772	1.3989	.77898
10.00	.05714	.02390	535.94	2.3905	1.4044	.78683
∞	0	0	∞	2.4495	1.4289	.82153

Table 4.26 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW
(Perfect Gas, k = 1.4 exactly) (Concluded)

M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
0	1.335	∞	∞	0	∞	∞
.05	1.334	2,3.099	11.,265	.05775	8.,687	2,34.36
.10	1.331	1,1.535	5.,661	.1154	4.,392	,55.83
.15	1.325	7.,674	3.,805	.1727	2.,982	2,3.21
.20	1.317	5.,739	2.8,87	.229,6	2.2,93	1,2.11
.25	1.308	4.5,74	2.3,44	.285,9	1.8,92	6.,980
.30	1.296	3.7,95	1.9,89	.341,5	1.6,35	4.,337
.35	1.282	3.2,35	1.7,41	.396,3	1.4,60	2.,810
.40	1.267	2.8,14	1.5,60	.450,2	1.33,6	1.8,68
.45	1.250	2.4,85	1.42,4	.503,1	1.24,5	1.2,60
.50	1.232	2.2,20	1.32,0	.554,9	1.17,8	.8,549
.55	1.212	2.00,2	1.23,9	.605,6	1.12,8	.5,787
.60	1.191	1.81,9	1.17,6	.654,8	1.09,09	.3,877
.65	1.169	1.66,4	1.12,6	.702,9	1.06,28	.2,548
.70	1.146	1.53,0	1.08,74	.749,6	1.04,18	.16,25
.75	1.1233	1.41,3	1.05,76	.794,9	1.02,65	.09,870
.80	1.0993	1.31,1	1.03,51	.838,8	1.015,5	.05,576
.85	1.0748	1.22,0	1.01,89	.881,2	1.008,0	.02,780
.90	1.0501	1.13,9	1.00,81	.922,2	1.003,3	.01,106
.95	1.0251	1.06,57	1.001,9	.961,8	1.000,8	.00,248
1.00	1.0000	1.00,00	1.000,0	1.000,0	1.000,0	0
1.05	.9749	.94,04	1.001,8	1.036,8	1.000,6	.002,03
1.10	.9499	.88,60	1.007,0	1.072,1	1.002,4	.007,40
1.15	.9251	.836,4	1.015,4	1.106,1	1.005,1	.015,22
1.20	.9006	.790,8	1.026,6	1.138,8	1.008,4	.024,81
1.25	.8763	.748,9	1.040,6	1.170	1.0124	.035,64
1.30	.8524	.710,2	1.057,3	1.200	1.0167	.047,33
1.35	.8289	.674,4	1.076,5	1.229	1.0213	.0595,7
1.40	.8059	.641,2	1.098,1	1.257	1.0262	.0721,2
1.45	.7833	.610,4	1.122,0	1.284	1.0313	.0848,1
1.50	.761,2	.581,7	1.148	1.309	1.0364	.0974,9
1.55	.739,7	.554,9	1.176	1.333	1.0416	.1101
1.60	.718,7	.529,8	1.207	1.356	1.0468	.1225
1.65	.698,2	.506,4	1.240	1.378	1.0520	.1346
1.70	.678,3	.484,5	1.275	1.400	1.0572	.1465

Notes: (1) For values of M from 0 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_4429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.27 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.67 exactly)

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M	T/T*	p/p*	p_o/p_o^*	V/V* ρ^*/ρ	F/F*	$4fL_{max}/D$
1.75	.659,0	.463,9	1.312	1.421	1.0623	.1580
1.80	.640,2	.444,5	1.351	1.440	1.0673	.1692
1.85	.621,9	.426,3	1.392	1.459	1.0722	.1800
1.90	.604,2	.409,1	1.436	1.477	1.0770	.1905
1.95	.587,1	.392,9	1.482	1.494	1.0817	.2007
2.00	.570,5	.377,6	1.530	1.510	1.0863	.2105
2.05	.554,4	.363,2	1.580	1.526	1.0908	.2199
2.10	.538,8	.349,6	1.632	1.541	1.0952	.2290
2.15	.523,8	.336,7	1.687	1.556	1.0994	.2377
2.20	.509,3	.324,4	1.744	1.570	1.1035	.2461
2.25	.495,2	.312,8	1.803	1.583	1.107	.2542
2.30	.4816	.301,7	1.865	1.596	1.111	.2620
2.35	.4684	.291,2	1.929	1.608	1.115	.2694
2.40	.4557	.281,3	1.995	1.620	1.119	.2766
2.45	.4434	.271,8	2.064	1.631	1.122	.2835
2.50	.4315	.2628	2.135	1.642	1.126	.2901
2.55	.4200	.2542	2.209	1.653	1.129	.2965
2.60	.4089	.2460	2.285	1.663	1.132	.3026
2.65	.3982	.2381	2.364	1.672	1.135	.3085
2.70	.3878	.2306	2.445	1.682	1.138	.3141
2.75	.3778	.2235	2.529	1.691	1.141	.3196
2.80	.3681	.2167	2.616	1.699	1.144	.3248
2.85	.3587	.2102	2.705	1.707	1.146	.3299
2.90	.3497	.2039	2.797	1.715	1.149	.3348
2.95	.3410	.1979	2.892	1.723	1.152	.3395
3.00	.3325	.1922	2.990	1.730	1.154	.3440
3.50	.2616	.1461	4.134	1.790	1.174	.3810
4.00	.2099	.1145	5.608	1.833	1.189	.4071
4.50	.1715	.09203	7.456	1.864	1.200	.4261
5.00	.1424	.07547	9.721	1.887	1.208	.4402
6.00	.10222	.05329	15.68	1.918	1.220	.4594
7.00	.07666	.03955	23.85	1.938	1.227	.4714
8.00	.05949	.03049	34.58	1.951	1.232	.4793
9.00	.04745	.02420	48.24	1.960	1.235	.4849
10.00	.03870	.01996	65.18	1.967	1.238	.4889
∞	0	0	∞	1.996	1.249	.5064

Table 4.27 FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (Perfect Gas, k = 1.67 exactly) (Concluded)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
1.00	1.000,0	1.00,0	1.00,0	1.000	1.000,0	1.64,9
1.05	.952,4	1.10,3	1.10,3	1.000	.999,8	1.73,5
1.10	.909,1	1.21,0	1.21,0	1.000	.998,8	1.82,9
1.15	.869,6	1.32,2	1.32,2	1.000	.996,4	1.93,0
1.20	.833,3	1.44,0	1.44,0	1.000	.991,9	2.03,8
1.25	.800,0	1.56,3	1.56,3	1.000	.985,1	2.15,2
1.30	.769,2	1.69,0	1.69,0	1.000	.975,9	2.27,2
1.35	.740,7	1.82,2	1.82,2	1.000	.964,0	2.39,8
1.40	.714,3	1.96,0	1.96,0	1.000	.949,4	2.53,0
1.45	.689,7	2.10,3	2.10,3	1.000	.932,1	2.66,7
1.50	.666,7	2.25,0	2.25,0	1.000	.912,2	2.81,0
1.55	.645,2	2.40,2	2.40,2	1.000	.889,9	2.95,8
1.60	.625,0	2.56,0	2.56,0	1.000	.865,3	3.11,2
1.65	.606,1	2.72,3	2.72,3	1.000	.838,6	3.27,1
1.70	.588,2	2.89,0	2.89,0	1.000	.810,0	3.43,6
1.75	.571,4	3.06,2	3.06,2	1.000	.779,8	3.60,6
1.80	.555,6	3.24,0	3.24,0	1.000	.748,2	3.78,1
1.85	.540,6	3.42,3	3.42,3	1.000	.715,5	3.96,1
1.90	.526,3	3.61,0	3.61,0	1.000	.681,9	4.14,6
1.95	.512,8	3.80,2	3.80,2	1.000	.6478	4.33,7
2.00	.500,0	4.00,0	4.00,0	1.000	.6134	4.53,2
2.05	.487,8	4.20,3	4.20,3	1.000	.5789	4.73,3
2.10	.476,2	4.41,0	4.41,0	1.000	.5446	4.94,0
2.15	.465,1	4.62,2	4.62,2	1.000	.510,6	5.15,1
2.20	.454,5	4.84,0	4.84,0	1.000	.477,2	5.36,7

Notes: (1) For values of M from 1.00 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_3429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.28 NORMAL SHOCK (Perfect Gas, k = 1.0 exactly)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
2.25	.4444	5.06,3	5.06,3	1.000	.444,6	5.58,8
2.30	.4347	5.29,0	5.29,0	1.000	.412,9	5.81,4
2.35	.4255	5.52,2	5.52,2	1.000	.382,2	6.04,5
2.40	.4167	5.76,0	5.76,0	1.000	.352,7	6.28,2
2.45	.4082	6.00,3	6.00,3	1.000	.324,4	6.52,4
2.50	.4000	6.25,0	6.25,0	1.000	.297,5	6.77,1
2.55	.3921	6.50,2	6.50,2	1.000	.272,0	7.02,2
2.60	.3846	6.76,0	6.76,0	1.000	.247,9	7.27,9
2.65	.3774	7.02,3	7.02,3	1.000	.225,2	7.54,1
2.70	.3704	7.29,0	7.29,0	1.000	.204,0	7.80,7
2.75	.3636	7.56,2	7.56,2	1.000	.184,2	8.07,9
2.80	.3571	7.84,0	7.84,0	1.000	.165,8	8.35,6
2.85	.3508	8.12,3	8.12,3	1.000	.148,8	8.63,8
2.90	.3448	8.41,0	8.41,0	1.000	.133,2	8.92,5
2.95	.3390	8.70,2	8.70,2	1.000	.118,8	9.21,7
3.00	.3333	9.000	9.000	1.000	.1055	9.514
3.50	.2857	12.25	12.25	1.000	.02791	12.76
4.00	.2500	16.00	16.00	1.000	.00554	16.51
4.50	.2222	20.25	20.25	1.000	$.0_3832$	20.76
5.00	.2000	25.00	25.00	1.000	$.0_4951$	25.51
6.00	.1667	36.00	36.00	1.000	$.0_6556$	36.50
7.00	.1429	49.00	49.00	1.000	$.0_8113$	49.50
8.00	.1250	64.00	64.00	1.000	$.0_{12}817$	64.50
9.00	.1111	81.00	81.00	1.000	$.0_{15}210$	81.50
10.00	.1000	100.00	100.00	1.000	$.0_{19}194$	100.50
∞	0	∞	∞	1.000	0	∞

Table 4.28 NORMAL SHOCK (Perfect Gas, k = 1.0 exactly) (Concluded)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
1.00	1.00,00	1.00,0	1.000	1.0000	1.000,0	1.71,0
1.05	.95,26	1.10,7	1.097	1.0093	.999,8	1.80,4
1.10	.909,9	1.22,0	1.198	1.0183	.998,8	1.90,6
1.15	.871,2	1.33,8	1.303	1.0271	.996,5	2.01,5
1.20	.836,0	1.46,1	1.410	1.0358	.992,1	2.13,2
1.25	.803,8	1.58,9	1.521	1.0444	.985,6	2.25,5
1.30	.774,3	1.72,3	1.636	1.0529	.976,9	2.38,4
1.35	.747,1	1.86,2	1.754	1.0615	.965,7	2.52,0
1.40	.722,1	2.00,6	1.875	1.0701	.951,9	2.66,2
1.45	.698,9	2.15,5	1.998	1.0788	.935,8	2.81,0
1.50	.677,3	2.30,9	2.124	1.0876	.917,4	2.96,4
1.55	.657,3	2.46,9	2.252	1.0965	.896,9	3.12,4
1.60	.638,6	2.63,4	2.383	1.1055	.874,4	3.28,9
1.65	.621,1	2.80,4	2.516	1.1146	.850,1	3.46,0
1.70	.604,8	2.98,0	2.651	1.1239	.824,2	3.63,7
1.75	.589,5	3.16,1	2.789	1.133	.797,0	3.82,0
1.80	.575,1	3.34,7	2.928	1.143	.768,6	4.00,8
1.85	.561,5	3.53,8	3.069	1.153	.739,3	4.20,2
1.90	.548,7	3.73,4	3.211	1.163	.7093	4.40,1
1.95	.536,6	3.93,6	3.355	1.173	.6789	4.60,6
2.00	.525,2	4.14,3	3.500	1.184	.6483	4.81,7
2.05	.514,4	4.35,5	3.646	1.194	.6175	5.03,3
2.10	.504,2	4.57,2	3.793	1.205	.5869	5.25,4
2.15	.494,5	4.79,5	3.942	1.216	.5566	5.48,1
2.20	.485,3	5.02,3	4.092	1.228	.526,7	5.71,3

Notes: (1) For values of M from 1.00 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_{3}429$ signifies .000429. The notation $5370_{,}$ signifies 5,370,000.

Table 4.29 NORMAL SHOCK (Perfect Gas, k = 1.1 exactly)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
2.25	.4765	5.25,6	4.242	1.239	.497,4	5.95,1
2.30	.4682	5.49,4	4.393	1.251	.468,7	6.19,4
2.35	.4603	5.73,8	4.544	1.263	.440,8	6.44,3
2.40	.4527	5.98,7	4.696	1.275	.413,8	6.69,7
2.45	.4454	6.24,1	4.848	1.287	.387,8	6.95,7
2.50	.4385	6.50,0	5.000	1.300	.362,7	7.22,2
2.55	.4319	6.76,4	5.152	1.313	.338,7	7.49,2
2.60	.4256	7.03,4	5.304	1.326	.315,7	7.76,8
2.65	.4196	7.30,9	5.457	1.339	.293,8	8.04,9
2.70	.4138	7.58,9	5.610	1.353	.273,0	8.33,5
2.75	.4082	7.87,5	5.762	1.367	.253,3	8.62,7
2.80	.4029	8.16,6	5.914	1.381	.234,7	8.92,5
2.85	.3978	8.46,2	6.065	1.395	.217,2	9.22,8
2.90	.3929	8.76,3	6.216	1.410	.200,7	9.53,6
2.95	.3882	9.06,9	6.367	1.424	.185,2	9.85,0
3.00	.3837	9.381	6.517	1.439	.17070	10.17
3.50	.3466	12.786	7.977	1.603	.07126	13.66
4.00	.3203	16.714	9.333	1.791	.02750	17.68
4.50	.3009	21.167	10.565	2.003	.01014	22.24
5.00	.2859	26.143	11.667	2.241	.00366	27.28
6.00	.2661	37.67	13.50	2.790	.0 ,472	39.16
7.00	.2531	51.29	14.91	3.439	.0 ,645	53.12
8.00	.2443	67.00	16.00	4.188	.0 ,965	69.23
9.00	.2381	84.81	16.84	5.036	.0 ,161	87.49
10.00	.2336	104.71	17.50	5.984	.0 ,297	107.90
∞	.2132	∞	21.00	∞	0	∞

Table 4.29 NORMAL SHOCK (Perfect Gas, k = 1.1 exactly) (Concluded)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
1.00	1.00,00	1.00,0	1.000	1.0000	1.000,0	1.77,2
1.05	.95,28	1.11,2	1.092	1.0178	.999,8	1.87,3
1.10	.910,6	1.22,9	1.187	1.0351	.998,9	1.98,2
1.15	.872,6	1.35,2	1.285	1.0521	.996,5	2.09,9
1.20	.838,3	1.48,0	1.385	1.0689	.992,3	2.22,4
1.25	.807,1	1.61,4	1.486	1.0855	.986,1	2.35,6
1.30	.778,7	1.75,3	1.590	1.1022	.977,7	2.49,5
1.35	.752,7	1.89,7	1.696	1.1189	.967,1	2.64,1
1.40	.728,8	2.04,7	1.803	1.1357	.954,2	2.79,3
1.45	.706,7	2.20,3	1.911	1.1527	.939,1	2.95,1
1.50	.686,4	2.36,4	2.020	1.170	.922,0	3.11,5
1.55	.667,6	2.53,0	2.131	1.187	.903,0	3.28,6
1.60	.650,1	2.70,2	2.242	1.205	.882,2	3.46,3
1.65	.633,8	2.87,9	2.354	1.223	.859,9	3.64,6
1.70	.618,6	3.06,2	2.466	1.241	.836,2	3.83,6
1.75	.604,4	3.25,0	2.579	1.260	.811,4	4.03,1
1.80	.591,2	3.44,4	2.692	1.279	.785,6	4.23,2
1.85	.578,8	3.64,3	2.805	1.299	.759,1	4.43,9
1.90	.567,1	3.84,7	2.918	1.319	.732,0	4.65,2
1.95	.556,1	4.05,7	3.031	1.339	.7045	4.87,1
2.00	.545,8	4.27,3	3.143	1.360	.6768	5.09,6
2.05	.536,0	4.49,4	3.255	1.381	.6490	5.32,6
2.10	.526,8	4.72,0	3.366	1.402	.6213	5.56,2
2.15	.518,1	4.95,2	3.477	1.424	.5938	5.80,5
2.20	.5099	5.18,9	3.587	1.446	.5667	6.05,3

Notes: (1) For values of M from 1.00 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_4429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.30 NORMAL SHOCK (Perfect Gas, k = 1.2 exactly)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
2.25	.5021	5.43,2	3.697	1.469	.5400	6.30,7
2.30	.4947	5.68,0	3.806	1.492	.5139	6.56,7
2.35	.4877	5.93,4	3.914	1.516	.4884	6.83,2
2.40	.4810	6.19,3	4.020	1.540	.4636	7.10,4
2.45	.4746	6.45,7	4.126	1.565	.4397	7.38,3
2.50	.4686	6.72,7	4.231	1.590	.416,2	7.66,4
2.55	.4629	7.00,3	4.335	1.616	.393,7	7.95,2
2.60	.4574	7.28,4	4.437	1.642	.372,1	8.24,7
2.65	.4521	7.57,0	4.538	1.668	.351,3	8.54,7
2.70	.4471	7.86,2	4.638	1.695	.331,4	8.85,3
2.75	.4424	8.15,9	4.737	1.723	.312,4	9.16,5
2.80	.4378	8.46,2	4.834	1.751	.294,2	9.48,3
2.85	.4334	8.77,0	4.930	1.779	.276,8	9.80,6
2.90	.4292	9.08,4	5.025	1.808	.260,3	10.13,5
2.95	.4252	9.40,3	5.118	1.837	.244,6	10.47,0
3.00	.4214	9.727	5.211	1.867	.2298	10.81
3.50	.3904	13.27	6.056	2.192	.1198	14.53
4.00	.3690	17.36	6.769	2.565	.06096	18.83
4.50	.3536	22.00	7.364	2.988	.03093	23.70
5.00	.3421	27.18	7.857	3.459	.01586	29.15
6.00	.3267	39.18	8.609	4.551	.00441	41.76
7.00	.3170	53.36	9.136	5.841	.00134	56.66
8.00	.3106	69.73	9.513	7.329	$.0_3450$	73.86
9.00	.3061	88.27	9.791	9.016	$.0_3164$	93.35
10.00	.3029	109.00	10.000	10.900	$.0_4650$	115.14
∞	.2887	∞	11.00	∞	0	∞

Table 4.30 NORMAL SHOCK (Perfect Gas, k = 1.2 exactly) (Concluded)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
1.00	1.00,00	1.00,0	1.000	1.0000	1.000,0	1.83,2
1.05	.95,30	1.11,6	1.088	1.0257	1.999,8	1.94,1
1.10	.91,12	1.23,7	1.178	1.0507	.998,9	2.05,8
1.15	.873,9	1.36,4	1.269	1.0752	.996,6	2.18,3
1.20	.840,3	1.49,7	1.362	1.0995	.992,5	2.31,6
1.25	.810,0	1.63,6	1.456	1.124	.986,6	2.45,7
1.30	.782,5	1.78,0	1.551	1.148	.978,6	2.60,5
1.35	.757,5	1.93,0	1.646	1.172	.968,4	2.76,0
1.40	.734,6	2.08,5	1.742	1.197	.956,2	2.92,2
1.45	.713,6	2.24,6	1.838	1.222	.942,1	3.09,0
1.50	.694,2	2.41,3	1.935	1.247	.926,1	3.26,5
1.55	.676,4	2.58,5	2.031	1.273	.908,4	3.44,7
1.60	.659,9	2.76,3	2.127	1.299	.889,1	3.63,5
1.65	.644,6	2.94,7	2.223	1.326	.868,4	3.83,0
1.70	.630,4	3.13,7	2.318	1.353	.846,6	4.03,1
1.75	.617,2	3.33,2	2.413	1.380	.823,8	4.23,8
1.80	.604,8	3.53,2	2.507	1.408	.800,1	4.45,2
1.85	.593,3	3.73,8	2.601	1.437	.775,8	4.67,2
1.90	.582,5	3.95,0	2.694	1.467	.7510	4.89,8
1.95	.572,4	4.16,8	2.785	1.497	.7259	5.13,1
2.00	.562,9	4.39,1	2.875	1.527	.7006	5.37,0
2.05	.553,9	4.62,0	2.964	1.558	.6752	5.61,5
2.10	.545,5	4.85,5	3.052	1.590	.6499	5.86,6
2.15	.5376	5.09,5	3.139	1.623	.6248	6.12,3
2.20	.5301	5.34,1	3.225	1.656	.6000	6.38,7

Notes: (1) For values of M from 1.00 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation .0 ,429 signifies .000429. The notation 5370 , signifies 5,370,000

Table 4.31 NORMAL SHOCK (Perfect Gas, k = 1.3 exactly)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
2.25	.5230	5.59,2	3.309	1.690	.575,5	6.65,7
2.30	.5163	5.84,9	3.392	1.725	.551,5	6.93,3
2.35	.5100	6.11,2	3.474	1.760	.528,0	7.21,5
2.40	.5040	6.38,1	3.554	1.796	.505,0	7.50,3
2.45	.4983	6.65,5	3.633	1.832	.482,7	7.79,8
2.50	.4929	6.93,5	3.710	1.869	.461,0	8.09,8
2.55	.4878	7.22,0	3.786	1.907	.440,0	8.40,5
2.60	.4829	7.51,1	3.860	1.946	.419,6	8.71,8
2.65	.4782	7.80,8	3.933	1.985	.399,9	9.03,7
2.70	.4738	8.11,0	4.005	2.025	.381,0	9.36,2
2.75	.4696	8.41,8	4.075	2.066	.362,8	9.69,3
2.80	.4655	8.73,2	4.144	2.108	.345,2	10.03
2.85	.4616	9.05,2	4.211	2.150	.328,4	10.37
2.90	.4579	9.37,7	4.277	2.193	.312,3	10.72
2.95	.4544	9.70,8	4.341	2.236	.296,9	11.08
3.00	.4511	10.04	4.404	2.280	.2822	11.44
3.50	.4241	13.72	4.964	2.763	.1677	15.39
4.00	.4058	17.96	5.412	3.318	.09932	19.96
4.50	.3927	22.76	5.768	3.946	.05941	25.18
5.00	.3832	28.13	6.053	4.648	.03612	30.90
6.00	.3704	40.57	6.469	6.271	.01422	44.31
7.00	.3625	55.26	6.749	8.189	.00610	60.14
8.00	.3573	72.22	6.943	10.40	.00283	78.40
9.00	.3536	91.43	7.084	12.91	.00140	99.10
10.00	.3510	112.91	7.188	15.71	.0 ,740	122.24
∞	.3397	∞	7.667	∞	0	∞

Table 4.31 NORMAL SHOCK (Perfect Gas, k = 1.3 exactly) (Concluded)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
1.00	1.0000,0	1.0000,0	1.0000,0	1.0000,0	1.00000	1.8929
1.01	.9901,3	1.0234,5	1.0166,9	1.0066,5	.99999	1.9152
1.02	.9805,2	1.0471,3	1.0334,4	1.01325	.99998	1.9379
1.03	.9711,5	1.0710,5	1.0502,4	1.01981	.99997	1.9610
1.04	.9620,2	1.0952,0	1.0670,9	1.02634	.99994	1.9845
1.05	.9531,2	1.1196	1.0839,8	1.03284	.99987	2.0083
1.06	.9444,4	1.1442	1.10092	1.03931	.99976	2.0325
1.07	.9359,8	1.1690	1.11790	1.04575	.99962	2.0570
1.08	.9277,2	1.1941	1.13492	1.05217	.9994,4	2.0819
1.09	.9196,5	1.2194	1.15199	1.05856	.9992,1	2.1072
1.10	.9117,7	1.2450	1.1691	1.06494	.9989,2	2.1328
1.11	.9040,8	1.2708	1.1862	1.07130	.9985,8	2.1588
1.12	.8965,6	1.2968	1.2034	1.07764	.9982,0	2.1851
1.13	.8892.2	1.3230	1.2206	1.08396	.9977,6	2.2118
1.14	.8820,4	1.3495	1.2378	1.09027	.9972,6	2.2388
1.15	.8750,2	1.3762	1.2550	1.09657	.9966,9	2.2661
1.16	.8681,6	1.4032	1.2723	1.10287	.9960,5	2.2937
1.17	.8614,5	1.4304	1.2896	1.10916	.9953,4	2.3217
1.18	.8548,8	1.4578	1.3069	1.11544	.9945,5	2.3499
1.19	.8484,6	1.4854	1.3243	1.12172	.9937,1	2.3786
1.20	.8421,7	1.5133	1.3416	1.1280	.9928,0	2.4075
1.21	.8360,1	1.5414	1.3590	1.1343	.9918,0	2.4367
1.22	.8299,8	1.5698	1.3764	1.1405	.9907,3	2.4662
1.23	.8240,8	1.5984	1.3938	1.1468	.9895,7	2.4961
1.24	.8183,0	1.6272	1.4112	1.1531	.9883,5	2.5263
1.25	.8126,4	1.6562	1.4286	1.1594	.9870,6	2.5568
1.26	.8070,9	1.6855	1.4460	1.1657	.9856,8	2.5876
1.27	.8016,5	1.7150	1.4634	1.1720	.9842,2	2.6187
1.28	.7963,1	1.7448	1.4808	1.1782	.9826,8	2.6500
1.29	.7910,8	1.7748	1.4983	1.1846	.9810,6	2.6816
1.30	.7859,6	1.8050	1.5157	1.1909	.9793,5	2.7135
1.31	.7809,3	1.8354	1.5331	1.1972	.9775,8	2.7457
1.32	.7760,0	1.8661	1.5505	1.2035	.9757,4	2.7783
1.33	.7711,6	1.8970	1.5680	1.2099	.9738,2	2.8112
1.34	.7664,1	1.9282	1.5854	1.2162	.9718,1	2.8444
1.35	.7617,5	1.9596	1.6028	1.2226	.9697,2	2.8778
1.36	.7571,8	1.9912	1.6202	1.2290	.9675,6	2.9115
1.37	.7526,9	2.0230	1.6376	1.2354	.9653,4	2.9455
1.38	.7482,8	2.0551	1.6550	1.2418	.9630,4	2.9798
1.39	.7439,6	2.0874	1.6723	1.2482	.9606,5	3.0144
1.40	.7397,1	2.1200	1.6896	1.2547	.9581,9	3.0493
1.41	.7355,4	2.1528	1.7070	1.2612	.9556,6	3.0844
1.42	.7314,4	2.1858	1.7243	1.2676	.9530,6	3.1198
1.43	.7274,1	2.2190	1.7416	1.2742	.9503,9	3.1555
1.44	.7234,5	2.2525	1.7589	1.2807	.9476,5	3.1915

Notes: (1) For values of M from 1.00 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_4429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.32 NORMAL SHOCK (Perfect Gas, k = 1.4 exactly)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
1.45	.7195,6	2.2862	1.7761	1.2872	.9448,3	3.2278
1.46	.7157,4	2.3202	1.7934	1.2938	.9419,6	3.2643
1.47	.7119,8	2.3544	1.8106	1.3004	.9390,1	3.3011
1.48	.7082,9	2.3888	1.8278	1.3070	.9360,0	3.3382
1.49	.7046,6	2.4234	1.8449	1.3136	.9329,2	3.3756
1.50	.7010,9	2.4583	1.8621	1.3202	.9297,8	3.4133
1.51	.6975,8	2.4934	1.8792	1.3269	.9265,8	3.4512
1.52	.6941,3	2.5288	1.8962	1.3336	.9233,1	3.4894
1.53	.6907,3	2.5644	1.9133	1.3403	.9199,9	3.5279
1.54	.6873,9	2.6003	1.9303	1.3470	.9166,2	3.5667
1.55	.6841,0	2.6363	1.9473	1.3538	.9131,9	3.6058
1.56	.6808,6	2.6725	1.9643	1.3606	.9097,0	3.6451
1.57	.6776,8	2.7090	1.9812	1.3674	.9061,5	3.6847
1.58	.6745,5	2.7458	1.9981	1.3742	.9025,5	3.7245
1.59	.6714,7	2.7828	2.0149	1.3811	.8988,9	3.7645
1.60	.66844	2.8201	2.0317	1.3880	.8952,0	3.8049
1.61	.66545	2.8575	2.0485	1.3949	.8914,4	3.8456
1.62	.66251	2.8951	2.0652	1.4018	.8876,4	3.8866
1.63	.65962	2.9330	2.0820	1.4088	.8838,0	3.9278
1.64	.65677	2.9712	2.0986	1.4158	.8799,2	3.9693
1.65	.65396	3.0096	2.1152	1.4228	.87598	4.0111
1.66	.65119	3.0482	2.1318	1.4298	.87201	4.0531
1.67	.64847	3.0870	2.1484	1.4369	.86800	4.0954
1.68	.64579	3.1261	2.1649	1.4440	.86396	4.1379
1.69	.64315	3.1654	2.1813	1.4512	.85987	4.1807
1.70	.64055	3.2050	2.1977	1.4583	.85573	4.2238
1.71	.63798	3.2448	2.2141	1.4655	.85155	4.2672
1.72	.63545	3.2848	2.2304	1.4727	.84735	4.3108
1.73	.63296	3.3250	2.2467	1.4800	.84312	4.3547
1.74	.63051	3.3655	2.2629	1.4873	.83886	4.3989
1.75	.62809	3.4062	2.2791	1.4946	.83456	4.4433
1.76	.62570	3.4472	2.2952	1.5019	.83024	4.4880
1.77	.62335	3.4884	2.3113	1.5093	.82589	4.5330
1.78	.62104	3.5298	2.3273	1.5167	.82152	4.5783
1.79	.61875	3.5714	2.3433	1.5241	.81711	4.6238
1.80	.61650	3.6133	2.3592	1.5316	.81268	4.6695
1.81	.61428	3.6554	2.3751	1.5391	.80823	4.7155
1.82	.61209	3.6978	2.3909	1.5466	.80376	4.7618
1.83	.60993	3.7404	2.4067	1.5542	.79926	4.8083
1.84	.60780	3.7832	2.4224	1.5617	.79474	4.8551
1.85	.60570	3.8262	2.4381	1.5694	.79021	4.9022
1.86	.60363	3.8695	2.4537	1.5770	.78567	4.9498
1.87	.60159	3.9130	2.4693	1.5847	.78112	4.9974
1.88	.59957	3.9568	2.4848	1.5924	.77656	5.0453
1.89	.59758	4.0008	2.5003	1.6001	.77197	5.0934

Table 4.32 NORMAL SHOCK (Perfect Gas, k = 1.4 exactly) (Continued)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
1.90	.59562	4.0450	2.5157	1.6079	.76735	5.1417
1.91	.59368	4.0894	2.5310	1.6157	.76273	5.1904
1.92	.59177	4.1341	2.5463	1.6236	.75812	5.2394
1.93	.58988	4.1790	2.5615	1.6314	.75347	5.2886
1.94	.58802	4.2242	2.5767	1.6394	.74883	5.3381
1.95	.58618	4.2696	2.5919	1.6473	.74418	5.3878
1.96	.58437	4.3152	2.6070	1.6553	.73954	5.4378
1.97	.58258	4.3610	2.6220	1.6633	.73487	5.4880
1.98	.58081	4.4071	2.6369	1.6713	.73021	5.5385
1.99	.57907	4.4534	2.6518	1.6794	.72554	5.5894
2.00	.57735	4.5000	2.6666	1.6875	.72088	5.6405
2.01	.57565	4.5468	2.6814	1.6956	.71619	5.6918
2.02	.57397	4.5938	2.6962	1.7038	.71152	5.7434
2.03	.57231	4.6411	2.7109	1.7120	.70686	5.7952
2.04	.57068	4.6886	2.7255	1.7203	.70218	5.8473
2.05	.56907	4.7363	2.7400	1.7286	.69752	5.8997
2.06	.56747	4.7842	2.7545	1.7369	.69284	5.9523
2.07	.56589	4.8324	2.7690	1.7452	.68817	6.0052
2.08	.56433	4.8808	2.7834	1.7536	.68351	6.0584
2.09	.56280	4.9295	2.7977	1.7620	.67886	6.1118
2.10	.56128	4.9784	2.8119	1.7704	.67422	6.1655
2.11	.55978	5.0275	2.8261	1.7789	.66957	6.2194
2.12	.55830	5.0768	2.8402	1.7874	.66492	6.2736
2.13	.55683	5.1264	2.8543	1.7960	.66029	6.3280
2.14	.55538	5.1762	2.8683	1.8046	.65567	6.3827
2.15	.55395	5.2262	2.8823	1.8132	.65105	6.4377
2.16	.55254	5.2765	2.8962	1.8219	.64644	6.4929
2.17	.55114	5.3270	2.9100	1.8306	.64185	6.5484
2.18	.54976	5.3778	2.9238	1.8393	.63728	6.6042
2.19	.54841	5.4288	2.9376	1.8481	.63270	6.6602
2.20	.54706	5.4800	2.9512	1.8569	.62812	6.7163
2.21	.54572	5.5314	2.9648	1.8657	.62358	6.7730
2.22	.54440	5.5831	2.9783	1.8746	.61905	6.8299
2.23	.54310	5.6350	2.9918	1.8835	.61453	6.8869
2.24	.54182	5.6872	3.0052	1.8924	.61002	6.9442
2.25	.54055	5.7396	3.0186	1.9014	.60554	7.0018
2.26	.53929	5.7922	3.0319	1.9104	.60106	7.0597
2.27	.53805	5.8451	3.0452	1.9194	.59659	7.1178
2.28	.53683	5.8982	3.0584	1.9285	.59214	7.1762
2.29	.53561	5.9515	3.0715	1.9376	.58772	7.2348
2.30	.53441	6.0050	3.0846	1.9468	.58331	7.2937
2.31	.53322	6.0588	3.0976	1.9560	.57891	7.3529
2.32	.53205	6.1128	3.1105	1.9652	.57452	7.4123
2.33	.53089	6.1670	3.1234	1.9745	.57015	7.4720
2.34	.52974	6.2215	3.1362	1.9838	.56580	7.5319

Table 4.32 NORMAL SHOCK (Perfect Gas, k = 1.4 exactly) (Continued)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
2.35	.52861	6.2762	3.1490	1.9931	.56148	7.5920
2.36	.52749	6.3312	3.1617	2.0025	.55717	7.6524
2.37	.52638	6.3864	3.1743	2.0119	.55288	7.7131
2.38	.52528	6.4418	3.1869	2.0213	.54862	7.7741
2.39	.52419	6.4974	3.1994	2.0308	.54438	7.8354
2.40	.52312	6.5533	3.2119	2.0403	.54015	7.8969
2.41	.52206	6.6094	3.2243	2.0499	.53594	7.9587
2.42	.52100	6.6658	3.2366	2.0595	.53175	8.0207
2.43	.51996	6.7224	3.2489	2.0691	.52758	8.0830
2.44	.51894	6.7792	3.2611	2.0788	.52344	8.1455
2.45	.51792	6.8362	3.2733	2.0885	.51932	8.2083
2.46	.51691	6.8935	3.2854	2.0982	.51521	8.2714
2.47	.51592	6.9510	3.2975	2.1080	.51112	8.3347
2.48	.51493	7.0088	3.3095	2.1178	.50706	8.3983
2.49	.51395	7.0668	3.3214	2.1276	.50303	8.4622
2.50	.51299	7.1250	3.3333	2.1375	.49902	8.5262
2.51	.51204	7.1834	3.3451	2.1474	.49502	8.5904
2.52	.51109	7.2421	3.3569	2.1574	.49104	8.6549
2.53	.51015	7.3010	3.3686	2.1674	.48709	8.7198
2.54	.50923	7.3602	3.3802	2.1774	.48317	8.7850
2.55	.50831	7.4196	3.3918	2.1875	.47927	8.8505
2.56	.50740	7.4792	3.4034	2.1976	.47540	8.9162
2.57	.50651	7.5391	3.4149	2.2077	.47155	8.9821
2.58	.50562	7.5992	3.4263	2.2179	.46772	9.0482
2.59	.50474	7.6595	3.4376	2.2281	.46391	9.1146
2.60	.50387	7.7200	3.4489	2.2383	.46012	9.1813
2.61	.50301	7.7808	3.4602	2.2486	.45636	9.2481
2.62	.50216	7.8418	3.4714	2.2589	.45262	9.3154
2.63	.50132	7.9030	3.4825	2.2693	.44891	9.3829
2.64	.50048	7.9645	3.4936	2.2797	.44522	9.4507
2.65	.49965	8.0262	3.5047	2.2901	.44155	9.5187
2.66	.49883	8.0882	3.5157	2.3006	.43791	9.5869
2.67	.49802	8.1504	3.5266	2.3111	.43429	9.6553
2.68	.49722	8.2128	3.5374	2.3217	.43070	9.7241
2.69	.49642	8.2754	3.5482	2.3323	.42713	9.7932
2.70	.49563	8.3383	3.5590	2.3429	.42359	9.8625
2.71	.49485	8.4014	3.5697	2.3536	.42007	9.9320
2.72	.49408	8.4648	3.5803	2.3643	.41657	10.0017
2.73	.49332	8.5284	3.5909	2.3750	.41310	10.0718
2.74	.49256	8.5922	3.6014	2.3858	.40965	10.1421
2.75	.49181	8.6562	3.6119	2.3966	.40622	10.212
2.76	.49107	8.7205	3.6224	2.4074	.40282	10.283
2.77	.49033	8.7850	3.6328	2.4183	.39945	10.354
2.78	.48960	8.8497	3.6431	2.4292	.39610	10.426
2.79	.48888	8.9147	3.6533	2.4402	.39276	10.498

Table 4.32 NORMAL SHOCK (Perfect Gas, k = 1.4 exactly) (Continued)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
2.80	.48817	8.9800	3.6635	2.4512	.38946	10.569
2.81	.48746	9.0454	3.6737	2.4622	.38618	10.641
2.82	.48676	9.1111	3.6838	2.4733	.38293	10.714
2.83	.48607	9.1770	3.6939	2.4844	.37970	10.787
2.84	.48538	9.2432	3.7039	2.4955	.37649	10.860
2.85	.48470	9.3096	3.7139	2.5067	.37330	10.933
2.86	.48402	9.3762	3.7238	2.5179	.37013	11.006
2.87	.48334	9.4431	3.7336	2.5292	.36700	11.080
2.88	.48268	9.5102	3.7434	2.5405	.36389	11.154
2.89	.48203	9.5775	3.7532	2.5518	.36080	11.228
2.90	.48138	9.6450	3.7629	2.5632	.35773	11.302
2.91	.48074	9.7127	3.7725	2.5746	.35469	11.377
2.92	.48010	9.7808	3.7821	2.5860	.35167	11.452
2.93	.47946	9.8491	3.7917	2.5975	.34867	11.527
2.94	.47883	9.9176	3.8012	2.6090	.34570	11.603
2.95	.47821	9.9863	3.8106	2.6206	.34275	11.679
2.96	.47760	10.055	3.8200	2.6322	.33982	11.755
2.97	.47699	10.124	3.8294	2.6438	.33692	11.831
2.98	.47638	10.194	3.8387	2.6555	.33404	11.907
2.99	.47578	10.263	3.8479	2.6672	.33118	11.984
3.00	.47519	10.333	3.8571	2.6790	.32834	12.061
3.50	.45115	14.125	4.2608	3.3150	.21295	16.242
4.00	.43496	18.500	4.5714	4.0469	.13876	21.058
4.50	.42355	23.458	4.8119	4.8751	.09170	26.539
5.00	.41523	29.000	5.0000	5.8000	.06172	32.654
6.00	.40416	41.833	5.2683	7.9406	.02965	46.815
7.00	.39736	57.000	5.4444	10.469	.01535	63.552
8.00	.39289	74.500	5.5652	13.387	.00849	82.865
9.00	.38980	94.333	5.6512	16.693	.00496	104.753
10.00	.38757	116.500	5.7143	20.388	.00304	129.217
∞	.37796	∞	6.0000	∞	0	∞

Table 4.32 NORMAL SHOCK (Perfect Gas, k = 1.4 exactly) (Concluded)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
1.00	1.00,00	1.00,0	1.0000	1.0000	1.000,0	2.05,5
1.05	.95,35	1.12,8	1.0748	1.0496	.999,8	2.18,9
1.10	.91,31	1.26,2	1.149	1.0985	.999,0	2.33,3
1.15	.877,6	1.40,3	1.223	1.147	.996,9	2.48,6
1.20	.846,3	1.55,0	1.297	1.195	.993,4	2.64,9
1.25	.818,4	1.70,3	1.370	1.244	.988,3	2.82,1
1.30	.793,5	1.86,3	1.441	1.293	.981,3	3.00,2
1.35	.771,1	2.02,9	1.511	1.343	.972,8	3.19,1
1.40	.750,9	2.20,1	1.580	1.394	.962,7	3.38,8
1.45	.732,5	2.37,9	1.647	1.445	.951,1	3.59,2
1.50	.715,8	2.56,3	1.713	1.497	.938,1	3.80,4
1.55	.700,6	2.75,4	1.777	1.550	.923,9	4.02,5
1.60	.686,6	2.95,1	1.840	1.604	.908,6	4.25,4
1.65	.673,8	3.15,4	1.901	1.659	.892,4	4.49,0
1.70	.662,0	3.36,4	1.960	1.716	.875,4	4.73,3
1.75	.651,1	3.58,0	2.018	1.774	.8577	4.98,4
1.80	.641,0	3.80,2	2.074	1.833	.8395	5.24,3
1.85	.631,6	4.03,0	2.128	1.893	.8209	5.51,0
1.90	.622,9	4.26,5	2.181	1.955	.8019	5.78,4
1.95	.614,8	4.50,6	2.232	2.018	.7827	6.06,5
2.00	.607,3	4.75,3	2.282	2.083	.7634	6.35,4
2.05	.600,2	5.00,6	2.330	2.149	.7441	6.65,0
2.10	.593,6	5.26,6	2.376	2.216	.7248	6.95,4
2.15	.5875	5.53,2	2.421	2.284	.7056	7.26,6
2.20	.5817	5.80,4	2.465	2.354	.6866	7.58,5

Notes: (1) For values of M from 1.00 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

(2) The notation $.0_3429$ signifies .000429. The notation 5370_4 signifies 5,370,000.

Table 4.33 NORMAL SHOCK (Perfect Gas, k = 1.67 exactly)

M_x	M_y	p_y/p_x	V_x/V_y ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* p_{oy}/p_{ox}	p_{oy}/p_x
2.25	.5762	6.08,2	2.507	2.426	.6678	7.91,1
2.30	.5711	6.36,6	2 548	2.499	.6493	8.24,4
2.35	.5663	6.65,7	2.587	2.574	.6310	8.58,5
2.40	.5617	6.95,4	2.625	2.650	.6130	8.93,4
2.45	.5574	7.25,7	2.662	2.727	.5954	9.29,0
2.50	.5534	7.56,7	2.697	2.806	.5783	9.653
2.55	.5495	7.88,3	2.731	2.886	.5615	10.02
2.60	.5459	8.20,5	2 764	2.968	.5450	10.40
2.65	.5425	8.53,3	2.796	3.052	.5289	10.79
2.70	.5392	8.86,8	2.827	3.137	.5133	11.18
2.75	.5361	9.20,9	2.857	3.223	.4981	11.58
2.80	.5331	9.55,6	2.886	3.311	.4833	11.99
2.85	.5303	9.90,9	2.914	3.401	.4689	12.41
2.90	.5276	10.27	2.941	3.492	.4550	12.83
2.95	.5251	10.64	2.967	3.584	.4415	13.26
3.00	.5227	11.01	2.992	3.678	.4283	13.69
3.50	.5036	15.07	3.204	4.704	.3177	18.47
4.00	.4910	19.76	3.358	5.885	.2384	23.99
4.50	.4822	25.08	3.473	7.221	.1816	30.24
5.00	.4758	31.02	3.560	8.714	.1406	37.23
6.00	.4674	44.78	3.680	12.17	.08831	53.40
7.00	.4623	61.04	3.756	16.25	.05842	72.53
8.00	.4589	79.81	3.808	20.96	.04059	94.59
9.00	.4566	101.08	3.843	26.30	.02920	119.6
10.00	.4550	124.84	3.870	32.26	.02167	147.6
∞	.4479	∞	3.985	∞	0	∞

Table 4.33 NORMAL SHOCK (Perfect Gas, k = 1.67 exactly) (Concluded)

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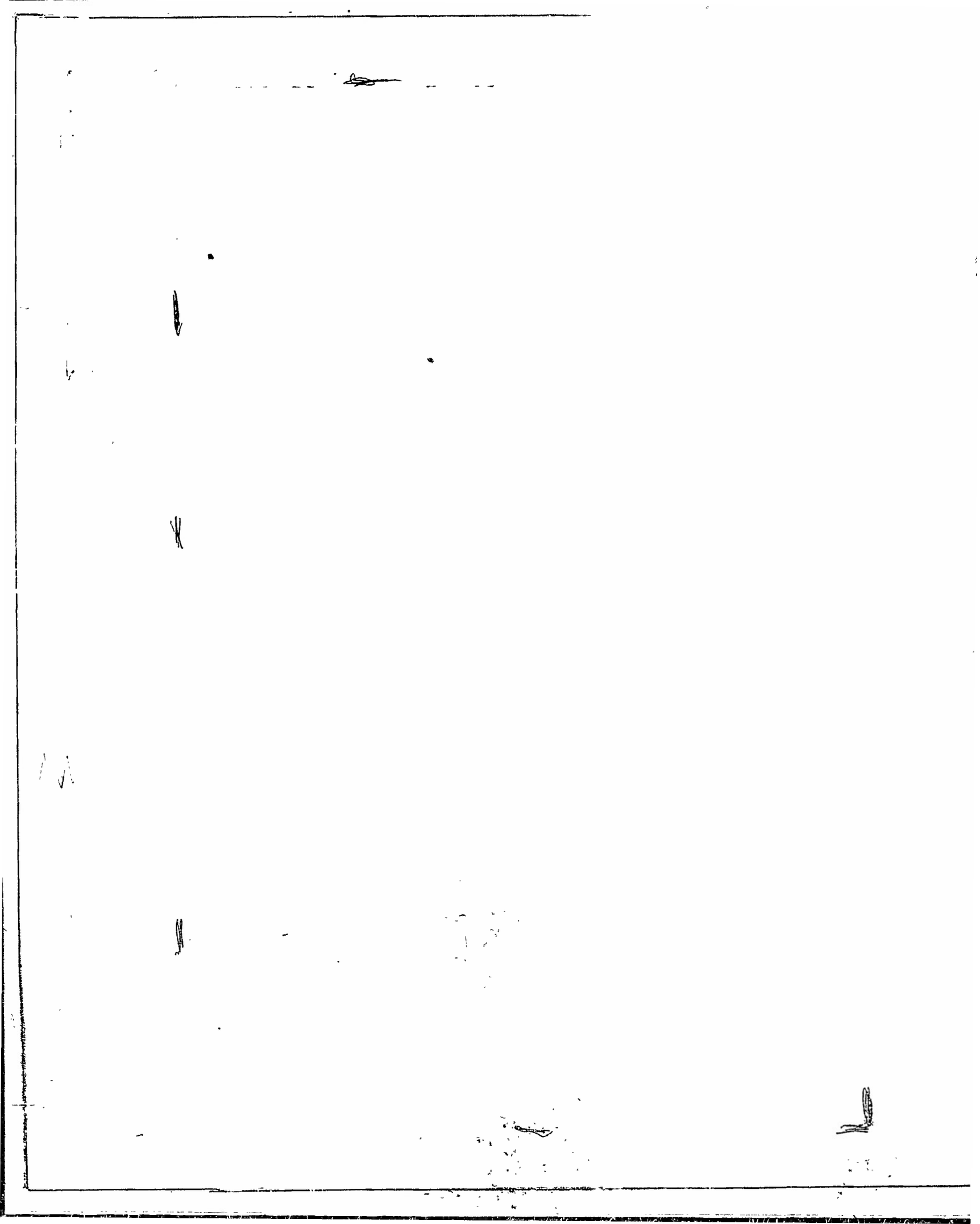
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