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TERRESTRIAL ENVIRONMENT (CLIMATIC) CRITERIA GUIDELINES FOR USE IN SPACE VEHICLE DEVELOPMENT, 1969 REVISION

By Glenn E. Daniels, Editor
Aero-Astrodynamics Laboratory

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16. ABSTRACT

This document provides guidlines on probable climatic extremes and probabilities-of-occurrence of terrestrial environment data specifically applicable for NASA space vehicles and associated equipment development. The geographic areas encompassed * are the Eastern Test Range (Cape Kennedy, Florida); Huntsville, Alabama; New Orleans, Louisiana; the Western Test Range (Point Arguello, California); Sacramento, California; Wallops Test Range (Wallops Island, Virginia); White Sands Missile Range, New Mexico; and intermediate transportation areas. In addition, sections have been included to provide information on the general distribution of natural environment extremes in the United States (excluding Alaska and Hawaii), cloud cover, and some worldwide climatic extremes.

This document presents the latest available information on probable climatic extremes, and superseded information presented in TM X-53328 (Ref. 1.2). The information in this document is recommended for employment in the development of space vehicles and associated equipment design criteria, unless otherwise stated in contract work specifications.

This second printing (March 15, 1970) includes corrections to the original printing.

* Although all areas are covered, the major emphasis is given to the Kennedy Space Center launch area due to importance in NASA's large space vehicle programs.

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TERRESTRIAL ENVIRONMENT (CLIMATIC) CRITERIA GUIDELINES FOR USE IN SPACE VEHICLE DEVELOPMENT, 1969 REVISION

Glenn E. Daniels, Editor

SUMMARY

This document provides guidelines on probable climatic extremes of terrestrial environment data specifically applicable for NASA space vehicles and associated equipment development. The geographic areas encompassed are the Eastern Test Range (Cape Kennedy, Florida); Huntsville, Alabama; New Orleans, Louisiana; the Western Test Range (Point Arguello, California); Sacramento, California; Wallops Test Range (Wallops Island, Virginia); White Sands Missile Range, New Mexico; and intermediate transportation areas. In addition, a section has been included to provide information on the general distribution of natural environmental extremes in the United States (excluding Alaska and Hawaii) that may be needed to specify design criteria in the transportation of space vehicle components. Although not considered as a specific space vehicle design criterion, a section on worldwide cloud cover has been added in this revision since certain earth orbital experiment missions are influenced by cloud cover. Some climatic extremes for worldwide operational conditions are included; however, launching and test areas are restricted due to the nonavailability of facilities and real estate. Specific reentry landing areas are not covered in this document.

Design guideline values are established for the following environmental parameters: (1) thermal (temperature and solar radiation), (2) humidity, (3) precipitation, (4) winds, (5) pressure, (6) density, (7) electricity (atmospheric), (8) corrosion (atmospheric), (9) sand and dust, (10) fungi and bacteria, (11) atmospheric oxidants, (12) composition of the atmosphere, and (13) inflight thermodynamic properties. Data are presented and discussions

of these data are given relative to interpretation as design guidelines. Additional information on the different parameters may be located in the numerous references cited in the text following each section.

FOREWORD

For climatic extremes, there is no known physical upper or lower bound, except for certain conditions; that is, for wind speed, there does exist a strict physical lower bound of zero. Therefore, for any observed extreme condition, there is a finite probability of its being exceeded. Consequently, climatic extremes for design must be accepted with the knowledge there is some risk of the values being exceeded. Also, the accuracy of measurement of many environmental parameters is not as precise as desired. In some cases, theoretical estimates of extreme values are believed to be more representative than those indicated by empirical distributions from short periods of record. Therefore, theoretical values are given considerable weight in selecting extreme values for some parameters, i.e., the peak surface winds.

With regard to surface and inflight winds, shears, and turbulence, it is understood that the space vehicle will not be designed for launch and flight in severe weather conditions; that is, hurricanes, thunderstorms, and squalls. Wind conditions are presented for various percentiles based on available data samples. Caution should be exercised in the interpretation of these percentiles in vehicle studies to ensure consistency with physical reality and the specific design and operational problems of concern.

Environmental data in this document are limited to information below 90 km. The document, NASA TM X-53957 "Space Environment Criteria Guidelines for Use in Space Vehicle Development, (1969 Revision)" (Ref. 1.1), provides information above 90 km. Specific space vehicle natural environmental design criteria are normally specified in the appropriate organizational space vehicle design ground rules and design criteria data documentation. The information in this document is recommended for use in the development of space vehicles and associated equipment, unless otherwise stated in contract work specifications.

Considerably more information is available, but not in final form, on some of the topics in this document, viz., solar radiation, and surface and inflight winds and thermodynamic properties. Users of this document who have questions or require further information on the data provided in this document shall direct their requests to the Aerospace Environment Division (S&E-AERO-Y), Aero-Astrodynamics Laboratory, Marshall Space Flight Center.

The data in all sections are based on extremes which have actually occurred, or are statistically probable in nature, over a longer period than the available data. When possible, cycles (diurnal or other) are given to provide information for environmental testing in the laboratory. In many cases, the natural test cycles do not agree with standard laboratory tests, frequently being less severe. Occasionally, the natural cycle as given is more severe than the laboratory test. Such cycles need careful consideration to determine whether the laboratory tests need adjustment.

THIS DOCUMENT IS A REVISION AND SHOULD BE USED IN LIEU OF THE DATA PRESENTED IN TM X-53328 (Ref. 1.2). SECTION V, WIND, HAS BEEN REVISED EXTENSIVELY FROM THAT CONTAINED IN NASA TM X-53328. THIS DOCUMENT, THEREFORE, SUPERSEDES FOR DESIGN, MISSION ANALYSIS, AND OPERATIONAL USE NASA TM X-53328 FOR ALL NEW PROJECT DESIGN CRITERIA DEVELOPMENT.

The environmental criteria data presented in this document were formulated based on discussions and requests from engineers involved in space vehicle development and operations. Therefore, they represent responses to actual engineering problems and not just a general compilation of environmental data. The following authored sections of this document: M. Alexander, S. C. Brown, D. Camp, G. Daniels, Dr. G. Fichtl, K. Hill, D. Johnson, J. Kaufman, O. E. Smith, W. W. Vaughan.

This report is used extensively by the Marshall Space Flight Center and the Manned Spacecraft Center in design.

Inquires may be directed through appropriate channels to the following persons:

Scientific Area	MSFC	MSC	KSC
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SECTION I. INTRODUCTION

By

Glenn E. Daniels and William W. Vaughan

1.1 General

A knowledge of the earth's atmospheric environmental parameters is necessary for the establishment of design requirements for space vehicles and associated equipment. Such data are required to define the design condition for fabrication, storage, transportation, test, pre-flight, and in-flight design conditions and should be considered for both the whole system and the components which make up the system. The purpose of this document is to provide guideline data on natural environmental conditions for the various major geographic locations which are applicable to the design of space vehicles and associated equipment for the National Aeronautics and Space Administration. The publications MIL-STD-210A (Ref. 1.3), U.S. Standard Atmosphere, 1962 (Ref. 1.4), the U.S. Standard Atmosphere Supplements (Ref. 1.5), and the Range Reference Atmospheres (Ref. 1.6), are suggested for use as sources of data for geographic areas not given in this document.

Good engineering judgment must be exercised in the application of the earth's atmospheric data to space vehicle design analysis. Consideration must be given to the overall vehicle mission and performance requirements. Knowledge still is lacking on the relationships between some of the atmopheric variates which are required as inputs to the design of space vehicles. Also, interrelationships between space vehicle parameters and atmospheric variables cannot always be clearly defined. Therefore, a close working relationship and team philosophy should exist between the design/operational engineer and the respective organization's aerospace meteorologists. Although a space vehicle design should accommodate all expected operational atmospheric conditions, it is neither economically nor technically feasible to design space vehicles to withstand all atmospheric extremes. For this reason, consideration should be given to protection of space vehicles from some extremes by use of support equipment, and by using specialized forecast personnel to advise of the expected occurrence of critical environmental conditions. The services of specialized forecast personnel may be very economical in comparison with more expensive designing which would be necessary to cope with all environmental possibilities.

This document does not specify how the designer should use the data in regard to a specific space vehicle design. Such specifications may be established only through analysis and study of a particular design problem. Although of operational significance, descriptions of some atmospheric conditions have been omitted since they are not of direct concern for structural and control system design. Induced environments (vehicle caused) may be more critical than natural environments for certain vehicle operational situations, and in some cases the combination of natural and induced environments will be more severe than either environment alone. Induced environments are considered in other space vehicle criteria documents which should be consulted for such data.

Reports such as the "Marine Climatic Guide" (Ref. 1.7) may be consulted for reentry landing area information.

1.2 Geographical Areas Covered (Fig. 1.1)

a. Huntsville, Alabama.

b. River transportation: Between Huntsville, Alabama (via Tennessee, Ohio, and Mississippi Rivers) and New Orleans, Louisiana.

c. New Orleans, Louisiana; Mississippi Test Operations, Mississippi; Houston, Texas, and transportation zones between these locations.

d. Gulf transportation: Between New Orleans, Louisiana (via Gulf of Mexico and up east coast of Florida) and Cape Kennedy, Florida.

e. Panama Canal transportation: Between Los Angeles or Point Arguello, California (via West Coast of California and Mexico, through the Panama Canal, and Gulf of Mexico) and New Orleans, Louisiana.

f. Eastern Test Range (ETR), Cape Kennedy, Florida.

g. Western Test Range (WTR), Point Arguello, California.

h. Sacramento, California.

i. Wallops Test Range, Wallops Island, Virginia.

j. West coast transportation: Between Los Angeles, California, and Sacramento, California.

k. White Sands Missile Range, New Mexico.

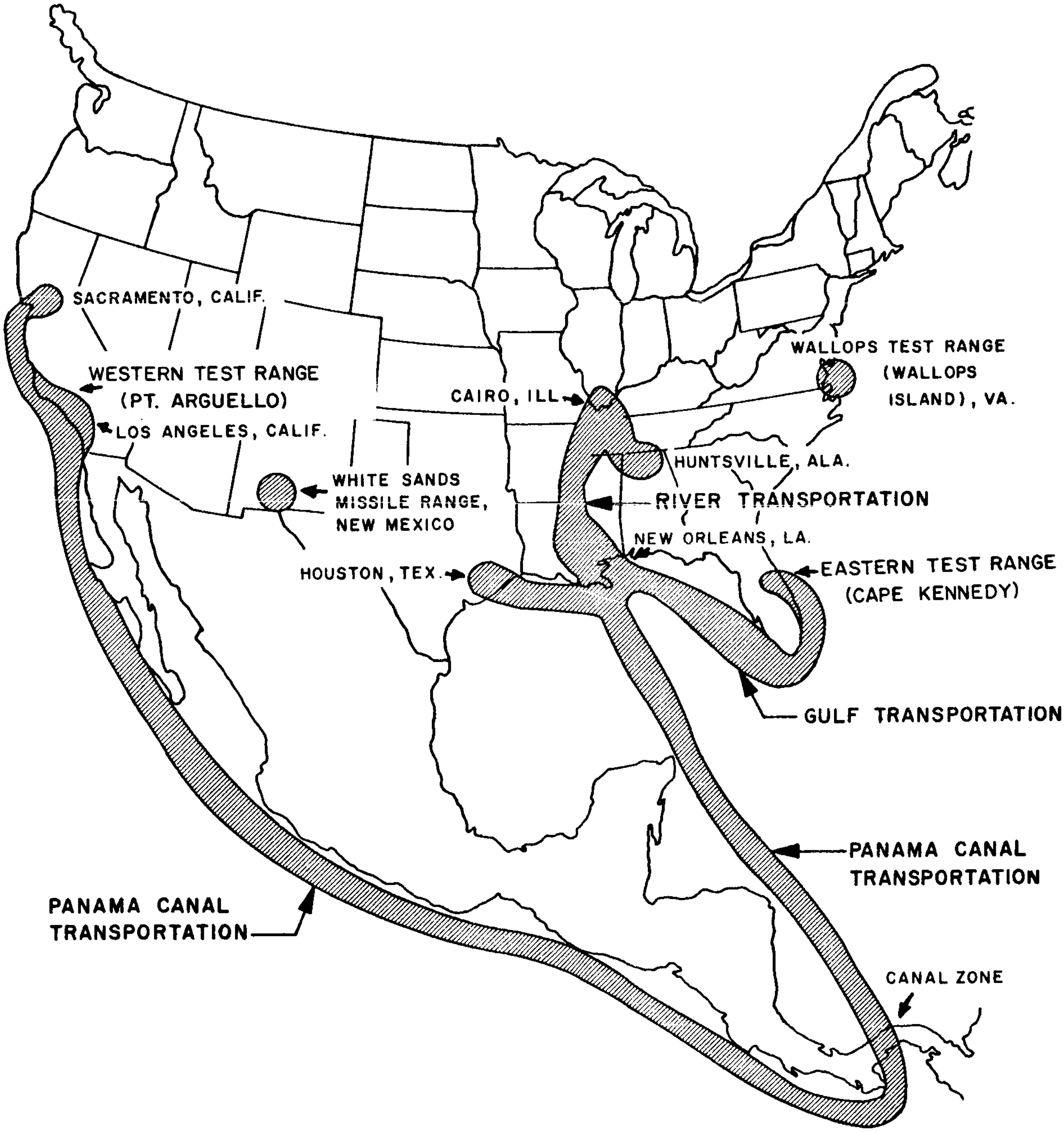


FIGURE 1.1 MAIN GEOGRAPHICAL AREAS COVERED IN DOCUMENT

1.3 Units of Conversion

Numerical values in this document are given in the International System of Units (Ref. 1.8, 1.9). The values in parentheses are equivalent U.S. Customary Units.* The metric and U. S. Customary Units employed in this report are those normally used for measuring and reporting atmospheric data.

By definition, the following fundamental conversion factors are exact (Ref. 1.8, 1.9, 1.10).

Type	U. S. Customary Units	Metric
Length	1 U. S. yard (yd)	0.9144 meter (m)
Mass	1 avoirdupois pound (lb)	453.59237 gram (g)
Time	1 second (s)	1 second (s)
Temperature	1 degree Rankine(°R)	5/9 degrees Kelvin (°K)
Electric current	1 ampere (A)	1 ampere (A)
Light intensity	1 candela (cd)	1 candela (cd)

To aid in conversion of units given in this document, conversion factors based on the above fundamental conversion factors are given in Table 1.1. Geometric altitude as employed herein is with reference to mean sea level (MSL) unless otherwise stated.

1.4 Definition of Percentiles

The values of the data corresponding to the cumulative percentage frequencies are called percentiles. The relationship between percentiles and probability is as follows: Given that the 90th percentile of the wind speed is, say, 60 m/s means that there is a probability of 0.90 that this value of the wind speed will not be exceeded, and there is probability of 0.10 that it will be exceeded for the sample of data from which the percentile was computed. Stated in another way: There is a 90 percent chance that the given wind speed of 60 m/s will not be exceeded or there is a 10 percent chance that it will be exceeded. If one considers the 10th and 90th percentiles for the wind speeds, it is clear that 80 percent of the wind speeds occur within the 10-90 percentiles range.

* English Units adopted for use by the United States of America.

TABLE 1.1 CONVERSION OF UNITS

	TYPE OF DATA	METRIC		U.S. CUSTOMARY		CONVERSION		
		UNIT	ABBREVIATION	UNIT	ABBREVIATION	MULTIPLY	BY	TO GET
SOLAR RADIATION	Solar Intensity	langley (per minute)	ly (min^{-1})	watt per square foot	watt ft^{-2}	ly (min^{-1})	0.69733	kJ $m^{-2}(s^{-1})$
		gram-calorie per square centimeter (per minute)	g-cal $cm^{-2}(min^{-1})$	British Thermal Unit per square foot (per minute)	B.T.U. ft^{-2} (min^{-1})	kJ $m^{-2}(s^{-1})$	1.4340	ly (min^{-1})
		watt per square meter	watt m^{-2}			ly (min^{-1})	1.000*	g-cal $cm^{-2}(min^{-1})$
		kilojoule per square meter (per second)	kJ $m^{-2}(s^{-1})$			g-cal $cm^{-2}(min^{-1})$	1.000*	ly (min^{-1})
						watt m^{-2}	0.09290304*	watt ft^{-2}
						watt ft^{-2}	10.7639	watt m^{-2}
						g-cal $cm^{-2}(min^{-1})$	64.784	watt ft^{-2}
						g-cal $cm^{-2}(min^{-1})$	697.33	watt m^{-2}
						watt ft^{-2}	0.015436	g-cal $cm^{-2}(min^{-1})$
						watt m^{-2}	0.0014340	g-cal $cm^{-2}(min^{-1})$
						g-cal $cm^{-2}(min^{-1})$	3.6867	B.T.U. ft^{-2} (min^{-1})
						B.T.U. $ft^{-2}(min^{-1})$	0.27125	g-cal $cm^{-2}(min^{-1})$
	Solar Insolation	gram-calorie per square centimeter per minute	g-cal cm^{-2} min^{-1}	British Thermal Unit per square foot per hour	B.T.U. ft^{-2} hr^{-1}	g-cal cm^{-2} min^{-1}	221.20	B.T.U. ft^{-2} hr^{-1}
						B.T.U. ft^{-2} hr^{-1}	0.0045208	g-cal cm^{-2} min^{-1}
TEMPERATURE	Ambient Temperature	degree Celsius	^oC	degree Fahrenheit	^oF	$^oF - 32$	0.5556	^oC
		degree Kelvin	^oK	degree Rankine	^oR	^oC	1.8*	$^oF - 32$
						^oR	1.00*	$^oF + 459.67$
						$^oR - 459.67$	1.00*	^oF
						^oK	1.00*	$^oC + 273.15$
						$^oK - 273.15$	1.00*	^oC
	Temperature Change	degree Celsius	^oC	degree Fahrenheit	^oF	^oC or ^oK	1.8*	temp. change ^oF or ^oR
		degree Kelvin	^oK	degree Rankine	^oR	^oF or ^oR	0.5556	temp. change ^oC or ^oK

* Defined exact conversion factor

TABLE 1.1 CONVERSION OF UNITS (Contiuned)

TYPE OF DATA		METRIC UNIT	METRIC ABBREVIATION	U.S. CUSTOMARY UNIT	U.S. CUSTOMARY ABBREVIATION	CONVERSION MULTIPLY	BY	TO GET
DENSITY	Water Vapor Vapor Concentration (Absolute Humidity)	gram per cubic meter	$g\ m^{-3}$	grain per cubic foot	$gr\ ft^{-3}$	$g\ m^{-3}$	0.43700	$gr\ ft^{-3}$
		gram per cubic centimeter	$g\ cm^{-3}$			$gr\ ft^{-3}$	2.2883	$g\ m^{-3}$
						$g\ m^{-3}$	10^{-6}*	$g\ cm^{-3}$
						$g\ cm^{-3}$	4.370×10^{5}	$gr\ ft^{-3}$
						$gr\ ft^{-3}$	2.288×10^{-6}	$g\ cm^{-3}$
	Air, Dust, and Hail	gram per cubic centimeter	$g\ cm^{-3}$	pound per cubic foot	$lb\ ft^{-3}$	$g\ cm^{-3}$	62.43	$lb\ ft^{-3}$
						$lb\ ft^{-3}$	1.6018×10^{-2}	$g\ cm^{-3}$
PRECIPITATION	Snow Unit Depth Mass	kilogram per square meter per centimeter (of depth)	$kg\ m^{-2}\ cm^{-1}$	pound per square foot per inch (of depth)	$lb\ ft^{-2}\ in.^{-1}$	$kg\ m^{-2}\ cm^{-1}$	0.5202	$lb\ ft^{-2}\ in.^{-1}$
						$lb\ ft^{-2}\ in.^{-1}$	1.922	$kg\ m^{-2}\ cm^{-1}$
	Snow Storm Total Mass	kilogram per square meter	$kg\ m^{-2}$	pound per square foot	$lb\ ft^{-2}$	$kg\ m^{-2}$	0.2048	$lb\ ft^{-2}$
						$lb\ ft^{-2}$	4.882	$kg\ m^{-2}$
	Depth	centimeter	cm	inch	in.	cm	0.3937	in.
						in.	2.54*	cm
WIND	Wind Speed	meter per second	$m\ s^{-1}$	mile per hour	mph	$m\ s^{-1}$	2.2369	mph
				knots	knots	mph	0.44704*	$m\ s^{-1}$
				feet per second	$ft\ s^{-1}$	$m\ s^{-1}$	1.9438	knots
						knots	0.51444	$m\ s^{-1}$
						mph	0.868976	knots
						knots	1.15078	mph
						$m\ s^{-1}$	3.2808	$ft\ s^{-1}$
						$ft\ s^{-1}$	0.3048*	$m\ s^{-1}$

*Defined exact conversion factor

TABLE 1.1 CONVERSION OF UNITS (Continued)

TYPE OF DATA		METRIC UNIT	METRIC ABBREVIATION	U.S. CUSTOMARY UNIT	U.S. CUSTOMARY ABBREVIATION	CONVERSION MULTIPLY	CONVERSION BY	CONVERSION TO GET
PRESSURE	Atmospheric	newton per square meter	newton m^{-2}	pound force per square inch	lbf $in.^{-2}$	mb	10^{-3}*	bar
						bar	10^{3}*	mb
		millimeter of Mercury	mmHg	inch of Mercury	in.Hg	newton m^{-2}	10^{-2}*	mb
						newton m^{-2}	$1.4504X10^{-4}$	lbf $in.^{-2}$
						lbf $in.^{-2}$	$6.8948X10^{3}$	newton m^{-2}
		bar	bar			mb	$1.4504X10^{-2}$	lbf $in.^{-2}$
		millibar	mb			lbf $in.^{-2}$	68.948	mb
		dyne per square centimeter (microbar)	dyne cm^{-2}			mb	10^{3}*	dyne cm^{-2}
						dyne cm^{-2}	10^{-3}*	mb
		kilogram force per square meter	kgf m^{-2}			lbf $in.^{-2}$	$6.8948X10^{4}$	dyne cm^{-2}
						dyne cm^{-2}	$1.4504X10^{-5}$	lbf $in.^{-2}$
						mb	10.1972	kgf m^{-2}
						kgf m^{-2}	0.0980665	mb
						lbf $in.^{-2}$	703.0696	kgf m^{-2}
						kgf m^{-2}	0.0014223	lbf $in.^{-2}$
						mb	$2.9530X10^{-2}$	in.Hg (32^{o} F)
						mb	0.75006	mmHg (0^{o} C)
						in.Hg(32^{o} F)	25.40*	mmHg (0^{o} C)
						mmHg(0^{o} C)	1.33322	mb
						in.Hg(32^{o} F)	33.8639	mb

* Defined exact conversion factor

TABLE 1.1 CONVERSION OF UNITS (Concluded)

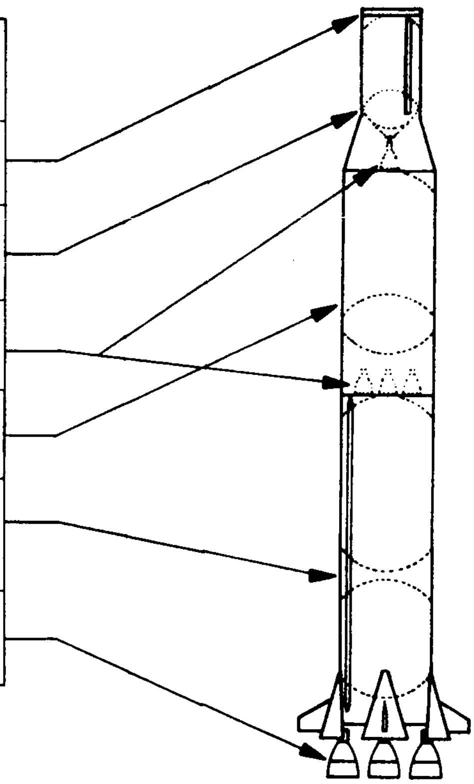
TYPE OF DATA		METRIC		U.S. CUSTOMARY		CONVERSION		
		UNIT	ABBREVIATION	UNIT	ABBREVIATION	MULTIPLY	BY	TO GET
DISTANCE	Length	meter	m	feet	ft	m	3.2808	ft
		micron	μ	inch	in.	ft	0.3048*	m
		Ångstrom unit	Å			in.	$2.54 \times 10^{+4}$*	μ
						in.	$2.54 \times 10^{+8}$*	Å
						m	10^{+6}*	μ
						m	10^{+10}*	Å
						μ	10^{-6}*	m
						μ	3.937×10^{-5}	in.
						Å	10^{-10}*	m
						Å	3.937×10^{-9}	in.
MASS	Weight	gram	g	grain	gr	lb	0.45359237*	kg
		kilogram	kg	pound	lb	lb	453.59237*	g
						kg	2.20462	lb
						g	15.4324	gr
						gr	0.06480	g

* Defined exact conversion factor

1.5 Geographical Areas Involved in Vehicle Design

Many geographical areas are involved in the fabrication, transportation, testing, and launch of a space vehicle, since the various segments are fabricated in different areas. Figure 1.2 shows an example of some major locations pertinent to the fabrication and testing of the Saturn V launch vehicle. Similar information may be prepared for other space vehicles. By the use of information such as that given in Figure 1.2, with the appropriate operational risk criteria, data from this guideline document can be readily extracted for use as design criteria. Figure 1.2 is given only as an example and is not intended for design-operational use.

SECONDARY FUNCTIONAL AREA	FUNCTION	ASSEMBLY	IN-PLANT CHECKOUT	ACCEPTANCE TEST	REFURBISH AND CHECKOUT	PREASSEMBLY CHECKOUT
INSTRUMENT UNIT		IBM HUNTSVILLE FACILITY	IBM HUNTSVILLE FACILITY	N/A	N/A	KSC
S-IV B STAGE		DAC HUNTINGTON BEACH FACILITY	DAC SACRAMENTO FACILITY	DAC SACRAMENTO FACILITY	DAC SACRAMENTO FACILITY	KSC
J-2 ENGINE	FACILITY	ROCKETDYNE CANOGA PARK FACILITY	NAA ROCKETDYNE CANOGA PARK FACILITY	ROCKETDYNE SANTA SUSANNA FACILITY	ROCKETDYNE SANTA SUSANNA FACILITY	KSC
S-II STAGE		SPACE & INFORMATION DIVISION SEAL BEACH FACILITY	SPACE & INFORMATION DIVISION SANTA SUSANNA FACILITY	MISSISSIPPI TEST FACILITY	MISSISSIPPI TEST FACILITY	KSC
S-IC STAGE		MSFC (S-IC-1 and -2)	MSFC (S-IC-1 and -2)	MSFC (S-IC-1 and -2)	MSFC (S-IC-1 and -2)	KSC
		TBC MICHOUD (S-IC-3 and subsequent)	TBC MICHOUD (S-IC-3 and subsequent)	TBC MTF (S-IC-3 and subsequent)	TBC MTF (S-IC-3 and subsequent)	
F-1 ENGINE		ROCKETDYNE CANOGA PARK FACILITY	ROCKETDYNE CANOGA PARK FACILITY	ROCKETDYNE EDWARDS AIR FORCE BASE FACILITY	ROCKETDYNE EDWARDS AIR FORCE BASE FACILITY	KSC



LEGEND

MSFC - MARSHALL SPACE FLIGHT CENTER
KSC - KENNEDY SPACE CENTER
MTF - MISSISSIPPI TEST FACILITY
IBM - INTERNATIONAL BUSINESS MACHINES
DAC - DOUGLAS AIRCRAFT COMPANY
TBC - THE BOEING COMPANY
N/A - NOT APPLICABLE

FIGURE 1.2 EXAMPLE OF LOCATIONS PERTINENT TO THE FABRICATION AND TESTING OF COMPONENTS OF THE SATURN V LAUNCH VEHICLE

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SECTION II. THERMAL

By

Glenn E. Daniels

2.0 Introduction

One of the more important environmental influences on a vehicle is due to the thermal environment. Combinations of air temperature, solar radiation, and sky radiation can cause various structural problems, i.e., heating of one side of the vehicle by the sun while the other side is cooled by a clear sky causes stresses since the vehicle sides will be of different length. The temperature of the fuel is desired since the volume-mass relationship of fuel varies with temperature. Too high a temperature may destroy the usefulness of a lubricant. The heating or cooling of a surface by air temperature and radiation is a function of the heat transfers taking place, therefore, methods of determining these relationships are presented in this section.

2.1 Definitions

The following terms are used in this section with the meanings specified here.

Absorption bands are those portions of the solar (or other continuous) spectrum which have lesser intensity because of absorption by gaseous elements or molecules. In general, elements give sharp lines, but molecules such as water vapor or carbon dioxide in the infrared, give broad diffuse bands.

Air mass is the amount of atmosphere that the solar radiation passes through where one air mass is referenced to when the sun is at the zenith.

Air temperature (surface) is the free or ambient air temperature measured under standard conditions of height, ventilation, and radiation shielding. The air temperature is normally measured with liquid-in-glass thermometers in a louvered wooden shelter, painted white inside and outside, with the base of the shelter normally 1.22 m (four feet) above a close-cropped grass surface (Ref. 2.1, page 59). Unless an exception is stated, surface air temperatures given in this report are temperatures measured under these standard conditions.

Astronomical unit is a unit of length defined as equal to the mean distance between the earth and sun. The current accepted value is 1.495978930×10^8 km.

Atmospheric transmittance is the ratio between the intensity of the extra-terrestrial solar radiation and intensity of the solar radiation after passing through the atmosphere. The tabular values of atmospheric transmittance given in Table 2.1 are based on a specific one air mass as defined in the text.

Black body is an ideal emitter which radiates energy at the maximum possible rate per unit area at each wavelength for any given temperature and which absorbs all incident radiation at all wavelengths.

Diffuse sky radiation is the solar radiation reaching the earth's surface after having been scattered from the direct solar beam by molecules or suspensoids in the atmosphere. It is measured on a surface after the direct solar radiation is subtracted from the total horizontal radiation.

Direct solar radiation is the solar radiation received on a surface directly from the sun, and does not include diffuse sky radiation.

Emittance is the ratio of the energy emitted by a body to the energy which would be emitted by a black body at the same temperature. A black body has an emittance of 1.0. In this document, the assumption is made that the emittance is numerically equal to the absorptivity of the object at the same wavelengths. In this way, the value of emittance represents the portion of the energy falling on an object that heats or cools the object.

Extraterrestrial solar radiation is that solar radiation received outside the earth's atmosphere at one astronomical unit from the sun.

Fraunhofer lines are the dark absorption bands in the solar spectrum due to gases in the outer portions of the sun and earth's atmosphere.

Horizontal solar radiation is the solar radiation measured on a horizontal surface.

Irradiation is often used to mean solar radiation received by a surface.

Normal incident solar radiation is the radiation received on a surface, normal to the direction of the sun, direct from the sun, and does not include diffuse sky radiation.

Radiation temperature is the temperature of a radiating body (assumed as black) determined by Wien's displacement law, expressed as

$$T_R = \frac{w}{\lambda max} \qquad \text{Eq. (2.1)}$$

where

T_R = Radiation temperature (°K)

w = Wien's displacement constant (0.2989 cm °K)

λmax = The wavelength corresponding to the maximum energy of radiation (cm).

Sky radiation temperature is the average radiation temperature of the sky when it is assumed to be a black body. Sky radiation is the radiation to and through the atmosphere from outer space. While this radiation is normally termed nocturnal radiation, it takes place under clear skies even during daylight hours.

Solar radiation in this document will be defined as the radiant energy from the sun between 2200 angstroms and 70,000 angstroms (See para. 2.2.2)..

Surface temperature is the temperature which a given surface will have when exposed to air temperature and radiation within the approximate wavelength interval of 0.22 to 20.0 microns. Extremes of surface temperatures will be dependent on the emittance of the surface, angle between the surface and the radiation source (such as the sun or sky), the radiation temperature of the source, and the subtended angle of the source. The actual temperature which a surface reaches is also dependent on the mass of the object, the heat conductivity within the surface material, and the shape of the entire object of which the surface is one portion. Therefore, any values computed of extreme surface temperatures should be considered as the heat flux (heat load) on the surface. The extreme value of temperature which a surface may reach when exposed to daytime (solar) or nighttime (night sky) radiation with no wind (calm), assuming it has no mass or heat transfer within the object, is as follows:

$$T_S = T_A + E\,(\Delta T_{BS}) \qquad \text{Eq. (2.2)}$$

where

T_S = Surface temperature (°K)

T_A = Air temperature (°K)

E = Emittance of surface

ΔT_{BS} = Increase in black-body temperature (°K) from daytime solar radiation (used as plus) or decrease in black-body temperature (°K) from nighttime sky radiation (used as minus) and is calulated from

$$\Delta T_{BS} = \left(\frac{I_{TS}}{\sigma}\right)^{\frac{1}{4}} - T_A \qquad \text{Eq. (2.3)}$$

Extreme values of ΔT_{BS} can be obtained from Figure 2.3A or Table 2.7 where

I_{TS} = Total radiation (solar by day) (sky for night) received at surface. These values can be extremes from Tables 2.2, 2.3, or 2.5 from this report.

σ = Stefans-Boltzman constant

$= 8.129 \times 10^{-11}$ g-cal cm^{-2} (deg K) (min^{-1})*

$= 5.6685 \times 10^{-12}$ watt cm^{-2} (deg K)$^{-4}$

The term $\left(\frac{I_{TS}}{\sigma}\right)^{\frac{1}{4}}$ is equal to the extreme black-body surface temperature.

If a correction for wind speed is desired, equation (2.2) can be used as follows:

$$T_S = T_A + E(\Delta T_{BS}) \frac{Wc}{100} \qquad \text{Eq. (2.2A)}$$

where

Wc = correction for wind speed in percent from Figure 2.3B.

Total solar radiation is the direct solar and diffuse sky radiation received by a surface.

Transmittance (see "Atmospheric transmittance").

2.2 Solar Electromagnetic Spectrum.

2.2.1 Introduction. The sun is emitting energy in the electromagnetic spectrum between 0.0001 angstroms and 1,000,000 angstroms. This radiation ranges from cosmic rays through the very long radio waves.

2.2.2 Solar Radiation Energy Distribution.

Of the total electromagnetic spectrum of the sun, only the radiant energy from that portion of the spectrum between 2200 angstroms and 70,000 angstroms (the light spectrum) will be considered in this document since it contains 99.8

* The unit (min^{-1}) should be included only if units of "I" includes (min^{-1}).

percent of the total electromagnetic energy. The spectral distribution of this region closely resembles the emission of a gray body radiating at 6000°C. This is the spectral region which causes nearly all of the heating or cooling of an object.

Solar radiation outside the earth's atmosphere is distributed in a continuous spectrum with many narrow absorption bands caused by the elements and molecules in the colder solar atmosphere. These absorption bands are the Fraunhofer lines, whose widths are usually very small (less than 1 angstrom in most cases).

The earth's atmosphere also absorbs a part of the solar radiation such that the major portion of the solar radiation reaching the earth's surface is between about 3500 angstroms and 40,000 angstroms. The distribution of the energy in this region of the spectrum outside the earth's atmosphere (extra-terrestrial) is as follows:

Region	Distribution* Percent	Solar Intensity** g-cal cm^{-2} (min^{-1})
Ultra Violet below 3800 Å	6.4	0.128
3800 Å to 7500 Å	46.8	0.936
Infrared above 7500 Å	46.8	0.936

The first detailed information, published for use by engineers on the distribution of solar radiation energy (solar irradiation) wavelength was that by Parry Moon in 1940 (Ref. 2.5). These data were generally based on theoretical curves, but are still used as the basic solar radiation in design by many engineers.

The information on the variation of solar radiation intensities with wavelength outside the earth's atmosphere, at the mean distance of the earth from the sun (one Astronomical Unit) must be extrapolated from measurements made at the earth's surface.*** The current procedure is to reduce the data to that equivalent to one air mass (sun in the zenith) when no clouds exist and then use an atmospheric transmittance curve based on measured and theoretical absorption values of ozone, water vapor (expressed as precipitable water), dust and atmospheric molecules to extrapolate to zero air mass. Moon computed his data by assuming a 6000°C gray body and assuming an atmospheric transmission

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* Mean of Johnson (Ref. 2.3) and Nicolet (Ref. 2.4)

** Based on Solar Constant of 2.00 g-cal cm^{-2} (min^{-1}).

*** Recent measurements by Jet Propulsion Laboratory and Eppley Laboratories by use of NASA B-57 jet aircraft and USAF/NASA X-15 rocket research aircraft have suggested that current values of the solar constant are too high with most of the error in the ultra violet (Ref. 2.4.1).

curve for computing his data for various air masses. The total area under the curve for solar intensities outside the earth's atmosphere (zero air mass) must equal the solar constant.

More recent measurements of solar radiation by the National Bureau of Standards (NBS) (Refs. 2.6, 2.7), and the National Geographic Society (Ref. 2.8) in conjunction with the revision of the value of the Solar Constant from 1.896 g-cal cm^{-2}, used by Moon (Ref. 2.5), to 2.00 g-cal cm^{-2} (min^{-1}) * * (1395 watt m^{-2}), now accepted as the correct value, have resulted in revised values for solar radiation intensities outside the earth's atmosphere and within the earth's atmosphere.

Additional information on the entire solar spectrum may be found in NASA TM X-53018, "Space Radiation: A Compilation and Discussion" (Ref. 2.2).

2.2.3 Intensity Distribution.

Table 2.1 shows data of the solar radiation intensity distribution with wavelength. The main purpose of the table is to provide guidance on the distribution of solar radiation at the earth's surface; therefore, the intensity of the solar radiation, after penetration of one air mass for a day with maximum solar radiation at the earth's surface, is given by a constant (atmospheric transmittance) to use in computation of the solar radiation intensity for other thicknesses of air mass. These data are based on two sets of measurements made at Sacramento Peak by the National Bureau of Standards (NBS) in 1953 and 1955 (Ref. 2.6 and 2.7) and Moon's (Ref. 2.5) data for wavelengths above 5450 angstroms. Because the NBS and Moon's data were based on an average air mass* without clouds, the atmospheric transmission was adjusted by considering less ozone and water vapor than that occurring for the average day. The adjustment was made to make the area under the curve for one air mass total 1.64 g-cal cm^{-2} (82 percent of the solar constant); i.e., the extreme value for total normal incident solar radiation for June at the Eastern Test Range (See Table 2.3). Actual measurements of the intensity of the solar spectrum in the infrared relative to the total incoming solar radiation are almost nonexistant because of the difficulty of calibrating a reference standard (See Refs. 2.9 and 2.10). The data presented in Table 2.1 for one air mass should represent closely the actual data that would be measured on the day when the extreme value occurred, because the adjustment of the data was restricted in making the area under the curve fit the extreme value measured.

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* This air mass is assumed to contain no clouds, 0.23 cm of ozone, 0.20 cm of water vapor and have a standard pressure (1013.25 millibars) at sea level.

* * See footnote * * * on page 2.5.

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2})

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
λ	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
2100					0	0	0	0	∞	0	0	0	0
2200					0	0	0	0	∞	0.015	0.008	0.00030	0.209
2300	Use Mean of Johnson and Nicolet for this section from 2100Å to 2900Å.				0	0	0	0	∞	0.035	0.032	0.00070	0.488
2400					0	0	0	0	∞	0.035	0.068	0.00070	0.488
2500					0	0	0	0	∞	0.045	0.108	0.00090	0.628
2600					0	0	0	0		0.093	0.178	0.00190	1.33
2700					0	0	0	0	∞	0.150	0.300	0.00300	2.09
2800					0	0	0	0	∞	0.140	0.445	0.00280	1.95
2900		0.672			0	0	0	0	∞	0.315	0.672	0.00630	4.39
2990	0.36		0.00715	4.99	0.009		0.00018	0.125	40				
2995	0.42		0.00865	6.04	0.022		0.00043	0.302	20				
3000	0.48	1.014	0.00967	6.75	0.048	0.007	0.00097	0.675	10	0.370	1.014	0.00740	5.16
3025	0.39		0.00778	5.43	0.082		0.00163	1.14	4.75				
3040	0.52		0.01030	7.19	0.128		0.00255	1.78	4.04				
3050	0.50		0.00994	6.94	0.135		0.00271	1.89	3.68				
3060	0.50		0.01009	7.04	0.148		0.00297	2.07	3.40				
3092	0.62		0.01241	8.66	0.220		0.00440	3.07	2.82				
3100	0.51	1.527	0.01023	7.14	0.189	0.141	0.00377	2.63	2.72	0.495	1.447	0.00991	6.91
3120	0.74		0.01482	10.34	0.297		0.00594	4.14	2.50				
3149	0.69		0.01381	9.64	0.310		0.00619	4.32	2.23				
3150	0.71		0.01414	9.86	0.318		0.00637	4.44	2.22				
3158	0.71		0.01419	9.90	0.329		0.00658	4.59	2.18				
3165	0.60		0.01211	8.45	0.283		0.00566	3.95	2.14				
3179	0.81		0.01628	11.36	0.391		0.00783	5.46	2.08				
3185	0.71		0.01410	9.84	0.344		0.00688	4.80	2.05				

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
λ	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
3200	0.75	2.224	0.01491	10.40	0.376	0.451	0.00753	5.25	1.98	0.565	1.977	0.01140	7.95
3211	0.82		0.01631	11.38	0.421		0.00842	5.87	1.94				
3217	0.74		0.01485	10.36	0.389		0.00777	5.42	1.91				
3228	0.71		0.01416	9.88	0.378		0.00757	5.28	1.87				
3235	0.65		0.01290	9.00	0.351		0.00701	4.89	1.84				
3250	0.72		0.01433	10.00	0.403		0.00806	5.62	1.78				
3255	0.75		0.01508	10.52	0.426		0.00852	5.94	1.77				
3275	0.96		0.01921	13.40	0.565		0.01130	7.88	1.70				
3285	0.92		0.01837	12.82	0.551		0.01101	7.68	1.67				
3300	1.03	3.035	0.02064	14.40	0.633	0.908	0.01266	8.83	1.63	0.730	2.624	0.01460	10.18
[illegible]	1.04		0.02081	14.52	0.642		0.01285	8.96	1.62				
3315	0.93		0.01852	12.92	0.583		0.01166	8.13	1.59				
3329	0.92		0.01835	12.80	0.589		0.01177	8.21	1.56				
3336	0.89		0.01782	12.43	0.575		0.01150	8.02	1.55				
3350	0.93		0.01863	13.00	0.613		0.01226	8.55	1.52				
3353	0.93		0.01852	12.92	0.609		0.01219	8.50	1.52				
3370	0.78		0.01559	10.88	0.523		0.01047	7.30	1.49				
3400	0.91	3.931	0.01827	12.75	0.630	1.494	0.01260	8.79	1.45	0.715	3.347	0.01430	9.97
3408	0.94		0.01872	13.06	0.650		0.01301	9.07	1.44				
3417	0.89		0.01784	12.45	0.624		0.01249	8.71	1.43				
3435	0.92		0.01832	12.78	0.649		0.01299	9.06	1.41				
3450	0.77		0.01534	10.70	0.560		0.01120	7.81	1.37				
3500	0.87	4.787	0.01746	12.18	0.642	2.108	0.01285	8.96	1.36	0.755	4.082	0.01510	10.53
3515	0.93		0.01855	12.94	0.687		0.01375	9.59	1.35				
3526	0.87		0.01734	12.10	0.642		0.01285	8.96	1.35				

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
λ	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
3550	0.97		0.01949	13.60	0.728		0.01456	10.15	1.34				
3551	0.98		0.01968	13.73	0.735		0.01470	10.25	1.34				
3580	0.71		0.01428	9.96	0.541		0.01083	7.55	1.32				
3600	0.91	5.659	0.01813	12.65	0.687	2.751	0.01374	9.58	1.32	0.755	4.837	0.01510	10.53
3610	0.85		0.01694	11.82	0.647		0.01293	9.02	1.31				
3637	0.91		0.01827	12.75	0.703		0.01407	9.81	1.30				
3650	0.99		0.01971	13.75	0.764		0.01529	10.66	1.29				
3667	1.07		0.02134	14.89	0.827		0.01655	11.54	1.29				
3682	1.01		0.02021	14.10	0.790		0.01580	11.02	1.28				
3700	1.02	6.580	0.02047	14.28	0.800	3.495	0.01600	11.16	1.28	0.815	5.622	0.01630	11.37
3705	1.03		0.02055	14.34	0.809		0.01619	11.29	1.27				
3742	0.81		0.01621	11.31	0.644		0.01288	8.98	1.26				
3750	0.84		0.01671	11.66	0.663		0.01326	9.25	1.26				
3788	1.11		0.02219	15.48	0.887		0.01775	12.38	1.25				
3800	1.04	7.538	0.02078	14.50	0.838	4.254	0.01676	11.69	1.24	0.775	6.417	0.01550	10.81
3804	0.99		0.01989	13.88	0.802		0.01605	11.19	1.24				
3845	0.66		0.01329	9.27	0.540		0.01081	7.54	1.23				
3850	0.68		0.01350	9.42	0.553		0.01107	7.72	1.22				
3874	0.83		0.01668	11.64	0.690		0.01380	9.62	1.21				
3900	1.02	8.372	0.02045	14.27	0.852	4.939	0.01705	11.89	1.20	0.760	7.148	0.01520	10.60
3912	1.06		0.02113	14.74	0.880		0.01761	12.28	1.20				
3937	0.69		0.01385	9.66	0.582		0.01164	8.12	1.19				
3950	0.80		0.01591	11.10	0.669		0.01338	9.33	1.19				
3960	0.94		0.01879	13.11	0.790		0.01580	11.02	1.19				
3970	0.84		0.01684	11.75	0.714		0.01428	9.96	1.18				

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
λ	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
4000	1.09	9.278	0.02177	15.19	0.930	5.702	0,01861	12.98	1.17	1.110	8.120	0.02220	15.48
4034	1.45		0.02905	20.26	1.25		0.02505	17.47	1.16				
4050	1.40		0.02808	19.58	1.21		0.02421	16.88	1.16				
4062	1.37		0.02745	19.14	1.18		0.02366	16.50	1.16				
4100	1.37	10.624	0.02745	19.14	1.19	6.863	0.02386	16.64	1.15	1.330	9.340	0.02660	18.55
4101	1.37		0.02745	19.14	1.19		0.02386	16.64	1.15				
4150	1.40		0.02802	19.54	1.24		0.02479	17.29	1.13				
4168	1.42		0.02846	19.85	1.27		0.02532	17.66	1.13				
4200	1.41	12.023	0.02822	19.68	1.26	8.101	0.02520	17.57	1.12	1.325	10.667	0.02650	18.48
4208	1.41		0.02819	19.66	1.26		0.02517	17.55	1.12				
4237	1.36		0.02713	18.92	1.22		0.02444	17.04	1.11				
4250	1.28		0.02553	17.80	1.15		0.02300	16.04	1.11				
4276	1.14		0.02289	15.96	1.03		0.02062	14.38	1.11				
4300	1.20	13.304	0.02409	16.80	1.09	9.253	0.02171	15.14	1.11	1.235	11.947	0.02471	17.23
4322	1.29		0.02584	18.02	1.16		0.02327	16.23	1.11				
4350	1.33		0.02667	18.60	1.20		0.02403	16.76	1.11				
4371	1.37		0.02746	19.15	1.24		0.02474	17.25	1.11				
4400	1.47	14.640	0.02940	20.50	1.34	10.461	0.02673	18.64	1.10	1.415	13.272	0.02831	19.74
4408	1.50		0.02996	20.89	1.36		0.02723	18.99	1.10				
4450	1.56		0.03126	21.80	1.42		0.02842	19.82	1.10				
4489	1.58		0.03163	22.06	1.44		0.02875	20.05	1.10				
4500	1.57	16.187	0.03137	21.88	1.43	11.686	0.02852	19.89	1.10	1.550	14.754	0.03100	21.62
4557	1.58		0.03153	21.99	1.43		0.02867	19.99	1.10				
4600	1.54	17.756	0.03076	21.45	1.40	13.292	0.02796	19.50	1.10	1.555	16.307	0.03110	21.69
4665	1.47		0.02948	20.56	1.34		0.02680	18.69	1.10				

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
λ	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		I_E / $I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
4700	1.47	19.249	0.02940	20.50	1.35	14.653	0.02697	18.81	1.09	1.565	17.867	0.03130	21.83
4800	1.51	20.739	0.03011	21.00	1.38	16.018	0.02763	19.27	1.09	1.560	19.430	0.03120	21.76
4820	1.53		0.03052	21.28	1.40		0.02799	19.52	1.09				
4870	1.38		0.02763	19.27	1.27		0.02535	17.68	1.09				
4900	1.42	22.190	0.02832	19.75	1.30	17.349	0.02598	18.12	1.09	1.445	20.932	0.02890	20.16
4970	1.49		0.02986	20.82	1.37		0.02743	19.13	1.09				
5000	1.46	23.659	0.02922	20.38	1.34	18.690	0.02682	18.70	1.09	1.460	22.384	0.02920	20.36
5090	1.50		0.03006	20.96	1.38		0.02758	19.23	1.09				
5100	1.49	25.141	0.02986	20.82	1.37	20.052	0.02739	19.10	1.09	1.455	23.841	0.02910	20.29
5190	1.42		0.02844	19.83	1.30		0.02608	18.19	1.09				
5200	1.42	26.564	0.02836	19.78	1.30	21.383	0.02603	18.15	1.09	1.370	25.254	0.02740	19.11
5225	1.47		0.02937	20.48	1.35		0.02694	18.79	1.09				
5265	1.49		0.02980	20.78	1.37		0.02733	19.06	1.09				
5275	1.53		0.03069	21.40	1.41		0.02815	19.63	1.09				
5300	1.52	28.050	0.03036	21.17	1.39	22.748	0.02785	19.42	1.09	1.430	26.654	0.02861	19.95
5350	1.49		0.02971	20.72	1.36		0.02726	19.01	1.09				
5400		29.540				24.108				1.440	28.088	0.02879	20.08
5450	1.50		0.02991	20.86	1.37		0.02745	19.14	1.09				
5500		31.040				25.478				1.395	29.506	0.02791	19.46
5550	1.48		0.02956	20.61	1.36		0.02712	18.91	1.09				
5600		32.520				26.838				1.404	30.906	0.02809	19.59
5650	1.46		0.02918	20.35	1.34		0.02677	18.67	1.09				
5700		33.980				28.178				1.385	32.300	0.03770	19.32
5750	1.44		0.02872	20.03	1.32		0.02636	18.38	1.09				
5800		35.420				29.498				1.385	33.685	0.02770	19.32

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
λ	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
5850	1.41		0.02822	19.68	1.29		0.02590	18.06	1.09				
5900		36.830				30.788				1.350	35.052	0.02700	18.83
5950	1.39		0.02772	19.33	1.27		0.02542	17.73	1.09				
6000		38.220				32.058				1.335	36.395	0.02670	18.62
6050	1.37		0.02733	19.06	1.25		0.02508	17.49	1.09				
6100		39.590				33.308				1.300	37.712	0.02600	18.13
6150	1.33		0.02666	18.59	1.22		0.02446	17.06	1.09				
6200		40.920				34.528				1.275	39.000	0.02550	17.78
6250	1.31		0.02613	18.22	1.20		0.02398	16.72	1.09				
6300		42.230				35.728				1.244	40.260	0.02489	17.36
6350	1.28		0.02558	17.84	1.17		0.02347	16.37	1.09				
6400		43.510				36.898				1.214	41.488	0.02429	16.94
6450	1.25		0.02504	17.46	1.15		0.02297	16.02	1.09				
6500		44.760				38.048				1.185	42.688	0.02370	16.53
6550	1.22		0.02441	17.02	1.12		0.02238	15.61	1.09				
6600		45.980				39.168				1.165	43.863	0.02330	16.25
6650	1.19		0.02388	16.65	1.10		0.02191	15.28	1.09				
6700		47.170				40.268				1.135	45.013	0.02270	15.83
6750	1.16		0.02325	16.21	1.07		0.02132	14.87	1.09				
6800		48.330				41.338				1.105	46.133	0.02210	15.41
6850	1.13		0.02257	15.74	1.01		0.02015	14.05	1.12				
6900		49.460			0.904	42.348	0.01807	12.60		1.085	47.228	0.02170	15.13
6950	1.09		0.02187	15.25	0.968		0.01936	13.50	1.13				
7000		50.550				43.316				1.049	48.295	0.02099	14.64
7050	1.06		0.02117	14.76	0.971		0.01942	13.54	1.09				

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
	per 100 Angstroms				per 100 Angstroms				RATIO(M)	per 100 Angstroms			
λ	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
7100		51.610				44.287				1.029	49.334	0.02059	14.36
7150	1.02		0.02046	14.27	0.913		0.01827	12.74	1.12				
7200		52.630			0.826	45.200	0.01652	11.52		1.000	50.348	0.02000	13.95
7250	0.989		0.01979	13.80	0.875		0.01751	12.21	1.13				
7300		53.620				46.075				0.980	51.339	0.01960	13.67
7350	0.956		0.01912	13.33	0.877		0.01754	12.23	1.09				
7400		54.575				46.952				0.945	52.301	0.01890	13.18
7450	0.923		0.01847	12.88	0.810		0.01620	11.30	1.14				
7500		55.498				47.762				0.925	53.236	0.01850	12.90
7550	0.893		0.01787	12.46	0.703		0.01407	9.81	1.27				
7600		56.371			0.640	48.465	0.01279	8.92					
7650	0.868		0.01737	12.11	0.775		0.01550	10.81	1.12				
7700		57.259				49.240							
7750	0.848		0.01696	11.83			0.01556	10.85	1.09				
7800		58.107			0.778	50.018							
7850	0.830		0.01660	11.58	0.761		0.01523	10.62	1.09				
7900		58.937				50.779							
7950	0.814		0.01628	11.35	0.746		0.01493	10.41	1.09				
8000		59.751				51.525				0.819	57.596	0.01639	11.43
8050	0.796		0.01593	11.11	0.705		0.01410	9.83	1.13				
8100		60.547			0.668	52.230	0.01336	9.32					
8150	0.779		0.01559	10.87	0.690		0.01380	9.62	1.13				
8200		61.326				52.920							
8250	0.764		0.01529	10.66	0.701		0.01402	9.78	1.09				
8300		62.090				53.621							

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
	per 100 Angstroms				per 100 Angstroms				RATIO(M)	per 100 Angstroms			
λ	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
8350	0.748		0.01496	10.43	0.686		0.01372	9.57	1.09				
8400		62.838				54.307							
8450	0.732		0.01464	10.21	0.672		0.01344	9.37	1.09				
8500		63.570				54.979				0.735	61.481	0.01470	10.25
8550	0.717		0.01434	10.00	0.657		0.01315	9.17	1.09				
8600		64.287				55.636							
8650	0.702		0.01405	9.80	0.644		0.01289	8.99	1.09				
8700		64.989				56.280							
8750	0.689		0.01378	9.61	0.604		0.01209	8.43	1.14				
8800		65.678				56.884							
8850	0.677		0.01354	9.44	0.533		0.01065	7.43	1.27				
8900		66.355				57.417							
8950	0.662		0.01325	9.24	0.505		0.01011	7.05	1.31				
9000		67.017				57.922				0.660	64.968	0.01321	9.21
9050	0.650		0.01301	9.07	0.475		0.00949	6.62	1.37				
9100		67.667				58.397							
9150	0.637		0.01273	8.88	0.424		0.00849	5.92	1.50				
9200		68.304				58.821							
9250	0.625		0.01250	8.72	0.378		0.00757	5.28	1.65				
9300		68.929				59.199							
9350	0.612		0.01225	8.54	0.358		0.00716	4.99	1.71				
9400		69.541				59.557							
9450	0.601		0.01202	8.38	0.426		0.00852	5.94	1.41				
9500		70.142				59.983				0.595	68.106	0.01190	8.30
9550	0.589		0.01177	8.21	0.487		0.00974	6.79	1.21				

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
λ	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
9600		70.731				60.470							
9650	0.577		0.01154	8.05	0.506		0.01012	7.06	1.14				
9700		71.308				60.976							
9750	0.566		0.01131	7.89	0.510		0.01020	7.11	1.11				
9800		71.874				61.486							
9850	0.554		0.01108	7.73	0.508		0.01017	7.09	1.09				
9900		72.428				61.994							
9950	0.544		0.01088	7.59	0.499		0.00998	6.96	1.09				
10000		72.972				62.493				0.535	70.931	0.01070	7.46
10050	0.533		0.01065	7.43	0.489		0.00978	6.82	1.09				
10100		73.505				62.982							
10150	0.521		0.01043	7.27	0.478		0.00956	6.67	1.09				
10200		74.026				63.460							
10250	0.512		0.01024	7.14	0.470		0.00939	6.55	1.09				
10300		74.538				63.930							
10350	0.502		0.01004	7.00	0.460		0.00921	6.42	1.09				
10400		75.040				64.390							
10450	0.491		0.00982	6.85	0.450		0.00901	6.28	1.09				
10500		75.531				64.840							
10550	0.482		0.00963	6.72	0.442		0.00885	6.17	1.09				
10600		76.013				65.282							
10650	0.472		0.00943	6.58	0.433		0.00866	6.04	1.09				
10700		76.485				65.715							
10750	0.462		0.00923	6.44	0.424		0.00847	5.91	1.09				
10800		76.947				66.139							

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
λ	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
10850	0.452		0.00903	6.30	0.414		0.00829	5.78	1.09				
10900		77.399				66.553							
10950	0.441		0.00883	6.16	0.405		0.00810	5.65	1.09				
11000		77.840			0.330	66.958	0.00660	4.60		0.435	75.781	0.00870	6.07
11100					0.275		0.00551	3.84					
11200					0.242		0.00485	3.38					
11300					0.254		0.00508	3.54					
11400					0.269		0.00538	3.75					
11500	0.399		0.00798	5.57	0.285		0.00571	3.98	1.40				
11600					0.301		0.00602	4.20					
11700					0.313		0.00627	4.37					
11800					0.323		0.00645	4.50					
11900					0.328		0.00655	4.57					
12000		81.830			0.329	69.877	0.00658	4.59		0.360	79.756	0.00720	5.02
12100					0.327		0.00654	4.56					
12200					0.322		0.00644	4.49					
12300					0.313		0.00627	4.37					
12400					0.301		0.00602	4.20					
12500	0.330		0.00659	4.60	0.292		0.00584	4.07	1.13				
12600					0.279		0.00558	3.89					
12700					0.283		0.00566	3.95					
12800					0.280		0.00559	3.90					
12900					0.271		0.00542	3.78					
13000		85.130			0.247	72.832	0.00493	3.44		0.300	83.056	0.00599	4.18
13100					0.227		0.00455	3.17					

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
λ	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
13200					0.202		0.00404	2.82					
13300					0.189		0.00377	2.63					
13400					0.172		0.00344	2.40					
13500	0.274		0.00548	3.82	0.153		0.00305	2.13	1.79				
13600					0.136		0.00272	1.90					
13700					0.004		0.00007	0.05					
13800					0.007		0.00014	0.10					
13900					0.007		0.00014	0.10					
14000		87.870			0.072	74.088	0.00143	1.00		0.250	85.806	0.00500	3.49
14100					0.120		0.00239	1.67					
14200					0.128		0.00257	1.79					
14300					0.129		0.00258	1.80					
14400					0.129		0.00258	1.80					
14500	0.223		0.00447	3.12	0.129		0.00258	1.80	1.73				
14600					0.129		0.00258	1.80					
14700					0.130		0.00261	1.82					
14800					0.137		0.00274	1.91					
14900					0.146		0.00291	2.03					
15000		90.100			0.153	75.378	0.00307	2.14		0.205	88.081	0.00410	2.86
15100					0.163		0.00326	2.27					
15200					0.168		0.00337	2.35					
15300					0.171		0.00343	2.39					
15400					0.166		0.00333	2.32					
15500	0.178		0.00355	2.48	0.163		0.00327	2.28	1.09				
15600					0.158		0.00317	2.21					

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
λ	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		I_E / $I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
15700					0.156		0.00311	2.17					
15800					0.151		0.00303	2.11					
15900					0.148		0.00295	2.06					
16000		91.880			0.144	76.970	0.00288	2.01		0.175	89.981	0.00350	2.44
16100					0.140		0.00280	1.95					
16200					0.138		0.00275	1.92					
16300					0.132		0.00264	1.84					
16400					0.129		0.00258	1.80					
16500	0.136		0.00273	1.90	0.125		0.00250	1.74	1.09				
16600					0.122		0.00244	1.70					
16700					0.118		0.00237	1.65					
16800					0.115		0.00231	1.61					
16900					0.112		0.00224	1.56					
17000		93.240			0.108	78.227	0.00217	1.51		0.140	91.556	0.00280	1.95
17100					0.105		0.00211	1.47					
17200					0.102		0.00204	1.42					
17300					0.099		0.00198	1.38					
17400					0.096		0.00192	1.34					
17500	0.101		0.00202	1.41	0.091		0.00182	1.27	1.11				
17600					0.082		0.00163	1.14					
17700					0.075		0.00151	1.05					
17800					0.070		0.00139	0.970					
17900					0.062		0.00125	0.870					
18000		94.250			0.056	79.091	0.00112	0.780		0.115	92.831	0.00229	1.60
18100					0.014		0.00029	0.200					

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Continued)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
λ	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
18200					0.004		0.00007	0.050					
18300					0.004		0.00007	0.050					
18400					0.004		0.00007	0.050					
18500	0.0771		0.00154	1.07	0.004		0.00007	0.050	21.0				
18600					0		0	0					
18700					0.004		0.00007	0.050					
18800					0.007		0.00014	0.100					
18900					0		0	0					
19000		95.021			0.014	79.167	0.00029	0.200		0.095	93.881	0.00189	1.32
19100					0.048		0.00096	0.670					
19200					0.067		0.00133	0.930					
19300					0.066		0.00132	0.920					
19400					0.065		0.00129	0.900					
19500	0.0662		0.00132	0.923	0.062		0.00125	0.870	1.09				
19600					0.062		0.00125	0.870					
19700					0.062		0.00123	0.860					
19800					0.057		0.00113	0.790					
19900					0.046		0.00092	0.640					
20000		95.693			0.045	79.725	0.00090	0.630		0.080	94.756	0.00161	1.12
20100					0.050		0.00100	0.700					
20200					0.057		0.00113	0.790					
20300					0.054		0.00109	0.760					
20400					0.054		0.00108	0.750					
20500	0.0580		0.00116	0.809	0.053		0.00106	0.740	1.09				
20600					0.052		0.00105	0.730					

TABLE 2.1 SOLAR RADIATION DISTRIBUTION WITH WAVELENGTH BASED ON A SOLAR CONSTANT OF 2.00 g cal cm^{-2} (1395 watt m^{-2}) (Concluded)

WAVE-LENGTH	EXTRATERRESTRIAL SOLAR RADIATION (I_E) NBS (Refs. 2.6 and 2.7)				SOLAR RADIATION FOR ONE (1.00) AIR MASS ($I_{1.00}$) NBS (Refs. 2.6 and 2.7)				ATMOSPHERIC TRANSMITTANCE	EXTRATERRESTRIAL SOLAR RADIATION MEAN OF JOHNSON (Ref. 2.3) and NICOLET (Ref. 2.4)			
	per 100 Angstroms				per 100 Angstroms				RATIO (M)	per 100 Angstroms			
λ	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY		$I_E / I_{1.00}$	PERCENT OF EXTRA-TERRESTRIAL TOTAL		INTENSITY	
Angstroms (Å)	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}	Unitless	%	Accumulative %	g-cal cm^{-2}	watt m^{-2}
20700					0.052		0.00103	0.720					
20800					0.052		0.00103	0.720					
20900					0.050		0.00100	0.700					
21000		96.263			0.049	80.246	0.00099	0.690		0.070	95.506	0.00140	0.977
21500	0.0497		0.00099	0.693	0.046		0.00091	0.636	1.09				
22000		96.760				80.706				0.060	96.156	0.00120	0.837
22500	0.0457		0.00091	0.637	0.042		0.00083	0.580	1.09				
23000		97.217				81.126				0.050	96.706	0.00100	0.697
23500	0.0414		0.00083	0.578	0.038		0.00076	0.530	1.09				
24000		97.631				81.506				0.040	97.156	0.00080	0.558
24500	0.0390		0.00078	0.544	0.036		0.00072	0.500	1.09				
25000		98.021				81.866				0.035	97.531	0.00070	0.488
27500	0.0178		0.00032	0.223	0.004		0.00009	0.060	37.0	0.022		0.00044	0.310
30000		98.911				81.886					98.641		
32500	0.0099		0.00018	0.124	0		0	0	∞	0.012		0.00025	0.173
35000		99.406									99.261		
37500	0.0059		0.00011	0.075	0		0	0	∞	0.007		0.00015	0.103
40000		99.702									99.631		
42500	0.0036		0.00006	0.045	0		0	0	∞	0.004		0.00009	0.063
45000		99.882									99.856		
47500	0.0024		0.00002	0.017	0		0	0	∞	0.003		0.00006	0.040
50000	0	100.002	0	0	0	81.886	0	0	–	0	100.001	0	0
TOTAL AREA UNDER CURVE			2.00	1395			1.64	1142	1.2215			2.00	1395

2.2.4 Atmospheric Transmittance.

The atmospheric transmittance constant can be used in the following equation for computations of intensities for any other number of air masses.

$$I_N = I_o \,(M^N) \qquad \text{Eq. (2.4)}$$

where

I_N = Intensity of solar radiation for "N" air mass thickness (Table 2.1)

I_o = Extraterrestrial solar radiation (Table 2.1)

M = Atmospheric transmittance

N = Number of air masses

Equation (2.4) can also be used to obtain solar radiation intensities versus wavelengths for other total normal incident solar radiation intensities (area under curve) by computation of new values of atmospheric transmittance as follows:

$$M_N = M \frac{I_{TN}}{1.64} \qquad \text{Eq. (2.5)}$$

where

I_{TN} = New value of total normal incident solar radiation intensity

M = Value for atmospheric transmittance given in Table 2.1

M_N = New value of atmospheric transmittance

Equations (2.4) and (2.5) are valid only for locations relatively near the earth's surface (below 5 km altitude). For higher altitudes, corrections would be needed for the change of the amount of ozone and water vapor in the atmosphere. Also equation (2.5) should be used only for values of I_{TN} greater than 1.10 g-cal cm^{-2} min^{-1} since values lower than this would indicate a considerably higher ratio of water vapor to ozone in the atmosphere and require that the curve be adjusted to give more absorption in the infrared water vapor bands without as large an increase in the ozone absorption.

Also included in Table 2.1 is the extraterrestrial solar radiation (solar radiation outside the atmosphere). There are two sets of data, both obtained by extrapolating from measured values through one or more air masses of atmosphere. The data from the National Bureau of Standards give the intensity of solar radiation for a high resolution [g-cal cm^{-2} $(100\ \text{Å})^{-1}$] obtained from the data presented in Table 2.1 for one air mass. To provide extraterrestrial solar radiation data below 2995 Å, values are given to a lesser resolution [g-cal cm^{-2} (10000 Å$)^{-1}$] based on mean values of Johnson (Ref. 2.3) and Nicolet (Ref. 2.4), with data for the entire spectrum for comparison purposes. The data were converted to [g-cal cm^{-2} (100 Å$)^{-1}$] to make the values agree with the NBS data. It is the belief of the author that the error in using the mean value of Johnson and Nicolet is less than the actual error of the figures presented.

2.3 Total Solar Radiation.

2.3.1 Introduction

The standard solar radiation sensors measure the intensity of direct solar radiation from the sun falling on a horizontal surface plus the diffuse (sky) radiation from the total sky hemisphere. Diffuse radiation is lowest with day clear air; it increases with increasing dust and moisture in the air. With extremely dense clouds or fog, the measured horizontal solar radiation will be nearly all diffuse radiation. The higher (≥ 95 percentile) values of measured horizontal solar radiation occur under clear skies. When solar radiation data are used in design studies, the direct solar radiation should be applied from one direction as parallel rays and, at the same time, the diffuse radiation should be applied as rays from all directions of a hemisphere to the object as shown in Figure 2.1.

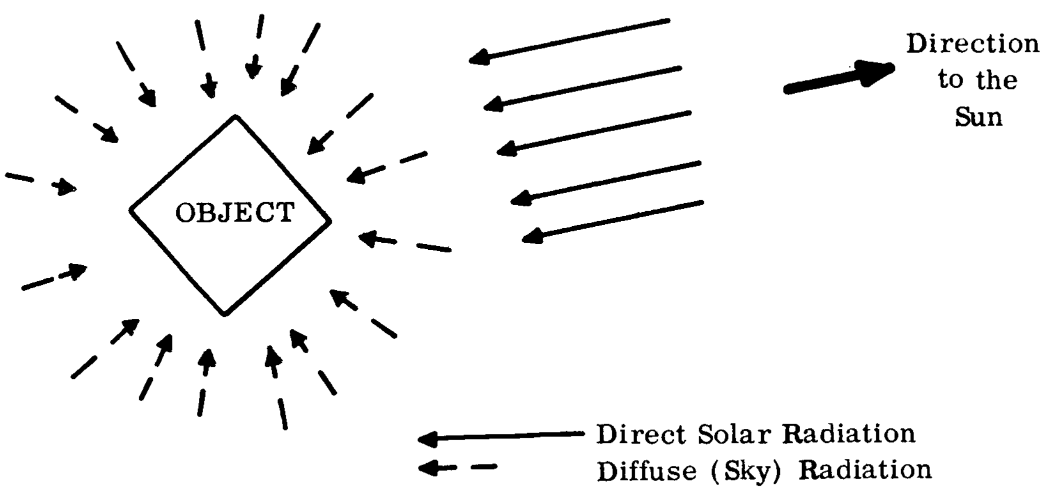

FIGURE 2.1 METHOD OF APPLYING DIFFUSE RADIATION FOR DESIGN

In this document all solar radiation values given are intensities. Solar radiation intensities are measured in gram calories per square centimeter (same as langleys per square centimeter) at U. S. Weather Bureau stations. Intensities of solar radiation are numerically equal to solar insolation per minute; i. e., gram calories per square centimeter per minute.

2.3.2 Basic Data Computation.

The solar radiation data given in the tables in this section were obtained from a study made by the National Weather Records Center of the Weather Bureau under contract to the NASA-Marshall Space Flight Center.

The basic data used were total horizontal solar and sky radiation (I_{TH}) for each hour of the day for ten year periods at two stations; Apalachicola, Florida and Santa Maria, California. Average intensity values for hourly periods were obtained by dividing each hourly total by 60. The diffuse sky radiation intensities (I_{dH}) were empirically estimated for each value, based on amount of total horizontal solar and sky radiation and solar altitude similar to the method used in Reference 2.11. After subtracting the diffuse sky radiation from the total horizontal solar and sky radiation, the resultant horizontal solar radiation (I) can be used to compute the direct normal incident solar radiation (I_{DN}) using the following equation (Refs. 2.12 and 2.13):

$$I_{DN} = \frac{I}{\sin b} \qquad \text{Eq. (2.6)}$$

where

I_{DN} = Direct Normal Incident Solar Radiation

I = Horizontal Solar Radiation = $I_{TH} - I_{dH}$

b = Sun's Altitude (Ref. 2.14).

The total normal incident solar radiation (I_{TN}) values were found by adding the direct normal incident solar radiation (I_{DN}) and the diffuse sky radiation (I_{dH}) previously estimated. This method of finding the total normal incident solar radiation may result in a slight overestimation of the value for low solar altitudes because the sky hemisphere is intercepted by the ground surface, but this error is small enough to be ignored when working with extreme values, or any values on the high end of the frequency distribution (i.e., mean plus one standard deviation or greater).

Total solar radiation intensities on a south-facing surface, with the normal to the surface at 45 degrees to the horizontal, are calculated as follows:

$$I_{D45} = I(\sin 45° + \cot b \cos a \cos 45°) \qquad \text{Eq. (2.7)}$$

where

I_{D45} = Intensity of direct solar radiation on a south-facing surface, with normal 45 degrees to the horizontal.

I = Horizontal Solar Radiation = $I_{TH} - I_{dH}$

a = Sun's azimuth measured from south direction

b = Sun's altitude.

The values of Total Intensity on a south-facing surface, with normal 45 degrees to the horizontal are calculated by adding the direct solar radiation on the south-facing surface, with normal 45 degrees to horizontal (I_D 45°) and the diffuse sky radiation (I_{dH}) previously estimated.

2.3.3 Solar Radiation Extremes.

To present the solar radiation data, the month of June was selected to represent the extremes* during summer and the longest days and December, to represent the extremes during winter and the shortest days. The June extreme data for normal incident solar radiation for Santa Maria, California, were increased for the period from 1100 to 1900 hours to reflect the higher values which occur early in July (first week) during the afternoon. Tables 2.2 and 2.3 give the solar radiation extreme data for time of day. The values given for diffuse radiation are the highest values associated with the other extremes of solar radiation given and not the extremes of diffuse radiation that occurred during the period of record. Since the diffuse radiation is low with high values of total measured solar radiation, the values given are considerably lower than the highest values of diffuse radiation which occurred during the period, and the values for association with the extremes are less than those for the 95 percentile. Figure 2.2 shows the June total horizontal and total normal incident data in graphical form for the Eastern Test Range, New Orleans, Gulf Transportation, and Huntsville.

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* Extreme as used in this section is the highest measured value of record.

TABLE 2.2 EXTREME VALUES OF SOLAR RADIATION FOR THE WESTERN TEST RANGE, WEST COAST TRANSPORTATION, SACRAMENTO, AND WHITE SANDS MISSILE RANGE

TIME OF DAY (Local Standard Time)	Total Horizontal Solar Radiation g-cal cm^{-2}		Diffuse Radiation Associated with Total Horizontal Solar Radiation Extremes g-cal cm^{-2}		Total Normal Incident Solar Radiation g-cal cm^{-2}		Total 45° Surface Solar Radiation g-cal cm^{-2}	
JUNE								
	EXTREME	95 Percentile	EXTREME	95 Percentile	EXTREME	95 Percentile	EXTREME	95 Percentile
0500	0	0	0	0	0	0	0	0
0600	0.16	0.11	.02	.04	1.14	0.78	0.04	0
0700	0.46	0.40	.05	.08	1.34	1.08	0.19	0.16
0800	0.82	0.76	.06	.09	1.54	1.38	0.34	0.31
0900	1.16	1.11	.04	.08	1.74	1.62	0.84	0.77
1000	1.45	1.42	0	.03	1.79	1.71	1.19	1.12
1100	1.64	1.56	0	.10	1.79	1.69	1.39	1.31
1200	1.69	1.63	0	.08	1.74	1.68	1.49	1.38
1300	1.69	1.64	0	.07	1.74	1.68	1.49	1.40
1400	1.59	1.54	.06	.12	1.74	1.68	1.34	1.29
1500	1.45	1.39	0	.06	1.79	1.70	1.14	1.09
1600	1.21	1.19	0	.02	1.79	1.71	0.89	0.78
1700	0.87	0.83	.03	.05	1.69	1.60	0.34	0.18
1800	0.46	0.42	.05	.08	1.39	1.23	0.19	0.13
1900	0.14	0.12	.02	.04	1.19	0.93	0.04	0
2000	0	0	0	0	0	0	0	0
DECEMBER								
	EXTREME	95 Percentile	EXTREME	95 Percentile	EXTREME	95 Percentile	EXTREME	95 Percentile
0800	0	0	0	0	0	0	0	0
0900	0.35	0.32	0.04	0.05	1.59	1.39	0.99	0.85
1000	0.65	0.60	0.03	0.05	1.64	1.53	1.29	1.21
1100	0.86	0.80	0	0.04	1.84	1.64	1.64	1.49
1200	0.96	0.89	0.02	0.06	1.79	1.69	1.74	1.63
1300	0.99	0.89	0	0.06	1.84	1.70	1.79	1.64
1400	0.85	0.80	0.01	0.04	1.79	1.64	1.59	1.49
1500	0.66	0.60	0.02	0.05	1.69	1.54	1.34	1.21
1600	0.38	0.31	0.02	0.05	1.64	1.38	1.04	0.87
1700	0	0	0	0	0	0	0	0

TABLE 2.3 EXTREME VALUES OF SOLAR RADIATION FOR EASTERN TEST RANGE, NEW ORLEANS, GULF TRANSPORTATION, HUNTSVILLE

TIME OF DAY (Local Standard Time)	Total Horizontal Solar Radiation g-cal cm^{-2}		Diffuse Radiation Associated with Total Horizontal Solar Radiation Extremes g-cal cm^{-2}		Total Normal Incident Solar Radiation g-cal cm^{-2}		Total 45° Surface Solar Radiation g-cal cm^{-2}	
	JUNE							
	EXTREME	95 Percentile	EXTREME	95 Percentile	EXTREME	95 Percentile	EXTREME	95 Percentile
0500	0	0	0	0	0	0	0	0
0600	0.12	0.07	0	0	1.09	1.00	0	0
0700	0.42	0.36	0.05	0.07	1.29	1.04	0.19	0.16
0800	0.82	0.71	0.04	0.10	1.59	1.30	0.34	0.27
0900	1.23	1.02	0	0.10	1.59	1.48	0.49	0.41
1000	1.35	1.30	0.02	0.06	1.59	1.54	0.99	0.95
1100	1.52	1.45	0.03	0.09	1.59	1.54	1.19	1.14
1200	1.58	1.53	0.10	0.16	1.64	1.55	1.29	1.24
1300	1.58	1.50	0.10	0.20	1.64	1.53	1.29	1.24
1400	1.50	1.44	0.05	0.12	1.59	1.52	1.19	1.09
1500	1.35	1.30	0.02	0.06	1.59	1.52	1.04	0.95
1600	1.10	1.01	0.05	0.12	1.54	1.44	0.54	0.44
1700	0.77	0.72	0.05	0.09	1.49	1.33	0.34	0.30
1800	0.48	0.40	0.03	0.06	1.44	1.14	0.19	0.18
1900	0.11	0.08	0	0	1.14	1.00	0.14	0.03
2000	0	0	0	0	0	0	0	0
	DECEMBER							
	EXTREME	95 Percentile	EXTREME	95 Percentile	EXTREME	95 Percentile	EXTREME	95 Percentile
0700	0	0	0	0	0	0	0	0
0800	0.16	0.10	0	0	1.34	1.12	0.64	0.50
0900	0.46	0.42	0.04	0.06	1.44	1.36	0.94	0.89
1000	0.79	0.71	0.01	0.07	1.69	1.60	1.39	1.29
1100	0.95	0.92	0.02	0.04	1.79	1.68	1.64	1.56
1200	1.09	1.02	0	0.03	1.79	1.70	1.74	1.66
1300	1.05	1.02	0	0.03	1.79	1.78	1.74	1.66
1400	0.94	0.89	0.02	0.05	1.74	1.67	1.59	1.63
1500	0.79	0.70	0	0.03	1.74	1.57	1.39	1.27
1600	0.46	0.41	0.04	0.06	1.54	1.40	0.99	0.91
1700	0.16	0.10	0	0	1.34	1.12	0.64	0.50
1800	0	0	0	0	0	0	0	0

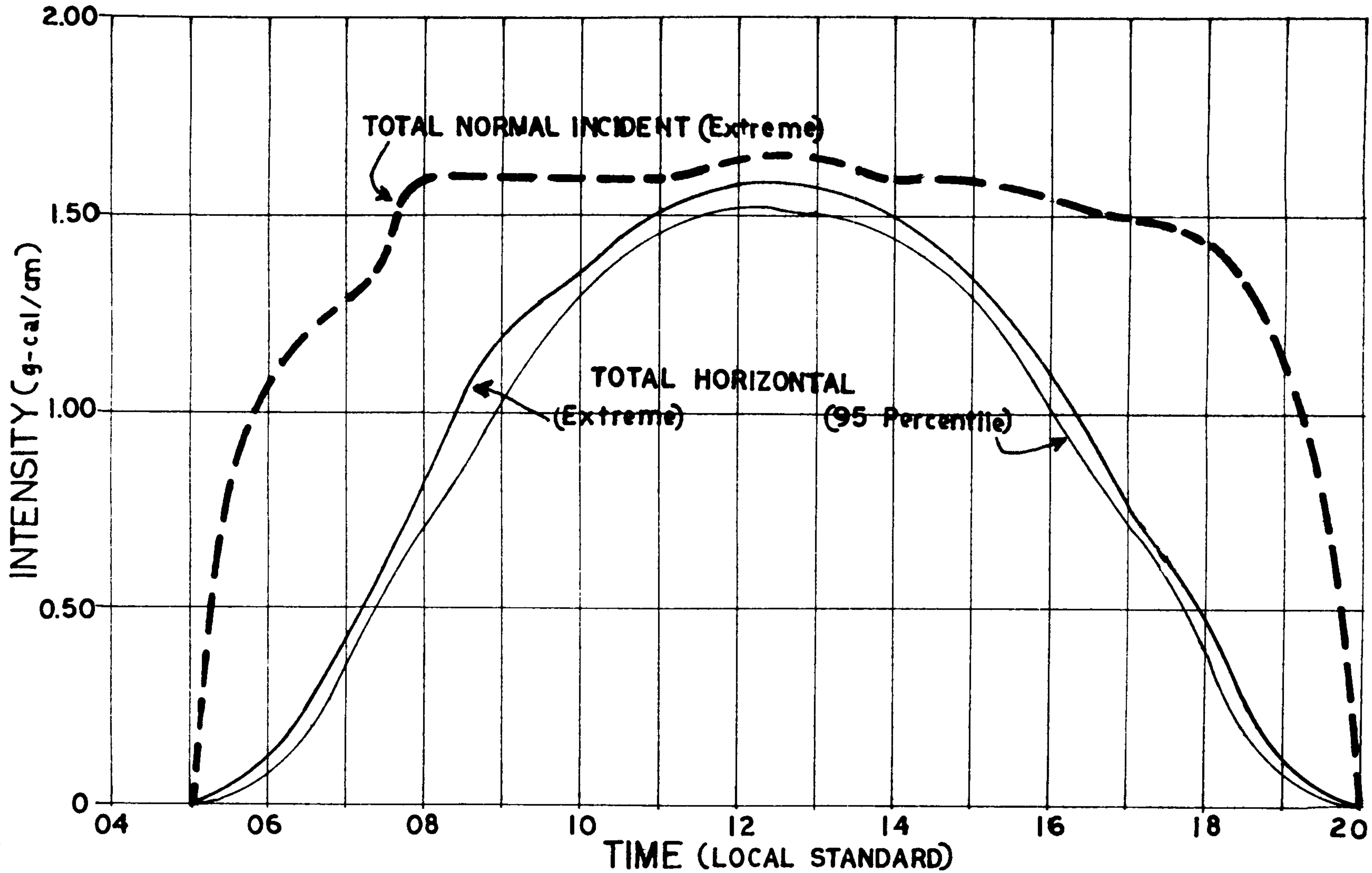

FIGURE 2.2 JUNE EXTREME VALUES OF SOLAR RADIATION FOR EASTERN TEST RANGE, NEW ORLEANS, GULF TRANSPORTATION, AND HUNTSVILLE

2.3.4 Variation with Altitude.

Solar radiation intensity on a surface will increase with altitude above the earth's surface, with clear skies, according to the following equation:

$$I_H = I_{DN} + (2.00 - I_{DN})\left(1 - \frac{\rho_H}{\rho_S}\right) \qquad \text{Eq. (2.8)}$$

where

I_H = Intensity of solar radiation normal to surface at required height,

I_{DN} = Intensity of solar radiation normal to surface at the earth's surface, assuming clear skies ($I_{DN} = I_{TN} - I_{dH}$)

ρ_H = Atmospheric density at required height (from U.S. Standard or Supplemental Atmosphere Data or this document) (kg m^{-3})

ρ_S = Atmospheric density at sea level (from U.S. Standard or Supplemental Atmosphere data or this document) (kg m^{-3})

2.00 = Solar constant (g-cal cm^{-2}).

The diffuse radiation (I_{dH}) decreases with altitude above the earth's surface, with clear skies. A good estimate of the value can be obtained from the following equation:

$$I_{dH} = 0.7500 - 0.4076\, I_H \qquad \text{Eq. (2.9)*}$$

where

I_{dH} = Intensity of diffuse radiation

I_H = Intensity of solar radiation normal to surface.

Equation (2.9) is valid for values of I_H from equation (2.8) up to 1.84 g-cal cm^{-2}. For values of I_H greater than 1.84 g-cal cm^{-2}, $I_{dH} = 0$.

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* Equation (2.9) is based on a cloudless and dust free atmosphere.

2.3.5 Solar Radiation during Extreme Conditions.

When ground winds occur which exceed the 95, 99, or 99.9 percentile winds given in this document in Section V, the associated weather normally is such that clouds, rain, or dust are generally present; therefore the intensity of the incoming solar radiation will be less than the maximum values given in Tables 2.2 and 2.3. Maximum values of solar radiation intensity to use with corresponding wind speeds are given in Table 2.4

TABLE 2.4 SOLAR RADIATION MAXIMUM VALUES ASSOCIATED WITH EXTREME WIND VALUES

	Maximum Solar Radiation (Normal Incident)					
Steady-State Ground Wind Speed at 18 m Height	Huntsville, New Orleans River Transportation, Gulf Transportation, Eastern Test Range, Western Test Range, Sacramento, West Coast Transportation and Wallops Test Range			White Sands Missile Range		
($m\ sec^{-1}$)	($kJm^{-2}\ sec^{-1}$)	($g\text{-}cal\ cm^{-2}\ min^{-1}$)	($BTU\ ft^{-2}\ hr^{-1}$)	($kJm^{-2}\ sec^{-1}$)	($g\text{-}cal\ cm^{-2}\ min^{-1}$)	($BTU\ ft^{-2}\ hr^{-1}$)
10	0.84	1.20	265	1.05	1.50	332
15	0.56	0.80	177	0.70	1.00	221
≥20	0.35	0.50	111	0.56	0.80	177

2.4 Air Temperature Near the Surface.

Surface air temperatures are presented in Table 2.5 for various geographic areas. The maximum extremes and minimum extremes and the 95 percentile values are given for the worst month based on 50 years of record. Values for extreme minimum sky radiation (equal to outgoing radiation) are also given in Table 2.5. The surface air temperature extreme values presented in Table 2.5 should be expected for only a few hours during a day. Generally,

TABLE 2.5 SURFACE AIR AND SKY RADIATION TEMPERATURE EXTREMES

Area		Surface Air Temperature Extremes**				Sky Radiation	
		Maximum		Minimum		Equivalent Temperature Minimum Extreme	Equivalent Radiation $g\text{-}cal\ cm^{-2}\ min^{-1}$
		Extreme	95%	Extreme	95%		
Huntsville	°C	43.9	41.7	-23.3	-21.7	-30.0	0.28
	°F	111	107 #	-10	-7#	-22	
River Transportation	°C	43.9	-	-30.6	-	-37.2	0.25
	°F	111	-	-23	-	-35	
New Orleans	°C	37.8	31.7	-12.8	7.8	-17.8	0.35
	°F	100	89 ≁	9	46 ≁	0	
Gulf Transportation	°C	40.6	-	-12.8	-	-17.8	0.35
	°F	105	-	9	-	0	
Eastern Test Range	°C	37.2	30.0	- 2.2	12.2	-15.0	0.36
	°F	99	86 ≁	28	54 ≁	5	
Panama Canal Transportation	°C	41.7	-	-12.8	-	-15.0	0.36
	°F	107	-	9	-	5	
Western Test Range	°C	41.7	31.1	- 2.2	3.9	-15.0	0.36
	°F	107	88 ≁	28	39 ≁	5	
West Coast Transportation	°C	46.1	-	- 6.1	-	-17.8	0.35
	°F	115	-	21	-	0	
Sacramento	°C	46.1	*	- 6.1	*	-17.8	0.35
	°F	115	*	21	*	0	
White Sands Missile Range	°C	41.1	*	-21.1	*	-30.0	0.28
	°F	106	*	- 6	*	-22	
Wallops Test Range	°C	39.4	*	-11.7	*	-17.8	0.35
	°F	103	*	11	*	0	

≁ Based on hourly data

\# Based on Worst Month extremes

\- Not applicable

* To be determined.

** The extreme maximum and minimum temperatures will be encountered during periods of wind speeds less than about one meter per second.

the extreme maximum temperature is reached after 12 noon and before 5 p.m., while the minimum temperature is reached just before sunrise. Table 2.6 shows the maximum and minimum air temperatures which have occurred on each hour at the Eastern Test Range (Cape Kennedy), but not necessarily on the same day.

2.5 Extreme Air Temperature Change.

Design values of extreme air temperature changes (thermal shock).

a. For all areas these values are:

(1) An increase of air temperature of 10°C (18°F) with a simultaneous increase of solar radiation (measured on a normal surface) from 0.50 g-cal cm^{-2} min^{-1} (110 BTU ft^{-2} hr^{-1}) to 1.85 g-cal cm^{-2} min^{-1} (410 BTU ft^{-2} hr^{-1}) may occur in a one-hour period. Likewise, the reverse change of the same magnitude may occur for decreasing air temperature and solar radiation.

(2) A 24-hour change may occur with an increase of 27.7° (50°F) in air temperature in a 5-hour period, followed by four hours of constant air temperature, then a decrease of 27.7°C (50°F) in a five-hour period, followed by ten hours of constant air temperature.

b. For Eastern Test Range (Cape Kennedy, Florida), the 99.9 percentile air temperature changes are as follows:

(1) An increase of air temperature of 5.6°C (11°F) with a simultaneous increase of solar radiation (measured on a normal surface) from 0.50 g cal cm^{-2} min^{-1} (110 BTU ft^{-2} hr^{-1}) to 1.60 g cal cm^{-2} min^{-1} (354 BTU ft^{-2} hr^{-1}), or a decrease of air temperature of 9.4°C (17°F) with a simultaneous decrease of solar radiation from 1.60 g cal cm^{-2} min^{-1} (354 BTU ft^{-2} hr^{-1}) to 0.50 g cal cm^{-2} min^{-1} (110 BTU ft^{-2} hr^{-1}) may occur in a one-hour period.

(2) A 24-hour temperature change may occur as follows. An increase of 16.1°C (29°F) in air temperature (wind speed under 5 m/sec) in an eight-hour period, followed by two hours of constant air temperature (wind speed under 5 m/sec), then a decrease of 21.7°C (39°F) in air temperature (wind speed between 7 and 10 m/sec) in a 14-hour period.

2.6 Surface (Skin) Temperature.

The temperature of the surface of an object exposed to solar, day sky or night sky radiation is usually different from the air temperature (Refs. 2.16 and 2.17). The amount of the extreme difference in temperature between the object

TABLE 2.6 MAXIMUM AND MINIMUM SURFACE AIR TEMPERATURES AT EACH HOUR FOR EASTERN TEST RANGE*

Time	Annual Maximum		Annual Minimum	
	°C	°F	°C	°F
1 a.m.	28.9	84	1.1	34
2	28.9	84	0.6	33
3	29.4	85	-1.1	30
4	28.3	83	-0.6	31
5	28.3	83	-1.1	30
6	29.4	85	-1.1	30
7	30.6	87	-1.7	29
8	30.6	87	-2.2	28
9	31.7	89	-0.6	31
10	33.9	93	1.1	34
11	35.0	95	2.2	36
12 noon	35.6	96	5.0	41
1 p.m.	37.2	99	5.6	42
2	35.6	97	5.0	41
3	35.6	97	5.6	42
4	35.6	97	5.6	42
5	35.6	97	5.6	42
6	35.0	95	3.9	39
7	33.3	92	2.2	36
8	31.7	89	2.2	36
9	30.0	86	1.7	35
10	30.0	86	1.7	35
11	30.0	86	1.1	34
12 mid	30.0	86	1.1	34

* Based on 10 years of record for Patrick AFB and Cape Kennedy.

and the surrounding air temperature is given in Table 2.7 and Figure 2.3, Part A, for exposure to a clear night (or day)* sky or to the sun on a clear day. Since the flow of air across an object changes the balance between the heat transfers from radiation and convection-conduction between the air and the object, the difference in the temperature between the air and the object will decrease with increasing wind speed (Ref. 2.16). Part B of Figure 2.3 provides information for making the corrections for wind speed. Values are tabulated in Table 2.7 for various wind speeds.

2.7 Compartment Temperature.

2.7.1 Introduction.

A cover of thin material enclosing an air space will conduct heat to (or remove heat from) the inside air when the cover is heated by solar radiation (or cooled by the night sky). This results in the compartment air space being frequently considerably hotter or cooler than the surrounding air (See 2.6 above). The temperature reached in a compartment is dependent on the location of the air space with respect to the heated surface, the type and thickness of the surface material, the type of construction, and the insulation; i.e., an addition of a layer of insulation on the inside surface of the compartment will greatly reduce the heating or cooling of the air in the compartment space (Refs. 2.18 and 2.19).

2.7.2 Compartment Extreme High Temperature.

A compartment probable extreme high temperature of 87.8°C (190°F) for a period of one hour and 65.6°C (150°F) for a period of six hours must be considered at all geographic locations while aircraft or other transportation equipment are stationary on the ground without air conditioning in the compartment. These extremes will be found at the top and center of the compartment.

2.8 Data on air temperature distribution with altitude are given in Section XIV.

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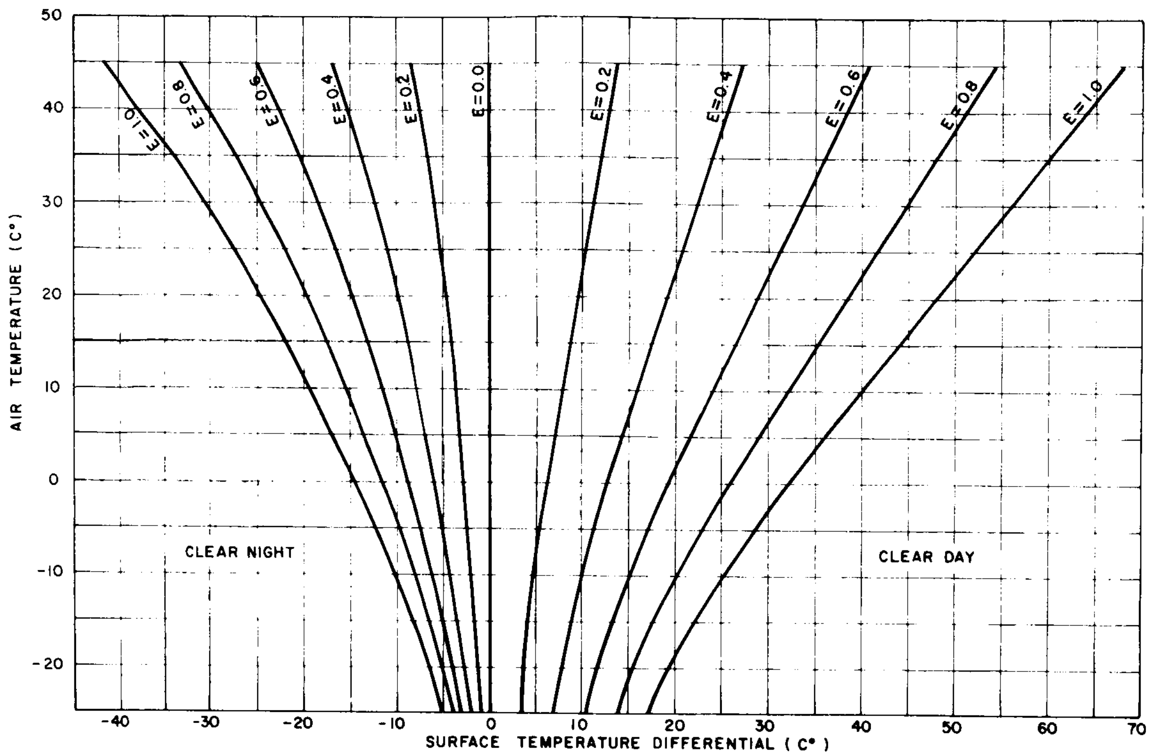
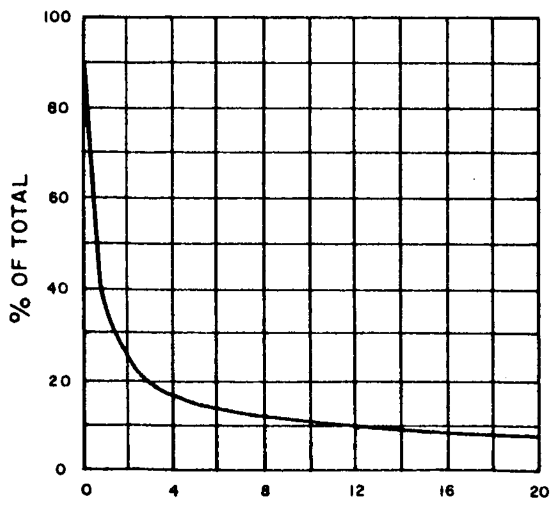
* Without sun's ray striking, the daytime sky is about as cold as the nighttime sky.



A. Surface temperature differentials with respect to air temperature for surface of emittance from 0. 0 to 1. 0 for calm wind conditions. Temperature difference after correction for wind is to be added or subtracted to the air temperature to give surface (skin) temperature.



B. Correction for wind speed obtained from Graph A. Valid only for a pressure of one atmosphere.

FIGURE 2. 3 EXTREME SURFACE (SKIN) TEMPERATURE OF AN OBJECT NEAR THE EARTH'S SURFACE (0 TO 300 m) FOR CLEAR SKY

TABLE 2.7. EXTREME SURFACE (SKIN) TEMPERATURE ABOVE OR BELOW AIR TEMPERATURE OF AN OBJECT NEAR THE EARTH'S SURFACE

Air Temperature	Surface Temperature (°C)									
	Clear Night					Clear Day				
	Wind Speed (m sec^{-1})					Wind Speed (m sec^{-1})				
	0	2	4	10	20	0	2	4	10	20
	Correction Factor					Correction Factor				
(°C)	1.00	0.25	0.17	0.11	0.08	1.00	0.25	0.17	0.11	0.08
-25	-5.0	-1.2	-0.8	-0.6	-0.4	16.9	4.2	2.9	1.9	1.4
-20	-6.5	-1.6	-1.1	-0.7	-0.5	19.2	4.8	3.3	2.1	1.5
-15	-8.2	-2.0	-1.4	-0.9	-0.6	22.0	5.5	3.7	2.4	1.8
-10	-10.2	-2.6	-1.7	-1.1	-0.8	25.1	6.3	4.3	2.8	2.0
- 5	-12.2	-3.0	-2.1	-1.3	-1.0	28.5	7.1	4.8	3.1	2.3
0	-14.5	-3.6	-2.5	-1.6	-1.2	32.0	8.0	5.4	3.5	2.6
5	-16.9	-4.2	-2.9	-1.9	-1.4	36.0	9.0	6.1	4.0	2.9
10	-19.4	-4.8	-3.3	-2.1	-1.6	40.0	10.0	6.8	4.4	3.2
15	-21.9	-5.5	-3.7	-2.4	-1.8	44.0	11.0	7.5	4.8	3.5
20	-24.6	-6.2	-4.2	-2.7	-2.0	48.0	12.0	8.2	5.3	3.8
25	-27.4	-6.8	-4.6	-3.0	-2.2	52.0	13.0	8.8	5.7	4.2
30	-30.5	-7.6	-5.2	-3.4	-2.4	56.0	14.0	9.5	6.2	4.5
35	-34.0	-8.5	-5.8	-3.7	-2.7	60.0	15.0	10.2	6.6	4.8
40	-37.7	-9.4	-6.4	-4.1	-3.0	64.0	16.0	10.9	7.0	5.1
45	-41.7	-10.4	-7.1	-4.6	-3.3	68.0	17.0	11.6	7.5	5.4

NOTE: Values are given for an emittance value of 1.0 Temperature differences for other emittance can be determined by multiplying tabular value by the appropriate emittance.

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SECTION III. HUMIDITY

By

Glenn E. Daniels

3.1 Definitions. (Ref. 3.1)

Dew point is the temperature to which a given parcel of air must be cooled at constant pressure and constant water vapor content in order for saturation to occur. Further cooling below the dew point normally produces condensation or sublimation.

Relative humidity is the ratio of the actual amount of water vapor in a given volume of air to the amount of water vapor that the same volume of air at the same temperature holds if saturated. Values given are in percent.

Vapor concentration [previously called absolute humidity (Ref. 3.2)] is the ratio of the mass of water vapor present to the volume occupied by the mixture, i.e., the density of the water vapor content. This is expressed in grams of water vapor per cubic meter of air.

Water vapor is water in gaseous state.

3.2 Vapor Concentration.

Water in vapor form in the atmosphere is invisible; however, the amount of liquid water available from a volume of warm air near saturation is considerable and must be considered in design of space vehicles because:

a. Small solid particles (dust) which settle on surfaces cause condensation (frequently when the atmosphere is not at the saturation level) and will dissolve. The resultant solution may be corrosive. Galvanic corrosion resulting from contact of dissimilar metals also takes place at a rapid rate in the presence of moisture. The rate of corrosion of the surface increases with higher humidity (Ref. 3.3). See Section X of this document for further details.

b. Humid conditions can impair the performance of electrical equipment. This may be by an alteration of the electrical constants of tuned circuits, deterioration of parts (resistors, capacitors, etc.), electrical breakdown of air gaps in high-voltage areas, or shorting of sections by conductive solutions formed from solid particles dissolving in the liquid formed.

c. To grow well, bacteria and fungi usually require high humidities associated with high temperatures.

d. A decrease in the temperature of the air to the dew point will result in condensation of water from the atmosphere in liquid or frozen form. Considerable difficulty may result from ice forming on space vehicles when moist air is cooled by the low temperature of the fuel, especially if pieces of this ice should drop into equipment areas of the vehicle or supporting ground equipment before or during takeoff. Optical surfaces (such as lenses of television cameras) may become coated with water droplets or ice crystals.

Test specifications still use an accelerated humidity test of temperature of 71.1°C (160°F) at a relative humidity of 95 percent ±5 percent for 10 cycles of 6 hours each spread over a total period of 240 hours. This represents a dew point of 68.9°C (156°F), values that are much higher than any natural extreme in the world. Dew points above 32.2°C (90°F) are extremely unlikely in nature (Ref. 3.4), since the dew point temperature is limited by the source of the water vapor; i.e., the surface temperature of the water body from which the water evaporates (Ref. 3.5). These tests with high temperatures can be advantageously used only as an aggravated test if high temperatures are not significant in the test after correlation of deterioration with that encountered in natural extremes. Also, if the mass of the test object is large, moisture may not condense on the test object because of thermal lag in the test object. Therefore, referenced specifications for tests which require high temperature must be carefully evaluated and should be used as guidelines along with this document.

3.2.1 High Vapor Concentration at Surface.

a. Huntsville, River Transportation, New Orleans, Gulf Transportation, Eastern Test Range, and Wallops Test Range:

(1) The following extreme humidity cycle of 24 hours with a wind of less than 5 m sec^{-1} (9.7 knots) should be considered in design: Three hours of 37.2°C (99°F) air temperature at 50 percent relative humidity and a vapor concentration of 22.2 g m^{-3} (9.7 gr ft^{-3}); six hours of decreasing air temperature to 24.4°C (76°F) with relative humidity increasing to 100 percent (saturation); eight hours of decreasing air temperature to 21.1°C (70°F), with a release of 3.8 grams of water as liquid per cubic meter of air (1.7 gr

of water per cubic foot of air),* humidity remaining at 100 percent; and seven hours of increasing air temperature to 37.2°C (99°F) and a decrease to 50 percent relative humidity (Fig. 3.1).

(2) An extreme relative humidity between 75 and 100 percent and air temperature between 22.8°C (73°F) and 27.8°C (82°F), which would result in corrosion and bacterial and fungal growths, can be expected for a period of 15 days. A humidity of 100 percent occurs one-fourth of the time at the lower temperature in cycles not exceeding 24 hours. Any loss of water vapor from the air by condensation is replaced from outside sources to maintain at least 75 percent relative humidity at the higher temperature.

b. Panama Canal Transportation:

(1) The following extreme humidity cycle of 24 hours with a wind of less than 5 m sec^{-1} (9.7 knots) should be considered in design: Three hours of 32.2°C (90°F) air temperature at 75 percent relative humidity, and a vapor concentration of 25.4 g m^{-3} (11.1 gr ft^{-3}); six hours of decreasing air temperature to 26.7°C (80°F) with relative humidity increasing to 100 percent; eight hours of decreasing air temperature to 21.7°C (71°F) with a release of 6.3 grams of water as liquid per cubic meter of air (2.8 gr of water per cubic foot of air),* humidity remaining at 100 percent; four hours of increasing air temperature to 26.7°C (80°F) and a decrease to 75 percent relative humidity; and three hours of increasing air temperature to 32.2°C (90°F) with the relative humidity remaining at 75 percent (moisture added to air by evaporation, mixing, or replacement with air of higher vapor concentration). See Figure 3.2.

(2) An extreme relative humidity between 85 and 100 percent and air temperature between 23.9°C (75°F) and 26.1°C (79°F), which would result in corrosion and bacterial and fungal growth, can be expected for a period of 30 days. The humidity should be 100 percent during one-fourth of the time at the lower temperature in cycles not exceeding 24 hours. Any loss of water vapor from the air by condensation is replaced from outside sources to maintain at least 85 percent relative humidity at the higher temperature.

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* The release of water as a liquid on the test object may be delayed for several hours after the start of this part of the test because of thermal lag in a large test object. If the lag is too large, the test should be extended in time for each cycle to allow condensation.

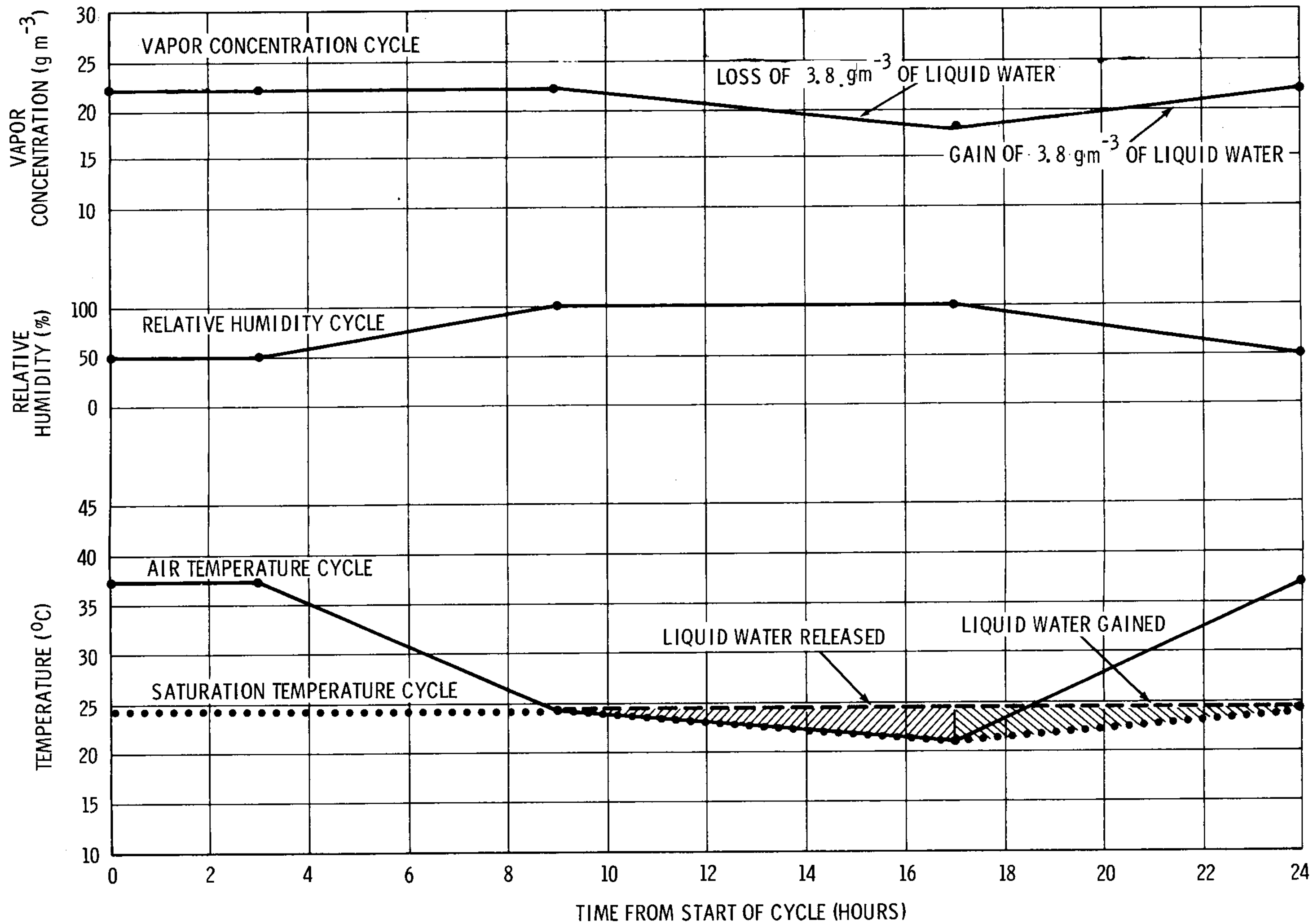

FIGURE 3.1 EXTREME HIGH VAPOR CONCENTRATION CYCLE FOR HUNTSVILLE, RIVER TRANSPORTATION, NEW ORLEANS, GULF TRANSPORTATION, EASTERN TEST RANGE, AND WALLOPS TEST RANGE

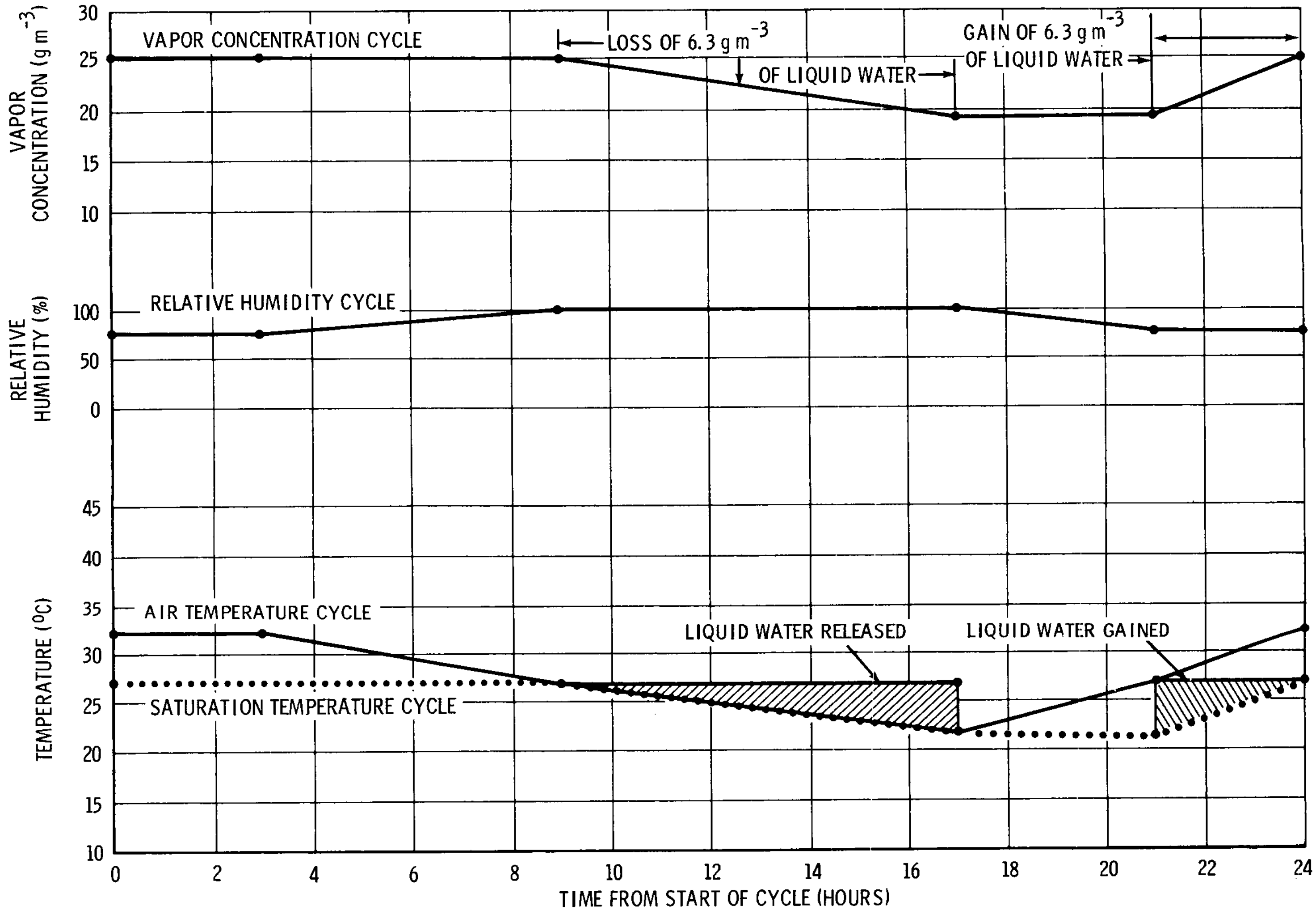

FIGURE 3.2 EXTREME HIGH VAPOR CONCENTRATION CYCLE FOR PANAMA CANAL TRANSPORTATION

(3) Equipment shipped from the West Coast, through the Panama Canal by ship may accumulate moisture (condensation) while in the ship's hold because of the increasing moisture content of the air while traveling south to the Panama Canal, and the slower increase of temperature of the equipment being transported. This condensation may result in corrosion, rusting, or other deterioration of the equipment (Ref. 3.6). Extreme values of condensation are:

(a) Maximum condensation conditions occur during the period between December and March, but condensation conditions may occur during all months.

(b) The maximum dew point expected is 30.0° C (86° F), with dew points over 21.1° C (70° F) for ship travel of 6 days prior to arrival at the Panama Canal from the west coast, and for the remainder of the trip to Cape Kennedy.

c. Western Test Range, West Coast Transportation, and Sacramento:

(1) The following extreme humidity cycle of 24 hours with a wind of less than 5 m sec^{-1} (9.7 knots) should be considered in design: Three hours of 23.9° C (75° F) air temperature at 75 percent relative humidity and a vapor concentration of 16.2 g m^{-3} (7.9 gr ft^{-3}); six hours of decreasing air temperature to 18.9° C (66° F) with relative humidity increasing to 100 percent; eight hours of decreasing air temperature to 12.8° C (55° F) with a release of 5.0 grams of water as liquid per cubic meter of air (2.2 gr of water per cubic foot of air),* humidity at 100 percent; and seven hours of increasing air temperature to 23.9° C (75° F) and the relative humidity decreasing to 75 percent (Fig. 3.3).

(2) Bacterial and fungal growth should present no problem because of the lower temperatures in this area. For corrosion, an extreme humidity of between 75 and 100 percent relative humidity and air temperature between 18.3° C (65° F) and 23.3° C (74° F) can be expected for a period of 15 days. The humidity should be 100 percent during one-fourth of the time at the lower temperature in cycles not exceeding 24 hours. Any loss of water vapor from the air condensation is replaced from outside sources to maintain at least 75 percent relative humidity at the higher temperature.

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* See footnote, page 3.3

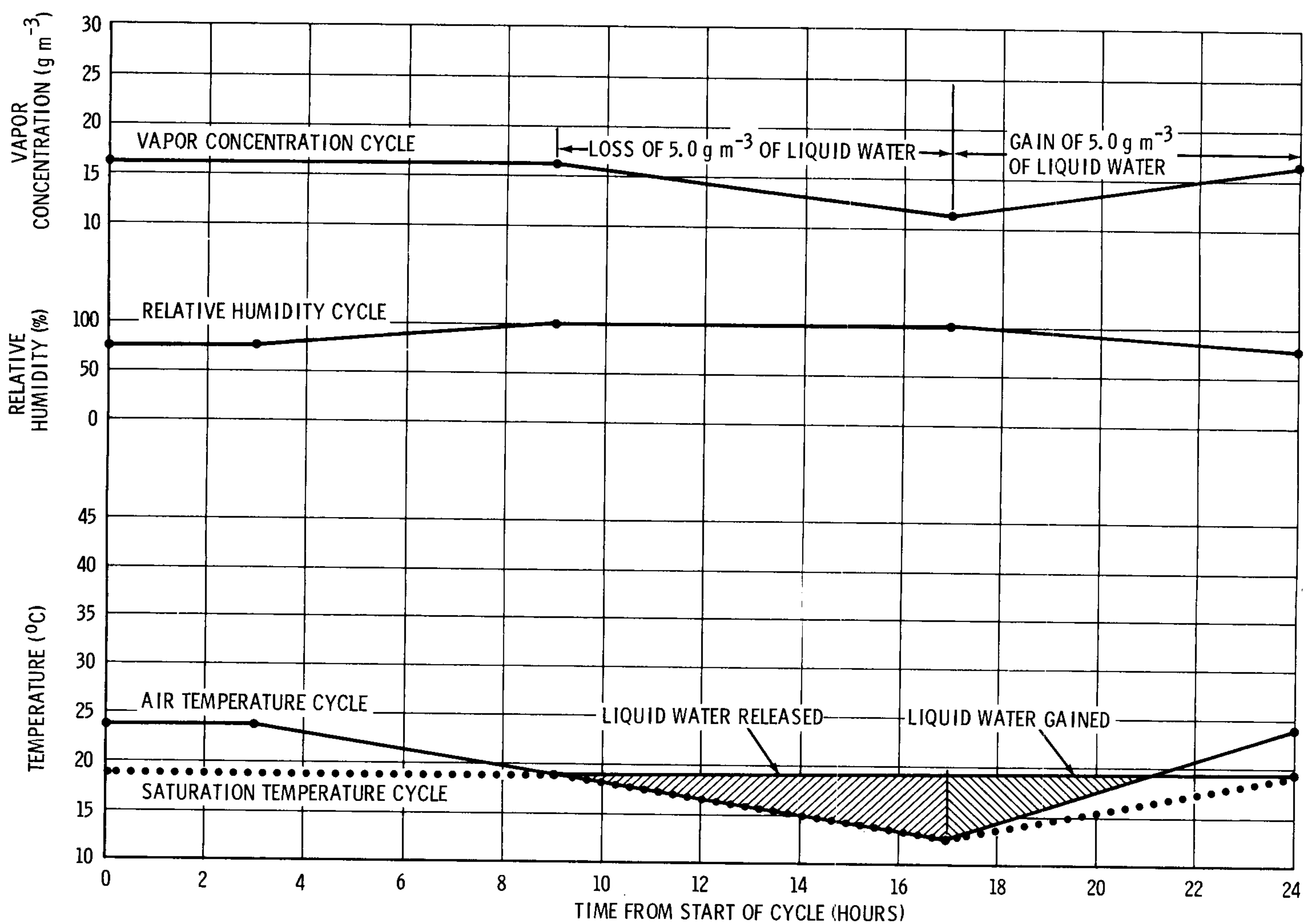

FIGURE 3.3 EXTREME HIGH VAPOR CONCENTRATION CYCLE FOR WESTERN TEST RANGE, WEST COAST TRANSPORTATION AND SACRAMENTO

d. White Sands Missile Range: This area is located at 1216 meters (4000 ft) above sea level, and is on the eastern side of higher mountains. The mean annual rainfall of 250 cm (10 inches) is rapidly absorbed in the sandy soil. Fog rarely occurs. Therefore, at this location, a high-vapor concentration need not be considered.

3.2.2 Low Vapor Concentration at Surface.

3.2.2.1 Introduction. Low water-vapor concentration can occur at very low or at high temperatures when the air is very dry. In both cases, the dew points are very low. However, in the case of low dew points and high temperatures, the relative humidity is low. When any storage area or compartment of a vehicle is heated to temperatures well above the ambient air temperature (such as the high temperatures of the storage area in an aircraft standing on the ground in the sun), the relative humidity will be even lower than the relative humidity of the ambient air. These two types of low water-vapor concentrations have entirely different environment effects. In the case of low air temperatures, ice or condensation may form on equipment while in the high temperature-low humidity condition; organic materials may dry and split or otherwise deteriorate. When a storage area (or aircraft) is considerably warmer than the ambient air (even when the air is cold), the drying increases even more. Low relative humidities may also result in another problem — that of static electricity. Static electrical charges on equipment may ignite fuel or result in shocks to personnel when discharged. Because of this danger two types of low water-vapor concentrations (dry extremes) are given for the surface.

3.2.2.2 Surface Extremes of Low Vapor Concentration.

a. Huntsville, River Transportation, Wallops Test Range, and White Sands Missile Range:

(1) A vapor concentration of 2.1 g m^{-3} (0.9 gr ft^{-3}), with an air temperature of -11.7°C (+11°F) and a relative humidity between 98 and 100 percent for a duration of 24 hours, must be considered.

(2) A vapor concentration of 4.5 g m^{-3} (2.0 gr ft^{-3}), corresponding to a dew point of -1.1°C (30°F) at an air temperature of 28.9°C (84°F) and a relative humidity of 15 percent occurring for 6 hours each 24 hours, and a maximum relative humidity of 34 percent at an air temperature of 15.6°C (60°F) for the remaining 18 hours of each 24 hours for a 10-day period, must be considered.

b. New Orleans, Gulf Transportation, Panama Canal Transportation, and Eastern Test Range:

(1) A vapor concentration of 4.2 g m^{-3} (1.8 gr ft^{-3}), with an air temperature of -2.2° C (28° F) and a relative humidity of 98 to 100 percent for a duration of 24 hours, must be considered.

(2) A vapor concentration of 5.6 g m^{-3} (2.4 gr ft^{-3}) corresponding to a dew point of 2.2° C (36° F) at an air temperature of 22.2° C (72° F) and a relative humidity of 29 percent occurring for 8 hours, and a maximum relative humidity of 42 percent at an air temperature of 15.6° C (60° F) for the remaining 16 hours of each 24 hours for 10 days, must be considered.

c. Western Test Range:

(1) A vapor concentration of 4.2 g m^{-3} (1.8 gr ft^{-3}), with an air temperature of -2.2° C (28° F) and a relative humidity of 98 to 100 percent for a duration of 24 hours, must be considered.

(2) A vapor concentration of 4.8 g m^{-3} (2.1 gr ft^{-3}), corresponding to a dew point of 0.0° C (32° F) at an air temperature of 37.8° C (100° F) and a maximum relative humidity of 26 percent at an air temperature of 21.1° C (70° F) for the remaining 20 hours of each 24 hours for 10 days, must be considered.

d. West Coast Transportation and Sacramento:

(1) A vapor concentration of 3.1 g m^{-3} (1.4 gr ft^{-3}), with an air temperature of -6.1° C (21° F) and a relative humidity of 98 to 100 percent for a duration of 24 hours, must be considered.

(2) A vapor concentration of 10.1 g m^{-3} (4.4 gr ft^{-3}), corresponding to a dew point of 11.1° C (52 °F) at an air temperature of 37.8° C (100° F) and a relative humidity of 22 percent occurring for 4 hours each 24 hours, and a maximum relative humidity of 55 percent at an air temperature of 21.1° C (70° F) for the remaining 20 hours of each 24 hours for 10 days, must be considered.

3.2.3 Compartment Vapor Concentration at Surface.

A low water-vapor concentration extreme of 10.1 g m^{-3} (44. gr ft^{-3}), corresponding to a dew point of 11.1° C (52 °F) at a temperature of 87.8 °C (190° F) and a relative humidity of two percent occurring for one hour, a linear change over a four-hour period to an air temperature of 37.8° C (100°F) and a relative humidity of 22 percent occurring for 15 hours, then a linear change over a four-hour period to the initial conditions, must be considered at all locations.

3.3 Vapor Concentration at Altitude.

In general, the vapor concentration decreases with altitude in the troposphere because of the decrease of temperature with altitude. The data given in this section on vapor concentration are appropriate for design purposes.

3.3.1 High Vapor Concentration at Altitude.

The following table present the relationship between maximum vapor concentration and the associated temperature normally expected as a function of altitude (Ref. 3.7).

a. Maximum Vapor Concentrations for Eastern Test Range, Table 3.1.

b. Maximum Vapor Concentrations for Wallops Test Range, Table 3.2.

c. Maximum vapor concentrations for White Sands Missile Range, Table 3.3.

TABLE 3.1. MAXIMUM VAPOR CONCENTRATION FOR EASTERN TEST RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Maximum Vapor Concentration	
(km)	(ft)	($g\ m^{-3}$)	($gr\ ft^{-3}$)	(°C)	(°F)
SRF (0.005 MSL)	(16)	27.0	11.8	30.5	87
1	3,300	19.0	8.3	24.5	76
2	6,600	13.3	5.8	18.0	64
3	9,800	9.3	4.1	12.0	54
4	13,100	6.3	2.8	5.5	42
5	16,400	4.5	2.0	-0.5	31
6	19,700	2.9	1.3	-6.8	20
7	23,000	2.0	0.9	-13.0	9
8	26,200	1.2	0.5	-20.0	-4
9	29,500	0.6	0.3	-27.0	-17
10	32,800	0.3	0.1	-34.5	-30
16.2	53,100	0.025	0.01	-57.8	-72
20	65,600	0.08	0.03	-47.8	-54

TABLE 3.2. MAXIMUM VAPOR CONCENTRATION FOR WALLOPS TEST RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Maximum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SRF (0.002 MSL)	(8)	22.5	9.8	27.5	81
1	3,300	20.0	8.7	26.1	79
2	6,600	13.9	6.1	17.2	63
3	9,800	10.3	4.5	12.8	55
4	13,100	7.4	3.2	7.8	46
5	16,400	6.0	2.6	2.8	37
6	19,700	3.9	1.7	-1.1	30
7	23,000	2.6	1.1	-5.0	23
8	26,200	1.7	0.7	-11.1	12
9	29,500	0.9	0.4	-17.8	0
10	32,800	0.4	0.2	-27.8	-18
16.5	54,100	0.08	0.03	-47.2	-44
20	65,600	0.09	0.04	-46.2	-43

TABLE 3.3. MAXIMUM VAPOR CONCENTRATION FOR WHITE SANDS MISSILE RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Maximum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(° C)	(°F)
SRF (1.2 MSL)	(3,989)	16.0	7.0	21.5	70
2	6,600	13.2	5.8	18.9	66
3	9,800	9.0	3.9	12.8	55
4	13,100	6.8	3.0	7.8	46
5	16,400	4.9	2.1	2.2	36
6	19,700	3.4	1.5	-2.2	28
7	23,000	2.2	1.0	-10.0	14
8	26,200	1.3	0.6	-16.1	3
9	29,500	0.6	0.3	-22.8	-9
10	32,800	0.2	0.1	-30.0	-22
16.5	54,100	0.08	0.03	-47.8	-44
20	65,600	0.05	0.02	-52.2	-47

3.3.2 Low Vapor Concentration at Altitude

The values presented as low extreme vapor concentrations in the following tables are based on data measured by standard radiosonde equipment.

a. Minimum Vapor Concentrations for Eastern Test Range, Table 3.4.

b. Minimum Vapor Concentrations for Wallops Test Range, Table 3.5.

c. Minimum Vapor Concentrations for White Sands Missile Range, Table 3.6.

TABLE 3.4. MINIMUM VAPOR CONCENTRATIONS FOR EASTERN TEST RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Minimum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SRF (0.005 MSL)	(16)	4.0	1.7	29	84.2
1	3,300	0.5	0.2	6	42.8
2	6,600	0.2	0.1	0	32.0
3	9,800	0.1	0.04	-11	12.2
4	13,100	0.1	0.04	-14	6.8

TABLE 3.5. MINIMUM VAPOR CONCENTRATION FOR WALLOPS TEST RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Minimum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SRF (0.002 MSL)	(8)	0.5	0.2	-4	24.8
1	3,300	0.3	0.1	-11	12.2
2	6,600	0.2	0.1	-17	1.4
3	9,800	0.2	0.1	-23	-9.4
4	13,100	0.2	0.1	-31	-23.8
5	16,400	0.1	0.04	-39	-38.2
7.5	24,600	0.08	0.03	-47	-43.9
10	32,800	0.017	0.007	-61	-51.7

TABLE 3.6. MINIMUM VAPOR CONCENTRATION FOR WHITE SANDS MISSILE RANGE

Geometric Altitude		Vapor Concentration		Temperature Associated with Minimum Vapor Concentration	
(km)	(ft)	(g m^{-3})	(gr ft^{-3})	(°C)	(°F)
SRF (1.2 MSL)	(3,989)	1.2	0.5	-1	30.2
2	6,600	0.9	0.4	-5	23.0
3	9,800	0.6	0.3	-12	10.4
4	13,100	0.4	0.2	20	-4.0
5	16,400	0.2	0.1	-26	-4.8
6	19,700	0.1	0.04	-36	-37.8
7	23,000	0.09	0.03	-42	-41.1
8	26,200	0.07	0.03	-49	-45.0
9	29,500	0.03	0.01	-55	-48.3
10	32,800	0.02	0.01	-60	-51.1

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SECTION IV. PRECIPITATION

By

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4.1 Definitions. (Ref. 4.1)

Precipitation is defined as all forms of hydrometeors, whether liquid or solid, which are free in the atmosphere and which may or may not reach the ground. Accumulation is reported in inches of depth for liquid, or in inches of depth of water equivalent, for frozen water particles.

Snow is defined as all forms of frozen precipitation except large hail; it encompasses snow pellets, snow grains, ice crystals, ice pellets, and small hail.

Hail is precipitation in the form of balls or irregular lumps of ice, and is always produced by convective clouds. Through established convention, the diameter of the ice must be 5 mm or more, and the specific gravity between 0.60 and 0.92 to be classified as hail.

Ice pellets are precipitation in the form of transparent, more or less globular, hard grains of ice under 5 mm in diameter, that rebound when striking hard surfaces.

Small hail is precipitation in the form of semitransparent, round or conical grains of frozen water under 5 mm in diameter. Each grain consists of a nucleus of soft hail (ball of snow) surrounded by a very thin ice layer. They are not crisp and do not usually rebound when striking a hard surface.

Precipitable water is the total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified levels. It is usually given as inches of water (if vapor were completely condensed).

4.2 Rain.

Although most long-duration rainfall world records (monthly or yearly) have been for regions far removed from the areas of interest for large space vehicle launch and test operations, the world maximum amount of short-duration rainfall has occurred in the thunderstorms or tropical storms within the United States, in the Gulf of Mexico, or in Canal Zone areas. A study of the rate of rainfall, compared with duration, shows that the average rate (per hour) decreases as the duration increases. Equipment must withstand both prolonged soaking rain and brief downpours. The following precipitation values at an air temperature between 21.1°C (70°F) (night) and 32.2°C (90°F) (day) are adequate for most design problems, although considerably less than world record extremes.

4.2.1 Rainfall at Surface.

a. Extreme Amounts. The design rainfall for the areas of interest are as follows:

(1) Huntsville, Eastern Test Range, Western Test Range, Sacramento, West Coast Transportation, River Transportation, White Sands Missile Range, and Wallops Test Range, rainfall information is given in Table 4.1.

(2) Gulf Transportation, Panama Canal Transportation, and New Orleans rainfall information is given in Table 4.2.

TABLE 4.1 DESIGN RAINFALL RATES FOR HUNTSVILLE, EASTERN TEST RANGE, WESTERN TEST RANGE, SACRAMENTO, WEST COAST TRANSPORTATION, RIVER TRANSPORTATION, WALLOPS TEST RANGE, AND WHITE SANDS MISSILE RANGE

Time Period	1 min	1 hour	24 hours
Total Amount (mm)	7.6	64	305
(in.)	0.3	2.5	12
Rate (mm/hr)	456	64	13
(in./hr)	18.0	2.5	0.5
Average Drop Diameter (mm)	3.8	2.6	2.0
Average Rate of Fall (m/sec)	8.5	7.3	6.4
Peak Wind Speed (m/sec)	30	20	20
Average Wind Speed (m/sec)	17	6	4.5

TABLE 4.2 DESIGN RAINFALL RATES FOR GULF TRANSPORTATION, PANAMA CANAL, AND NEW ORLEANS

Time Period	1 min	1 hour	24 hours
Total Amount (mm)	12.7	102	508
(in.)	0.5	4	20
Rate (mm/hr)	762	102	21
(in./hr)	30.0	4.0	0.8
Average Drop Diameter (mm)	4.1	2.9	1.8
Average Rate of Fall (m/sec)	8.8	7.6	6.1
Peak Wind Speed (m/sec)	30	20	20
Average Wind Speed (m/sec)	17	6	4.5

b. Probability of Precipitation Not Exceeding Selected Amounts. The probability of precipitation not exceeding selected amounts on any one day was determined by a study of six years of data at Cape Kennedy, Florida. This information is given in Table 4.3.

4.2.2 Rainfall at Altitude.

Rainfall rates normally decrease with altitude when rain is striking the ground. The rainfall rates at various altitudes in percent of the surface rates are given in Table 4.4 for all areas (Ref. 4.2).

The precipitation above the ground is generally colder than at the ground and frequently occurs as supercooled drops which can cause icing on any object moving through the drops. Such icing can be expected to occur when the air temperature is -2.2°C (28°F). The amount of icing (i.e., rate of formation) is related to the speed and shape of the object. For the geographic areas considered in this report, these conditions usually occur between 3 and 10 km altitude.

TABLE 4.3 PROBABILITY THAT PRECIPITATION WILL NOT EXCEED A SPECIFIC AMOUNT IN ANY ONE DAY, EASTERN TEST RANGE

AMOUNT (Inches)	MONTH					
	JAN %	FEB %	MAR %	APR %	MAY %	JUNE %
0.00	79.0	75.7	68.8	75.6	76.3	59.4
0.05	86.6	82.8	73.7	85.5	84.4	68.9
0.20	90.3	86.4	80.1	90.0	91.4	74.4
0.50	93.0	89.3	87.1	95.0	95.7	86.1
1.00	96.2	96.4	95.7	97.8	99.5	96.1
2.00	98.9	100.0*	98.9	100.0*	100.0*	98.9
5.00	100.0*	100.0*	99.5	100.0*	100.0*	100.0*

AMOUNT (Inches)	MONTH					
	JULY %	AUG %	SEPT %	OCT %	NOV %	DEC %
0.00	61.8	59.1	52.8	65.6	75.0	75.8
0.05	69.4	66.1	63.3	73.1	81.7	86.6
0.20	79.6	74.7	73.3	82.3	89.4	92.5
0.50	87.1	83.9	83.9	90.3	92.8	95.7
1.00	94.1	92.5	93.9	96.8	96.7	98.4
2.00	97.3	98.4	97.8	100.0*	100.0*	100.0*
5.00	100.0*	100.0*	100.0*	100.0*	100.0*	100.0*

* Although the available data records indicate no chance of exceeding certain amounts of precipitation during most of the months, it should be realized that the length of data studied is not long and that there is always a chance of any meteorological extreme of record being exceeded.

TABLE 4.4 DISTRIBUTION OF RAINFALL RATES WITH HEIGHT FOR ALL LOCATIONS

Height (Geometric) Above Surface (km)	Percent of Surface Rate
SRF	100
1	90
2	75
3	57
4	34
5	15
6	7
7	2
8	1
9	0.1
10 and over	< 0.1

4.3 Snow.

The accumulation of snow on a surface produces stress. For a flat horizontal surface, the stress is proportional to the weight of the snow directly above the surface. For long narrow objects, such as pipes or wires lying horizontally above a flat surface (which can accumulate the snow), the stress can be figured as approximately equal to the weight of the wedge of snow with the sharp edge along the object and extending above the object in both directions at about 45 degrees to the vertical. (In such cases, the snow load would be computed for the weight of the snow wedge above the object and not the total snow depth on the ground.) The weight of new fallen snow on a surface varies between 0.5 kg m^{-2} per cm of depth (0.25 lb ft^{-2} $in.^{-1}$) and 2.0 kg m^{-2} per cm of depth (1.04 lb ft^{-2} $in.^{-1}$), depending on the weather situation at the time of snowfall. When the amount is sufficient to be important in load design, the weight on the surface is near 1.0 kg m^{-2} cm^{-1} (0.52 lb ft^{-2} $in.^{-1}$). Snow on the ground becomes more dense, and the depth decreases with time.

4.3.1 Snow Loads at Surface.

Maximum snow loads for the following areas are:

a. Huntsville, Wallops Test Range, and River Transportation areas. For horizontal surfaces a snow load of 25 kg m^{-2} (5.1 lb ft^{-2}) per 24-hour period (equivalent to a 10-inch snowfall) to a maximum of 50 kg m^{-2} (10.2 lbft^{-2}) in a 72-hour period, provided none of the snow is removed from the surface during the period, should be considered for design purposes.

b. New Orleans, West Coast Transportation, White Sands Missile Range, and Sacramento areas. For horizontal surfaces, a maximum snow load of 10 kg m^{-2} (2.0 lb ft^{-2}) per one 24-hour period, should be considered for design purposes.

4.3.2 Snow Particle Size.

Snow particles may penetrate openings (often openings of minute size) in equipment and cause malfunction of mechanical or electrical components, either before or after melting. Particle size, associated wind speed, and air temperature to be considered are as follows:

a. Huntsville, Wallops Test Range, and River Transportation areas. Snow particles 0.1 mm (0.0039 in.) to 5 mm (0.20 in.) diameter; wind speed 10 m sec^{-1} (19 knots); air temperature -17.8°C (0°F).

b. New Orleans, West Coast Transportation, White Sands Missile Range, and Sacramento areas. Snow particles 0.5 mm (0.020 in.) to 5 mm (0.20 in.) diameter; wind speed 10 m sec^{-1} (19 knots); air temperature -5.0°C (23°F).

4.4 Hail.

Hail is one of the most destructive weather forces in nature, being exceeded only by hurricanes and tornadoes. Hail normally forms in extremely well-developed thunderstorms during warm weather and rarely occurs in winter months or when the air temperature is below 0°C (32°F). Although the average diameter of hailstones is 8 mm (0.31 in.) (Ref. 4.3), hailstones larger than 12.7 mm (0.5 in.) in diameter frequently fall, while stones 50 mm (2.0 in.) in diameter can be expected annually somewhere in the United States. The largest measured hailstone in the United States was 137 mm (5.4 in.) in diameter and had a weight of 0.68 kg (1.5 lb) (Refs. 4.4, 4.5 and 4.6). Three environmental effects on equipment must be considered:

The accumulation of hail, as with snow, stresses the object by its weight. Although hail has a higher density than snow, 2.4 kg m^{-2} cm^{-1} (1.25 lb ft^{-2} $in.^{-1}$), the extreme load from hail will not exceed the extreme snow load at any area of interest; therefore, the snow load design will adequately cover any hail loads expected.

Large hailstones, because of weight and velocity of fall, are responsible for structural damage to property (Ref. 4.7). To actually designate locations where hailstones, with specific sizes of hail, will fall is not possible. However, the following information can be used as a guide for design and scheduling (these values are most applicable to the design of ground support equipment and protective covering for the space vehicles during the transporting of vehicles between Huntsville and New Orleans). Hail as an abrasive is discussed in Section VI.

4.4.1 Hail at Surface.

a. Huntsville, River Transportation, Gulf Transportation, New Orleans, Wallops Test Range, and White Sands Missile Range.

(1) A maximum hailstone size of 50 mm (2 in.) in diameter with an occurrence probability of one time in 15 years.

(2) Damaging hailstorms occur most frequently between 3 p.m. and 9 p.m. during May through September. April is the month of highest frequency-of-occurrence of hailstorms for Huntsville, River Transportation, and Gulf Transportation. March is the month of highest frequency-of-occurrence of hailstorms for White Sands Missile Range, and May is the month of highest frequency-of-occurrence of hailstorms for Wallops Test Range.

(3) The period of large hail (over 25 mm in diameter) will not be expected to last more than 15 minutes and should have a maximum total accumulation of 50 mm (2 in.) for depth of hailstones on horizontal surfaces.

(4) Velocity of fall equals 30.5 m sec^{-1} (100 ft sec^{-1}) for each stone.

(5) Wind speed equals 10 m sec^{-1} (33 ft sec^{-1}).

(6) Density of hailstones equals 0.80 g cm^{-3} (50 lb ft^{-3}).

b. Eastern Test Range.

(1) A maximum hailstone size of 25.4 mm (1 in.) in diameter with an occurrence probability of one time in 30 years may be expected.

(2) Damaging hailstones occur most frequently between 3 p.m. and 9 p.m. during April through June. May is the month of highest frequency-of-occurrence for hailstorms.

(3) The period of large hail will not be expected to last more than 15 minutes and should have a maximum total accumulation of 12.5 mm (0.5 in.) for depth of hailstones on horizontal surfaces.

(4) Velocity of fall equals 20 m sec^{-1} (66 ft sec^{-1}) for each stone.

(5) Wind speed equals 10 m sec^{-1} (33 ft sec^{-1}).

(6) Density of hailstones equals 0.80 g cm^{-3} (50 lb ft^{-3}).

4.4.2 Distribution of Hail with Altitude.

Although it is not the current practice to design space vehicles for flight in thunderstorms, data on distribution with altitude are presented as an item of importance. The probability of hail increases with altitude from the surface to 5 km and then decreases rapidly with increasing height. Data on Florida thunderstorms, giving the number of times hail was encountered at various altitudes during aircraft flights (Ref. 4.8), are given in Table 4.5 for areas specified in paragraph 4.4.1.

TABLE 4.5 DISTRIBUTION OF HAIL WITH HEIGHT FOR ALL LOCATIONS (Ref. 4.8)

Height (Geometric) Above Surface (km)	Occurrence of Hail (percent of flights through thunderstorms)
2	0
3	3.5
5	10
6	4
8	3

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SECTION V. WIND*

By

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5.0 Introduction

The determination of a space vehicle's response to atmospheric disturbances cannot be reduced to the evaluation of one discrete set of response criteria, such as vehicle loads, but it must include many response parameters, the choice of criteria (parameters) depending upon the vehicle configuration and the specific mission. It is also impractical to use only one method for all phases of vehicle design. Therefore, the studies must be separated into their various phases, using different approaches and methods of evaluation, as the particular phase demands. Although not independent, these various phases include (1) preliminary design, (2) final structural design, (3) guidance and control system design and optimization (preliminary and final), and (4) establishment of limits and procedures for launch and flight operations. Thus, the proper selection, representation, and use of wind information require the skillfully coordinated efforts of aerospace meteorologists and engineers.

Winds are characterized by three-dimensional motions of the air, accompanied by large temporal and spacial variations. The characteristics of these variations are a function of synoptic conditions, atmospheric stability and season, as well as the geographic location of the launch site. It is necessary, therefore, to use good technical judgment and to consider the engineering application of the wind data in preparing criteria that are descriptive and yet concise. The wind environment affects the various vehicle design and operational problem areas in a different manner and requires a unique interpretation and application of the data for each analysis.

During the initial and intermediate phases of the development cycle, the synthetic ground and inflight wind criteria concept has its major value and contribution to the design. Although a certain overall vehicle performance capability in terms of probability may be mentioned as a guideline, it is not realistic to expect a design to be developed that will precisely meet this specified performance capability because of the many unknowns in the vehicle characteristics and design criteria. With the status of current space vehicle technology it is not possible to make, as a result of design procedures or tests,

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* This section contains considerable detail on development of the wind criteria and for use in mission analyses. Appendix A, page 5.227, summarizes a typical Space Vehicle Wind Criteria. This can also be used as an example in development of specific wind criteria specifications for future projects.

a candid statement about the specific calculated overall design risk or operational capability of a space vehicle. Therefore, it makes good engineering sense to establish a set of idealized or synthetic ground and inflight wind characteristics, which include such features as wind magnitude versus height of profile, gust factors, turbulence spectra, wind shears, and directional features of the wind. They may then be referenced and used in a consistent manner to establish the preliminary and intermediate designs necessary to ensure accomplishment of the expected range of missions for the vehicle development. Furthermore, they assist in isolating those aspects of the wind structure critical to a vehicle design area.

It is currently the accepted practice, which is further endorsed by this report, to use the synthetic wind criteria approach described herein for NASA space vehicle developments during the preliminary and intermediate design phases. These criteria should be carefully formulated to ensure that the appropriate data are employed in vehicle construction and use in order to be consistent with the degree of resolution available from other vehicle input criteria and the structural/control system simulation models. The synthetic wind profile features may readily be employed to isolate specific design problem areas without resorting to elaborate computations, which are not justified with respect to the other unknown system parameters. In addition, by use of this approach, the designer may, for example, closely approximate the steady-state wind limits for a design or operational configuration. The other features of the wind forcing function may be accommodated with a specified risk level. Using these steady-state wind limits, a multitude of mission analysis studies can rapidly be accomplished relative to launch windows, etc., using the entire available historical record from the steady-state inflight wind (rawinsonde) or ground wind measurement systems. Such records, described in this section, are available for all major launch areas. These statistical records and the synthetic profile concept are also adequate for bias of pitch and yaw programs, range safety studies, preliminary abort analysis, and related space vehicle operational problems.

When adequately documented and referenced, the synthetic wind criteria concept provides a powerful tool for ensuring consistent design inputs for all users, and it essentially avoids the problem of any oversight errors, which may be very costly to correct in later development phases. Furthermore, they enable various design teams to simultaneously conduct studies and to compare their results on a common basis.

During the latter stages of a vehicle development program, when adequate vehicle response data are available, it is considered highly desirable, if not mandatory, to simulate the vehicle flight and response to actual wind velocity profiles. However, these wind profiles should contain an adequate frequency content through at least the vehicle's first bending moment frequency. Otherwise, only another preliminary design approximation is derived, and no specific new design information is obtained relative to the synthetic wind profile concept. The current acceptable practice is to use a selection of detailed inflight wind profiles (resolution to at least one cycle per 100 meters) obtained by either the smoke trail/photographic or the FPS-16 Radar/Jimsphere technique for the major launch range(s) of concern. These data and their availability are discussed elsewhere in this document. The number of flight performance simulations and detailed wind profiles selected will depend upon the particular vehicle and the design problem involved and how well the vehicle characteristics were established during the preliminary and intermediate design work. The vehicle simulation to detailed inflight wind profiles should constitute, essentially, a verification of the design. It should provide the design organization with added confidence in the capability of the vehicle design and enable them to isolate any critical areas requiring further indepth study to refine the control and structural systems. The profiles used should constitute a selection from the available detailed wind profile records. This selection should be based upon the mission objectives and should be established through discussions between the affected design group and the cognizant NASA organization concerned with wind criteria.

For the prelaunch simulation and flight evaluation of a space vehicle relative to the inflight wind environment, it is recommended that established ground wind reference height anemometers and detailed inflight wind profiles measured by the FPS-16 Radar/Jimsphere system be used to provide adequate resolution, accurate data, timely measurements, and a rapid reduction scheme, ensuring a prompt input into the prelaunch simulation program and flight evaluation. It is during the prelaunch phase that accurate and near real time wind data are mandatory, especially if an almost critical launch wind condition exists. The consequences are obvious. Furthermore, adequate flight evaluations cannot be made without timely and accurate launch wind data.

The above remarks are intended to reflect the currently accepted practices for use of available wind data in the design, development, mission analysis, prelaunch and flight evaluation phases of a space vehicle program. It is apparent that the wind input employed in terms of resolution, accuracy, representativeness, etc. will depend upon the status of the space vehicle design's use of reliable data that are consistent with the design requirements at the particular stage of development. An understanding of the use and limitations of wind data in making engineering decisions is required to design a space vehicle for a given mission objective(s). This can only be accomplished through a team relationship with the design engineer and meteorologist concerned with wind criteria.

5.4

The information given in Section V constitutes guidelines for data that are applicable to various design problems. The selected risk levels employed to determine those characteristics of the ground and inflight winds used in the design are a matter of organizational design philosophy and management decision. To maximize performance flexibility, it is considered best to utilize those data associated with the minimum acceptable risk levels. In addition, such critical mission related parameters as vehicle free-standing period, launch windows, and launch turnaround period should be carefully considered. Initial design work on the basis of nondirectional ground or inflight winds is recommended unless the vehicle and its mission are well-known and the exact launch azimuth and time(s) are established and rigidly adhered to throughout the project. In designs that use directional wind criteria, rather severe wind constraints can result if the vehicle is used for another mission or in another configuration. Therefore, caution must be exercised in the employment of wind data to ensure consistency with the physical interpretation relative to the specific design problem. References 5.1, 5.2, 5.3, 5.4, and 5.5 are a few of the many works related to the problems involved in using wind in space vehicle design programs.

5.1 Definitions

The following terms are used in this section with the meanings specified here.

5.1.1 Ground Winds.

Average Wind Speed: The mean wind speed measured at a fixed height and for some selected time interval depending upon the intended use of the data. They are sometimes referred to as quasi-steady-state winds.

Gust: A sudden increase in the ground wind speed. It is frequently stated with respect to a mean wind speed. A sudden decrease in the wind speed is sometimes referred to as a gust (negative).

Ground Winds: For purposes of this document, winds below a height of about 150 meters above the natural grade.

Free-Standing Winds: The ground winds that are applied when the vehicle is standing on the launch pad (with or without fuel), after any service structure, support, or shelter has been removed.

Gust Factor: The ratio of peak ground wind speed to the average or mean ground wind speed over a finite time period.

Hurricanes: Severe tropical storms (usually over water) having ground winds of 64 knots (33 ms^{-1}) or greater. These storms normally cover thousands of square miles.

Launch Design Winds: Maximum ground winds for which the vehicle can be launched, normally involving a stated design wind at a reference height plus the associated 3 σ ($\sim$ 99.9 %) wind profile shape.

Peak Wind Speed: The maximum (essentially, instantaneous) wind speed measured during a specified reference period, such as hour, day, or month.

Steady-State or Average Wind Speed: The mean, over a period of about ten minutes or longer, of the wind speed measured at a fixed height. It is usually assumed constant as, for example, in spectrum calculations. Thus, the steady-state or average wind should be the mean which filters out, over a sufficient duration, the effects that would very definitely contribute to random response of vehicle.

Reference Height (ground winds): The height above the ground surface (natural grade) at which wind speeds are referred for establishing climatological conditions, reference for construction of design wind profiles, and for statements of a space vehicle's wind constraints.

5.1.2 Inflight Winds.

Design Wind Speed Profile Envelopes: Envelopes of scalar or component wind speeds representing the extreme steady-state inflight wind value for any selected altitude that will not be exceeded by the probability selected for a given reference period.

Inflight Winds: Winds above a height of about 150 meters.

Steady-State Inflight Wind: In this document, it refers to the mean wind speed as computed by the rawinsonde system and averaged over approximately 600 meters in the vertical direction.

Reference Height (inflight winds): The height referred to in constructing a synthetic wind profile.

Scale-of-Distance: The vertical distance between two wind measurements (thickness of layer) used in computing wind shears.

Serial Complete Data: The completion of a sample of data (selected period) by filling in (inserting) missing data by interpolation, by extrapolation, or by use of data from nearby stations. Such an operation is performed by professional meteorological personnel familiar with the data.

Shear Build-Up Envelope: The curve determined by combining the reference height wind speed from the wind speed profile envelope with the shears (wind speed change) below the selected altitude (reference height). The shear build-up envelope curve starts at zero altitude and zero wind speed and ends at the design wind speed value at the referenced altitude for inflight wind response studies.

Synthetic Wind Speed Profile: A design wind profile representing the combination of a reference height design wind with associated envelope shears (wind speed change) and gusts for engineering design and mission analysis purposes.

Wind Shear/Wind Speed Change Envelopes: Value of the change in wind speed over various increments of altitude (100 m to 5000 m) are computed for a given probability level and associated reference height or related wind speed value at the reference height. These values are combined, and an envelope of the wind speed change is found to use in constructing synthetic wind profiles. Usually the 99 percentile or larger probability levels are used for design purposes.

5.1.3 General.

Calm Winds: A wind speed of less than one knot (0.5 ms^{-1}).

Component Wind Speed: The equivalent wind speed that any selected wind vector would have if resolved to a specific direction, that is, a wind from the northeast (45-degree azimuth) of 60 ms^{-1} would have a component from the east (90-degree azimuth) of $(60) \cos 45° = 42.4 \text{ ms}^{-1}$. This northeast wind would be equivalent to a 42.4 ms^{-1} head wind on the vehicle, if the vehicle is launched on an east (90-degree) azimuth.

Percentile: The percentage of time that a variable does not exceed a given magnitude. Section I, page 1.8 of this document should also be consulted for more details on percentiles and probabilities. The following relationships exist between probabilities and percentiles in a normal distribution function:

Probability Level	Percentile
Minimum	0.000
Mean - 3σ (standard deviation)	0.135
Mean - 2σ (standard deviation)	2.275
Mean - 1σ (standard deviation)	15.866
Mean $\pm 0\sigma$ (standard deviation)	50.000
Mean + 1σ (standard deviation)	84.134
Mean + 2σ (standard deviation)	97.725
Mean + 3σ (standard deviation)	99.865
Maximum	100.000

Scalar Wind Speed: The magnitude of the wind vector without regard to direction.

Wind Direction: The direction from which the wind is blowing, measured clockwise from true North.

Windiest Monthly Reference Period: Any month that has the highest wind speeds at a given probability level.

Wind Shear: The difference between wind speeds measured at two specific locations, that is, the rate of change of wind speed with height (vertical wind shear) or distance (horizontal wind shear).

5.2 Ground Winds (0-150 meters)

5.2.1 Introduction.

Ground winds for space vehicle application are defined in this report as those winds in the lowest 150 meters of the atmosphere. A vehicle positioned vertically on-pad may penetrate this entire region. Therefore, it is necessary to model the structure of the atmosphere in the vehicle's vicinity. This requirement exists because of the complicated and possibly critical manner in which a vehicle responds to certain wind profile configurations, both while stationary on the launch pad and while in the first few seconds of launch, especially for vehicle clearance of the service structure. The problem, therefore, may be resolved initially into the basic identification of the wind speed profile and its behavior within the 150-meter layer.

Until recently, several years of average wind speed data measured at the 10-meter level above ground were the only available records with which to develop design and launch ground wind profile criteria. With the evolution of larger and more sophisticated space vehicles, the requirements for more adequate wind profile information have increased. For example, to fulfill the need to provide improved ground wind data, a 150-meter meteorological tower facility was constructed on Merritt Island, Kennedy Space Center, Florida, in close proximity to the Apollo/Saturn launch complex 39. Wind and temperature profile data from this facility have been used in many new studies that have contributed to a significant portion of the information in this chapter on wind profile shaping, gusts, and turbulence spectra.

Since ground wind data are applied by space vehicle engineers in various ways and degrees, dependent upon the specific problem, there are, consequently, several analytical techniques utilized to obtain the results presented here. Program planning, for instance, requires considerable climatological insight, discussed in Sections 5.2.3 and 5.2.4, to determine the frequency and persistence distributions for wind speeds and wind directions. However, for design purposes the space vehicle must withstand certain unique predetermined structural loads that are generated from exposure to known peak ground wind conditions. The design ground wind profiles are described in Section 5.2.5, and the ground wind turbulence spectra model is presented in Section 5.2.6. These data contribute to the development of the ground wind models. Surface roughness, thermal environment, and various transient local and large-scale meteorological systems influence the ground wind environment for each launch site. Other pertinent ground wind studies have been performed on wind gusts and associated duration times (see Section 5.2.7) that directly affect the response characteristics of space vehicles.

5.2.2 Measurement of Ground Winds.

Ground wind speeds and directions are normally measured by anemometers and wind vanes, respectively. Operational anemometers and wind vanes are common both as single sensing units and as separate units for speed and direction sensing. The single sensing unit resembles an airplane fuselage with a tail fin and a propeller. Wind direction is provided by the fuselage and tail fin, while the propeller provides a measure of wind speed. This system, as is common to all wind systems of this type, has a relatively slow response with respect to wind speed; that is, it will respond to (measure) only about 50 percent of the amplitudes of wind gusts with a period of 4 seconds when the mean wind speed is 5 ms^{-1} (Ref. 5.6).

The separate speed and direction type of unit consists of cups to measure wind speed and a separate vane to measure wind direction. In general, the cup-vane systems have a better frequency response than the single sensing unit. For example, the cup-vane system is capable of indicating about 50 percent of the amplitudes of wind gusts with a period of 1 second when the mean wind speed is 5 ms^{-1} (Ref. 5.7). The response of the vane to wind direction is generally characterized by the vane's damping ratio. A vane can be fabricated to have a given damping ratio. For the most part, the vanes used to obtain wind direction at Marshall Space Flight Center and at Kennedy Space Center have a damping ratio of 0.6.

When measuring average or mean wind speeds for time averages of several minutes, either of the above anemometer types provide reliable data. However, because of their slow responses, neither is suited for resolving gust frequencies above approximately one cycle per second. Most climatological wind measurement records available today used to establish quasi-steady-state winds are based on these sensors which are adequate for this purpose.

Higher frequency gusts are usually measured by research oriented anemometers. These anemometers, which are usually composed of hot wires, hot film, sonics, bivanes, etc., are not commonly used because of operational and other difficulties. Some of the higher frequency gust data are based primarily upon measurements from anemometers of the research type. High-frequency gust data do not exist in large quantities and are generally available only from the original investigator.

Measurement of wind speeds and directions presents an additional problem; that is, it is usually necessary to place the instrument in the airstream being measured and to install towers or poles in the vicinity to hold the measuring instruments. Such obstructions to the natural environment may cause interference to the normal air flow and can result in measurements that do not represent the true air flow. See References 5.8 and 5.9 for more details of this problem.

5.2.3 Ground Wind Climatology for the Eastern Test Range, Florida.

All wind observations described in this section were made on Cape Kennedy at a reference height of 10 meters* above natural grade. The hourly peaks were extracted from continuous wind records, the peak being the highest instantaneous wind speed (and associated direction) occurring during each hour. Steady-state winds were averaged over approximately two minutes and recorded at hourly intervals.

5.2.3.1 General Characteristics.

Some general characteristics of the Cape Kennedy surface winds are illustrated in Figures 5.2.1 thru 5.2.5. (The maximum speeds shown occurred during the period Sept. 1958 - Dec. 1966, exclusive of hurricanes.) First, the diurnal change of wind speeds — light in the morning and stronger in the afternoon — is clearly shown by the hourly variability of percentiles in Figures 5.2.1 and 5.2.2. The greater diurnal wind speed variation in July is evidence of the association between wind generating forces and wind speeds. In summer, with weak pressure gradients, the diurnal thermal effects control the wind regime. Of course, during this season, afternoon thunderstorms produce most strong winds. In winter, the pressure gradient is stronger, thermal effects are less pronounced, and strong winds are more evenly distributed throughout the day.

Figures 5.2.3 and 5.2.4 also illustrate the diurnal variation of winter (January) and summer (July) peak wind speeds. From these cumulative percentage frequency plots, it is apparent that moderately strong winds, $\approx$ 15-25 knots, occur more frequently in winter, while the possibly destructive winds of > 25 knots are more likely during a summer afternoon.

Secondly, the seasonal change of surface peak wind speeds, Figure 5.2.5, is less than some diurnal changes. All hours of the day were combined to produce the percentiles for the monthly reference periods shown here. Consequently, we see a slight decrease in the summer wind speeds.

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* For design and reference purposes, the 18.3 meter reference level wind values are used in engineering documentation for Kennedy Space Center based on agreements with Marshall Space Flight Center. A reference level should always be stated when discussing ground winds.

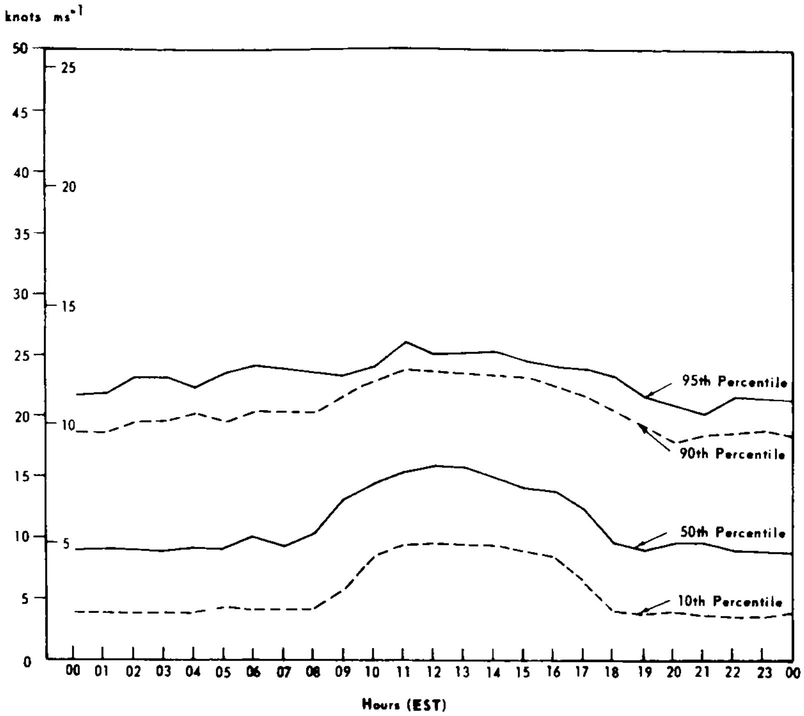

FIGURE 5.2.1 JANUARY HOURLY PEAK GROUND WIND SPEED PERCENTILES VERSUS TIME OF DAY (10-m level), CAPE KENNEDY, FLORIDA

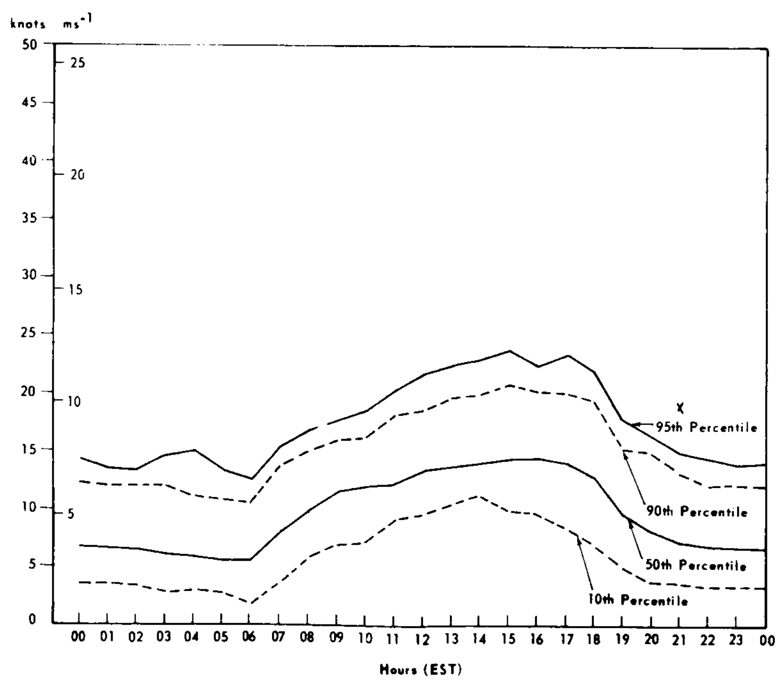

FIGURE 5.2.2 JULY HOURLY PEAK GROUND WIND SPEED PERCENTILES VERSUS TIME OF DAY (10-m level), CAPE KENNEDY, FLORIDA

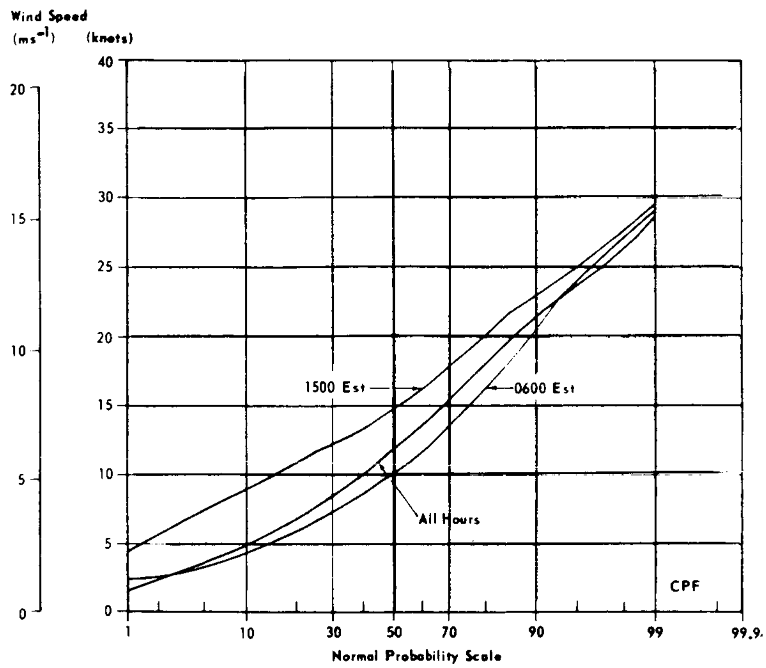

FIGURE 5.2.3 JANUARY HOURLY PEAK GROUND WIND SPEED CUMULATIVE PERCENTAGE FREQUENCY (10-m level), CAPE KENNEDY, FLORIDA

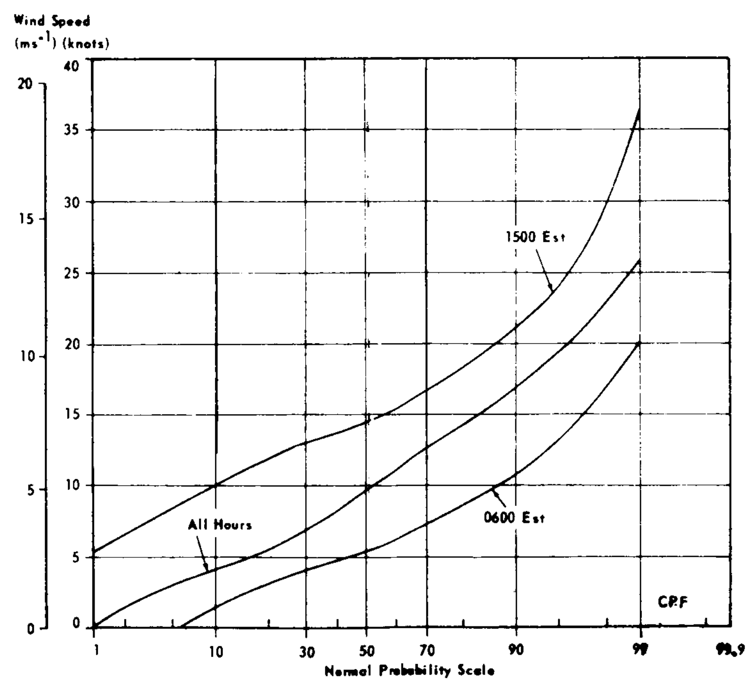

FIGURE 5.2.4 JULY HOURLY PEAK GROUND WIND SPEED CUMULATIVE PERCENTAGE FREQUENCY (10-m level), CAPE KENNEDY, FLORIDA

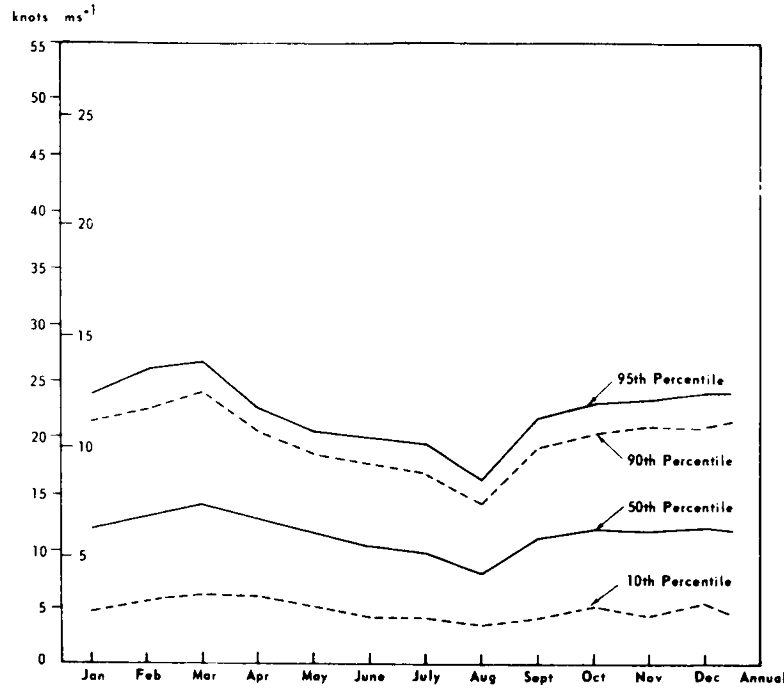

FIGURE 5.2.5 MONTHLY PERCENTILE (all hours) HOURLY PEAK GROUND WIND SPEED (10-m level), CAPE KENNEDY, FLORIDA

Although the general characteristics of the ground winds apply equally to peak and steady-state, there is a very significant difference in speed. For example, after combining all hours in January, 90 percent of the steady-state winds were $\leq$ 14 knots, while 90 percent of the hourly peaks were $\leq$ 22 knots. The occurrence of the peak wind speed is generally the more important and meaningful statistic to aerospace problems. Also, operationally, it is much easier to monitor peak wind speeds.

5.2.3.2 Frequency of Calm Winds.

Generally, design criteria wind problems are concerned with high wind speeds, but a condition of calm or very low wind speeds may also be important. For example, with no wind to disperse venting vapors such as LOX, a poor visibility situation could develop around the vehicle. Table 5.2.1 shows the frequency of calm winds at the 10-meter reference height as a function of time of day and month. The maximum percentage of calms appears in the summer and during the early morning hours, with the minimum percentage appearing throughout the year during the afternoon.

5.2.3.3 Standard Vector Distribution Wind Rose.

Although peak wind speeds are generally more useful, some engineering problems require steady-state wind inputs. Because the conventional wind roses have few applications to aerospace problems, it was decided to depict the steady-state surface winds by means of the Standard Vector Distribution Wind Rose (Ref. 5.10). These circular or elliptical representations are considered superior to conventional wind roses, although ground winds, in general, consist of mixed distributions.

TABLE 5.2.1 FREQUENCY (%) OF CALM WIND AT THE 10-METER LEVEL, CAPE KENNEDY, FLORIDA

Hour EST	Month												Annual
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
00	4.8	4.0	3.6	1.3	7.3	9.2	11.7	13.7	6.3	6.9	6.3	6.0	6.8
01	2.8	1.3	2.4	1.7	8.9	8.3	10.9	14.1	7.1	4.8	6.3	6.5	6.3
02	4.8	2.2	3.6	2.9	7.7	10.0	11.7	13.7	10.4	7.3	5.4	4.0	7.0
03	5.2	3.1	2.0	3.8	8.5	12.1	11.3	17.3	12.1	5.2	2.9	3.2	7.3
04	2.8	4.4	2.4	3.8	5.2	13.8	14.5	13.7	10.8	5.2	4.6	2.8	7.0
05	4.4	4.0	3.2	2.9	9.7	16.3	15.3	18.5	13.3	3.6	4.6	4.4	8.4
06	4.4	4.0	4.4	2.9	8.9	16.3	19.8	19.0	13.3	3.2	5.0	5.2	8.9
07	3.6	4.4	4.8	6.3	10.5	16.7	18.1	19.4	15.8	4.4	5.4	5.6	9.6
08	3.6	6.6	6.5	2.9	2.4	5.4	6.0	6.9	4.6	4.0	8.8	4.4	5.2
09	3.6	1.8	2.0	2.1	2.8	3.8	4.8	1.6	4.2	0.8	4.6	5.6	3.1
10	0.4	1.8	1.6	1.7	0.4	3.8	4.0	2.8	2.1	*	1.3	2.4	1.8
11	0.4	1.3	1.2	1.7	0.8	1.3	2.4	0.8	2.9	0.8	1.7	0.8	1.3
12	1.6	0.4	*	*	*	0.8	0.8	0.4	1.3	0.4	2.1	1.2	0.8
13	2.0	0.4	*	*	0.4	1.3	0.4	1.6	0.8	0.4	1.7	0.4	0.8
14	0.8	4.0	0.8	0.4	0.4	0.8	1.2	1.6	1.3	0.8	*	0.4	0.7
15	0.4	1.3	*	*	*	0.8	0.4	1.6	2.5	0.4	0.4	0.4	0.7
16	0.4	0.4	0.4	*	0.8	0.4	0.8	0.4	1.3	0.8	*	0.8	0.5
17	1.6	0.4	*	0.4	0.4	2.1	0.8	3.2	2.1	1.6	1.7	2.0	1.4
18	4.0	1.8	0.8	0.4	1.6	2.5	3.2	4.0	2.9	1.2	5.0	7.7	2.9
19	2.8	3.5	2.0	*	1.6	5.0	2.8	5.2	4.6	1.2	7.1	6.5	3.5
20	4.4	3.5	2.8	1.7	3.2	6.7	5.6	8.5	7.5	1.6	6.3	6.0	4.8
21	5.2	4.0	3.2	1.3	4.8	7.5	10.5	8.9	8.3	4.4	5.0	6.0	5.8
22	3.6	2.2	2.4	1.7	6.0	7.5	7.7	12.9	7.9	4.8	6.3	5.2	5.7
23	5.6	3.5	4.8	0.8	6.5	8.3	10.5	15.3	10.0	5.6	4.6	5.2	6.8
All Hours	3.1	2.5	2.3	1.7	4.1	6.7	7.3	8.6	6.4	2.9	4.0	3.9	4.5

* values < 0.4 percent

An individual wind observation, V_i, is a vector composed of a direction and a speed. The direction, θ_i, is measured clockwise in degrees from north. The speed, $|V_i|$, is measured in knots for this illustration. The resultant vector, V_r, of the individual wind vectors in a distribution likewise consists of a direction, θ, and a speed, $|V_r|$. These and other statistics listed in Table 5.2.2 are defined as follows:

Resultant Wind Direction (θ) is the angle of the resultant derived from the following relation:

$$\theta = \arctan \frac{\Sigma x}{\Sigma y} \quad \text{or} \quad \tan\theta = \frac{\Sigma x}{\Sigma y} \quad . \qquad (1)\ 5.2.3$$

Each wind observation is separated into its zonal, x, and meridional, y, components; x is positive from the west, y is positive from the south.

$$\Sigma x = \sum_{i}^{N} |V_i| \sin(\theta_i + \pi) \qquad (2)\ 5.2.3$$

$$\sigma_x = \sqrt{\frac{\Sigma x^2}{N-1} - \frac{(\Sigma x)^2}{N(N-1)}} \qquad (3)\ 5.2.3$$

$$\Sigma y = \sum_{i}^{N} |V_i| \cos(\theta_i + \pi) \qquad (4)\ 5.2.3$$

$$\sigma_y = \sqrt{\frac{\Sigma y^2}{N-1} - \frac{(\Sigma y)^2}{N(N-1)}} \quad . \qquad (5)\ 5.2.3$$

<u>Resultant Wind Speed (V_r)</u> is the magnitude of the resultant wind vector computed from

$$|V_r| = \sqrt{\frac{(\Sigma x)^2 + (\Sigma y)^2}{N^2}} \quad . \qquad (6)\ 5.2.3$$

<u>Vector Standard Deviation of Wind Velocity (σ_v)</u> is the standard deviation of the distribution of the origins of the wind vectors about the origin of the resultant wind vector. In the diagram below, the symbols "O" represent the origins of the individual wind vectors, each vector terminating at the origin of the x and y axes. The vector, V_r, with origin at O_r, as shown in Figure 5.2.6, is the resultant wind vector. The magnitude of the circle about O_r is proportional to the value of the vector standard deviation, σ_v, and is expressed in knots. Here, the use of σ_v assumed that the distribution of the origins of the individual wind vectors is circular with respect to the point, O_r.

TABLE 5.2.2 STANDARD VECTOR DEVIATION GROUND WIND STATISTICS FOR THE EASTERN TEST RANGE, FLORIDA (10 METER REFERENCE HEIGHT)

Month	θ	V_r	σ_v	σ_a	σ_b	r	Ψ	$\bar{V}$	N
Jan	316	2.188	9.189	7.291	5.592	-0.184	112	8.4	5952
Feb	286	1.285	10.215	8.005	6.346	-0.203	121	9.2	5424
Mar	265	0.370	10.205	7.955	6.393	-0.193	95	9.1	5952
Apr	110	2.500	9.520	7.335	6.068	-0.178	125	8.9	5760
May	106	3.227	8.006	5.869	5.445	-0.056	156	7.7	5952
June	141	2.994	7.179	5.134	5.017	0.023	48	6.8	5760
July	153	3.663	6.409	5.076	3.913	-0.049	174	6.5	5952
Aug	133	2.239	6.563	4.955	4.304	0.114	27	5.9	5952
Sept	88	3.512	8.319	6.306	5.426	0.149	43	7.6	5760
Oct	35	3.519	8.849	6.424	6.086	-0.042	154	8.5	5952
Nov	14	2.140	8.698	6.802	5.422	-0.220	130	7.9	5760
Dec	329	2.625	8.808	6.887	5.491	-0.201	122	8.1	5952

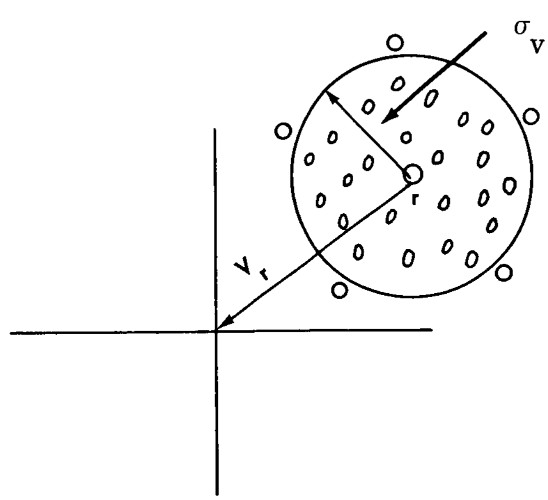

FIGURE 5.2.6 DIAGRAM OF THE VECTOR STANDARD DEVIATION OF GROUND WIND VELOCITY

<u>Standard Deviation of Wind Components Along the Major and Minor Axes of the Distribution (σ_a) and (σ_b)</u>: If the origins of the individual wind vectors are distributed in an elliptical rather than a circular pattern, a major and a minor axis of the ellipse exist. The standard deviations, σ_a and σ_b, are the square roots of K_1 and K_2, respectively, where K_1 and K_2 are the roots of the determinant

$$\begin{vmatrix} \sigma_x^2 - K & \sigma_x \sigma_y r \\ \sigma_x \sigma_y r & \sigma_x^2 - K \end{vmatrix} = 0 \quad .$$

The larger value of K applies to the major axis, the smaller value, to the minor axis.

<u>Correlation Coefficient of Zonal and Meridional Components (r)</u>: In a truly circular distribution there is no correlation between the zonal and meridional components of the individual wind vectors; that is, $r = 0$. Since this is rarely the case, the correlation coefficient can be computed from

$$r = \frac{N\Sigma xy - \Sigma x \Sigma y}{N(N-1)\sigma_x \sigma_y} \quad . \qquad (7)\ 5.2.3$$

<u>Angle of Rotation of the Major Axis of the Wind Distribution (Ψ)</u>: The angle, Ψ, is the angle of rotation of the ellipse, measured from the east-west or zonal axis counterclockwise to the major axis of the distribution. It is derived from

$$\Psi = \frac{1}{2} \arctan \left[2r\sigma_x\sigma_y / (\sigma_x^2 - \sigma_y^2)\right] \quad . \qquad (8)\ 5.2.3$$

<u>The scalar mean wind speed ($\bar{V}$)</u> is as follows:

$$\bar{V} = \frac{\Sigma |V_i|}{N} \quad . \qquad (9)\ 5.2.3$$

<u>The Total Number of Observations (N)</u> is the total number of wind observations included in the frequency distribution and in the calculations.

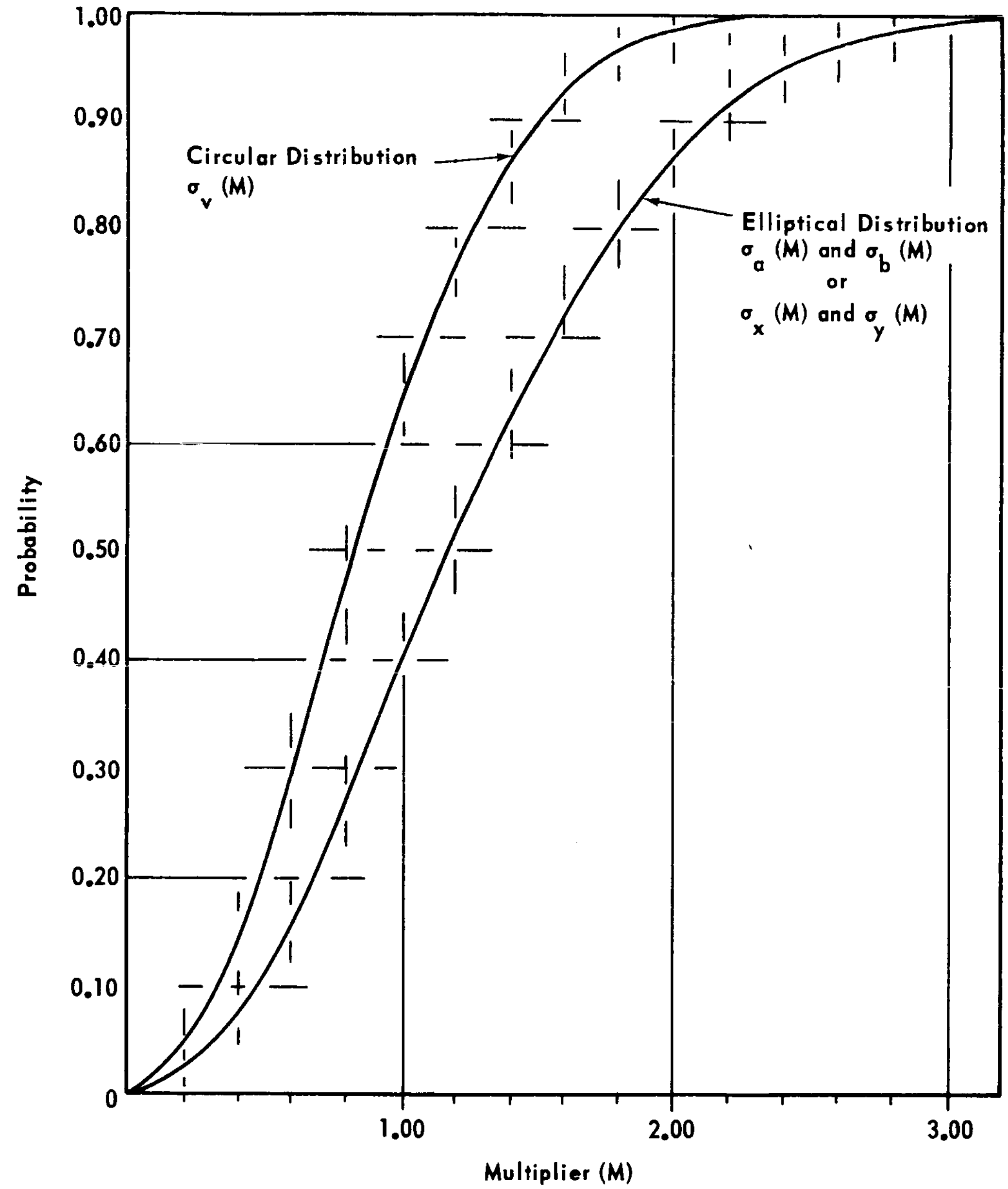

FIGURE 5.2.7 VECTOR RADII FOR VARIOUS PROBABILITY ELLIPSES

To obtain the radius of a circle (radii of an ellipse) that will contain a specified percentage of the wind vector origins, a multiplier can be obtained from the appropriate curve of Figure 5.2.7. For example, the probability is 0.50 that winds will occur within a circle of radius $M\sigma_v$ (an

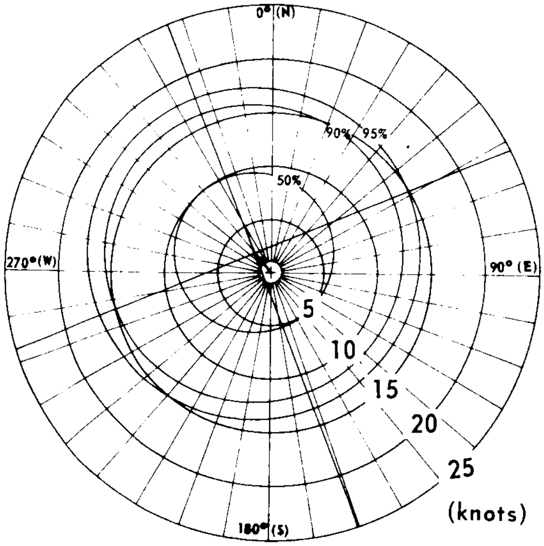

FIGURE 5.2.8 CIRCULAR STANDARD VECTOR DEVIATION OF JANUARY STEADY-STATE GROUND WINDS, CAPE KENNEDY, FLORIDA

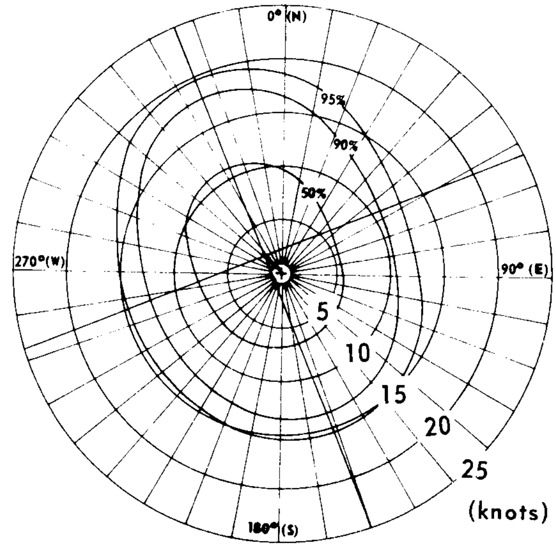

FIGURE 5.2.9 ELLIPTICAL STANDARD VECTOR DEVIATION OF JANUARY STEADY-STATE GROUND WINDS, CAPE KENNEDY, FLORIDA

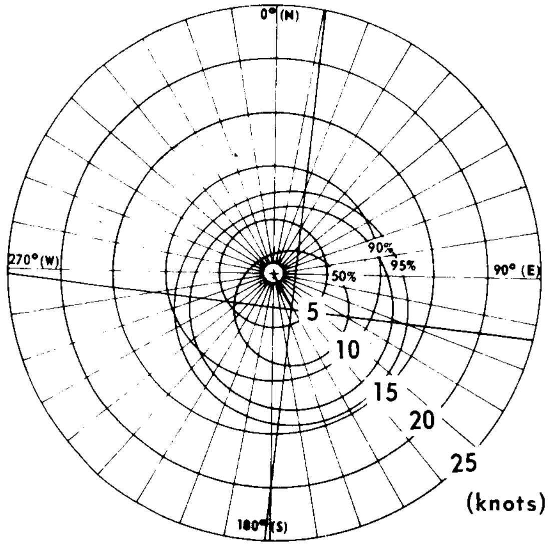

FIGURE 5.2.10 CIRCULAR STANDARD VECTOR DEVIATION OF JULY STEADY-STATE GROUND WINDS, CAPE KENNEDY, FLORIDA

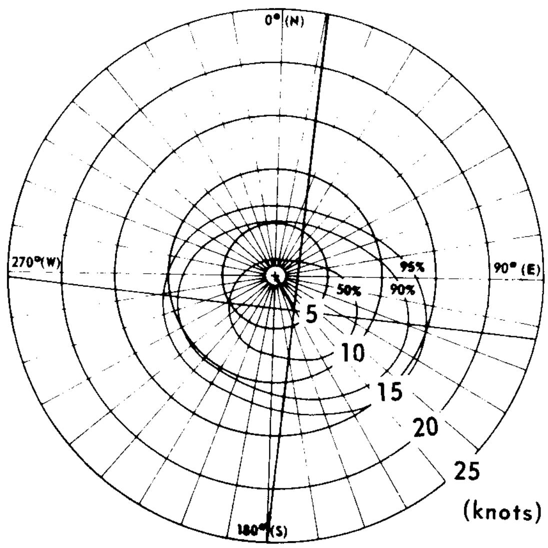

FIGURE 5.2.11 ELLIPTICAL STANDARD VECTOR DEVIATION OF JULY STEADY-STATE GROUND WINDS, CAPE KENNEDY, FLORIDA

All Figures are for a 10 meter Reference Height ellipse of radii $M\sigma_a$ and $M\sigma_b$). From the curve for circular distributions a value of $M = 0.83$ is obtained, while from the elliptical distribution curve a value of $M = 1.2$ is found.

The circular and elliptical standard vector deviation wind roses of Figures 5.2.8 thru 5.2.11 were prepared from the January and July wind statistics given in Table 5.2.2. As indicated in the previous discussion, the percentage label on each circle or ellipse indicates the percent of wind vectors that will originate in that circle or ellipse.

The analysis of ground wind data for other ranges (Western Test Range, Wallops Island Test Range, and White Sands Missile Range) will be published when available.

Results of a study of $3\frac{1}{2}$ years of wind data from a 250-foot (76.2-m) tower at Wallops Island, Virginia are given in Reference 5.11.

5.2.4 Exposure Period Probabilities.

5.2.4.1 Considerations in Ground Wind Design Criteria.

To establish the ground wind design criteria for aerospace vehicles, several important factors must be considered.

a. Where is the vehicle to operate? What is the launch location?

b. What are the proposed vehicle missions?

c. How many hours, days, or months will the vehicle be exposed to ground winds?

d. What are the consequences of operational constraints that may be imposed upon the vehicle because of wind constraints?

e. What are the consequences if the vehicle is destroyed or damaged by ground winds?

f. What are the cost and engineering practicalities for designing a functional vehicle to meet the desired mission requirements?

g. What risk that the vehicle will be destroyed or damaged by excessive wind loading?

In view of this list of questions or any similar list a design group may enumerate, it becomes obvious that, in establishing the ground wind environment design criteria for a space vehicle, an interdisciplinary approach between the several engineering and scientific disciplines is required; furthermore, the process is an interative one. To begin the interative process, specific information on ground winds is required. Section (5.2.5) presents wind statistics for this purpose.

5.2.4.2 Introduction to Exposure Period Analysis.

Valid, quantitative answers to such questions as the following are of primary concern in the design, mission planning, and operations of space vehicles.

a. How probable is it that the peak surface wind at some specified reference height will exceed (or not exceed) a given magnitude in some specified time period?

b. Given a design wind profile in terms of peak wind speed versus height from 10- to 150 meters, how probable is it that the design wind profile will be exceeded in some specified time period?

Given a statistical sample of peak wind measurements for a specific location, the first question can be answered in as much detail as a statistical analysist finds necessary and sufficient. This first question has been thoroughly analyzed for Cape Kennedy, but not for the other locations of interest to NASA, and will be answered in detail in the following pages of this Section.

The analysis becomes considerably more complex in answering the second question. A wind profile model is required, and, to develop the model, measurements of the wind profiles by properly instrumented meteorological towers are required as well as a program for scheduling the measurements and data reduction. Every instantaneous wind profile is unique; similarity is a matter of degree. Given the peak wind speed at one height, there is a whole family of possible profiles extending from the specified wind. For each specified wind speed at a given height, there is a statistical distribution of wind profiles. These distributions are presented in a model in Section 5.2.5; the design wind profile is specified in Section 5.2.5.3 for

Cape Kennedy; and recommended profile shapes for other stations are given in Section 5.2.5.5. The analysis needed to answer the second question is not complete, but we can make the assumption that, given a long period of time, the design wind profile shape will occur for a specified wind speed at a given height. In the event that a thunderstorm passes across the vehicle, it is logical to assume that the design wind profile shape will occur and that the chance of the design wind profile being exceeded is the same as the probability that the peak wind during the passage of the thunderstorm will strike the vehicle or point of interest. Some statistics on peak winds at a point in association with thunderstorms for Cape Kennedy are presented in Section 5.2.10.

5.2.4.3 The Development of Exposure Period Concepts.

In Reference 5.12, Court proposed the concept of "calculated risk" as wind design criteria for facilities; Gumbel (Ref. 5.13) uses Court's term "calculated risk" in this connection. With an aerospace vehicle exposed to the surface winds on the pad, it becomes obvious that the longer the vehicle is exposed, the higher the probability becomes that the vehicle will experience a high wind speed. From this simple notion, the concept of exposure period statistics for daily peak winds for from one day exposure to one year exposure, were computed (Ref. 5.13). As originally conceived, an exposure period probability is an empirical statistic of winds near the ground, derived from a time ordered sample that involves counting the exceedance of wind speeds equal to or greater than specified magnitudes, taking all possible combinations in time increments. The procedure is that of counting as events the occurrence of wind speed greater than or equal to specified values, in overlapping time increments. Such a system of counting is found in combinational analysis.

Another technique that gives identical results is to derive the exceedances from an analysis of runs. This procedure is indicated by means of an example in Section 5.3.4.1. Thus, an exposure period statistic expresses the probability that an event will occur one or more times in k-consecutive time intervals. The probability of the event may vary with respect to time (from trial to trial) without invalidating any fundamental principle. The principle of multi-event probabilities, upon which calculated risk is based, requires the probability from trial to trial to remain constant. Use of this concept will be made in establishing calculated risk for facilities design. The main difficulties in using empirical exposure period probabilities are that no simple model for the statistics exists, a large sample is required, the observations should be serially complete, and, since the statistics are empirical, comparisons for generalizations are difficult, and extrapolations beyond the observed sample range are not possible. When the variable of interest is the largest in a set of observations, a model including extreme values seems appropriate. The theory of extreme values developed by Gumbel (Ref. 5.13) was found to be an efficient and adequate statistical model for the analysis of peak ground wind speeds for vehicle design and mission planning purposes. It is the application of this model that will be developed in Section 5.2.4.4.

5.2.4.4 Development of Extreme Value Samples.

It has been estimated that only a few seconds are required for the wind to produce steady drag loads on a vehicle such as the Saturn V when it is in an exposed condition on the launch pad. Because of vortex shedding, a steady wind as low as 9 m/s (18 knots) blowing for 15 or more seconds may introduce dynamic loads on a vehicle while it is in some configurations. For these and other reasons given in Section 5.2.5, we have adopted the peak wind speed as our fundamental measurement of wind. More importantly, when the engineering applications of winds can be made in terms of peak wind speeds, it is possible to obtain an appropriate statistical sample that conforms to the fundamental principles of the extreme value theory. One hour is a convenient time interval from which to select the peak wind. After a brief description of statistical samples for the analysis of extreme value statistics, the analytical treatment and specific statistics of peak winds will be presented.

5.2.4.4.1 Hourly Peak Winds for Cape Kennedy.

From the continuously recording charts, the highest instantaneous wind speed (and associated direction) that occurred during each hour was selected for the data sample. The resulting sample of hourly peak wind speeds (and associated directions) has only been completed for Cape Kennedy, Florida. The reference height for these data is 10 meters above natural grade. The original period of record was from September 1958 to December 1966, with missing data from March 1961 to November 1961 and from November 29, 1962, to March 31, 1963. This sample has proven to be very useful for many aerospace problems and is being continuously updated to add more years of data. A reference period is then the basic interval normally taken as the monthly, seasonal, or annual period for which a sample of like variables is summarized statistically.

5.2.4.4.2 Daily Peak Winds.

Daily peak wind samples were obtained from the hourly peak wind sample. Since the diurnal variation in the wind magnitude is eliminated by this sample, the daily peak winds become an interesting sample to analyze. It was also found that the percentiles of daily peak winds are only slightly greater than the corresponding percentiles for hourly peak winds taken in the afternoon hours. This is particularly true for the summer months at Cape Kennedy, which indicates that the peak wind for the day often occurs during the afternoon.

5.2.4.4.3 Monthly-Bimonthly-Trimonthly and Yearly Peak Wind.

For each higher order sample of largest peak wind, the sample size decreases proportionately; for example, a sample size of monthly peak winds taken from a sample of daily peak winds is reduced by a factor of 1/30. A larger sample of monthly and yearly peak winds than was available from the 8 years of hourly peak winds was needed; therefore, the monthly peak winds were obtained from the standard weather records form WBAN-10 for the period 1950 to 1958 and from the hourly peak wind records from 1958 to 1966. Thus, 17 years of monthly peak winds were obtained.

From the monthly peak winds, it is convenient to obtain the largest peak wind in 2-month periods, in 3-month periods, etc. The largest peak wind in each year is referred to as the yearly peak wind. From the hourly peak wind sample, the largest magnitude for any desired period greater than one hour can be obtained. For particular mission analysis problems, these samples have been grouped as 3-hour, 6-hour, 9-hour, 12-hour, 15-hour, 21-hour, 24-hour, or daily peak winds for beginning times at 0000 EST, 0300 EST, etc. This analysis has not been completed, and so could not be included in this document. Other groupings of hourly peak winds include:

a. Hourly peak winds grouped by all like hours for like months.

b. All hourly peak winds for like months.

c. All hourly peak winds for the period of record.

By definition, groupings a and b are hourly peak winds grouped by like hours; all hourly peak winds grouped by like months are summarized by monthly reference period, and groupings like c above are referred to as "annual reference periods."

5.2.4.4.4 Treatment – Hurricane Winds.

Since some vehicle operations are not conducted during the presence of a hurricane in the Cape Kennedy area, the statistical analysis for the wind samples were treated both with and without hurricane influenced winds. An arbitrary rule for excluding a hurricane influenced wind was established. If a hurricane was within a 400-nautical mile radius of Cape Kennedy, and if the winds at the Cape exceeded 35 knots, the winds during which this condition existed were removed from the sample, resulting in more homogeneous samples and more systematic month-to-month wind statistics. From a sampling point of view, hurricane winds could be considered as a separate population. Peak winds in association with thunderstorms are, however, included in all samples used in the development of the design wind criteria. The frequency of hurricanes for various distances from Cape Kennedy is discussed in Section 5.2.10.

5.2.4.4.5 Analytical Treatment.

The fundamental statistical principles used in this analysis are based upon Gumbel's extreme value theorem (Ref. 5.13), Fisher's and Tippett's (Ref. 5.15) extreme value distribution functions, and Thom's Fréchet Distribution (Ref. 5.16).

For Cape Kennedy, the computational forms that are valid for the distributions of largest values of peak winds for 1 hour to 24 hours annual reference period, hurricane winds excluded, are,

$$\bar{x}(t) = 12.100 + 2.36982 \ln t \qquad (1)\ 5.2.4$$

$$\sigma_{x_N}(t) = 6.00 + 0.03578 \ln t \quad , \qquad (2)\ 5.2.4$$

where t is time in hours and the units for $\bar{x}$ and σ_{x_N} are in knots.

The corresponding equations valid for 1 day to 365 days are

$$\bar{x}(t) = 19.6314 + 4.95788 \ln t \qquad (3)\ 5.2.4$$

and

$$\sigma_{x_{(N)}} = 6.1137 + 0.47287 \ln t \qquad (4)\ 5.2.4$$

where t is time in days and the units for $\bar{x}$ and σ_{x_N} are in knots.

Upon substitution of Equations (1) 5.2.4 and (2) 5.2.4 and also Equations (3) 5.2.4 and (4) 5.2.4 into the following:

$$x = \bar{x}(t) + \frac{\sqrt{6}}{\pi} \sigma_{x_N}(t)\ (y - \gamma) \quad . \qquad (5)\ 5.2.4$$

where $y = -\ln[-\ln \Phi]$ and γ is Euler's constant of 0.57722

then the distributions of the largest peak wind at the 10-meter level, for Cape Kennedy, annual reference period, hurricane winds excluded, can be evaluated for 1 hour to 24 hours and from 1 day to 365 days. Resulting evaluations for selected distributions are given in Table 5.2.3. From the properties of the Gumbel distribution at $y = 0$, $\Phi = 0.36788$, and the corresponding statistic, the 36.788 percentile is the mode. (The mode of a set of measurements is defined as the measurement with the maximum frequency). The median is the 50th percentile, which corresponds to the reduced variate, $y = 0.36651$, and the mean is the 57.040 percentile, which corresponds to $y = 0.57722 = \gamma$.

TABLE 5.2.3 GUMBEL DISTRIBUTIONS OF LARGEST PEAK WINDS (10-m level), ANNUAL REFERENCE PERIOD, HURRICANE WINDS EXCLUDED, CAPE KENNEDY, FLORIDA

y	Φ	U	1 Hour	1 Day	2 Days	10 Days	15 Days	30 Days	60 Days	90 Days	180 Days	365 Days
0.00000	0.36788	0.63212	9.40	16.88	20.17	27.81	29.73	33.02	36.31	38.23	41.52	44.88
0.08742	0.40	0.60	9.81	17.30	20.61	28.30	30.23	33.55	36.86	38.79	42.10	45.48
0.36651	0.50	0.50	11.11	18.63	22.01	29.86	31.84	35.23	38.61	40.59	43.97	47.42
0.57722	0.57040	0.42960	12.10	19.63	23.07	31.05	33.06	36.49	39.93	41.94	45.38	48.88
0.67173	0.60	0.40	12.54	20.08	23.54	31.58	33.60	37.06	40.52	42.55	46.01	49.54
1.03093	0.70	0.30	14.22	21.79	25.35	33.60	35.67	39.23	42.78	44.86	48.41	52.03
1.49994	0.80	0.20	16.42	24.03	27.70	36.23	38.38	42.05	45.72	47.87	51.54	55.29
2.25037	0.90	0.10	19.93	27.61	31.47	40.44	42.70	46.57	50.43	52.69	56.56	60.50
2.97020	0.95	0.05	23.29	31.04	35.09	44.49	46.85	50.90	54.95	57.32	61.37	65.49
4.60016	0.99	0.01	30.92	38.81	43.27	53.64	56.25	60.72	65.18	67.79	72.26	76.81
6.90726	0.999	0.001	41.71	49.81	54.86	66.60	69.55	74.61	79.66	82.62	87.61	92.83

$1 - \Phi = U$

Other percentiles of common usage are also given in Table 5.2.3. The probability that the largest peak wind in a given time will be less than or equal to the tabulated values is read directly from Table 5.2.3. The probability that the wind will exceed the tabulated values is 1 - Φ. For example, there is a 50-percent chance that the daily peak wind at the 10-meter level, annual reference period, hurricane winds excluded, will be less than or equal to 18.63 knots, and a 50-percent chance that the daily peak winds for this reference period will exceed 18.63 knots. An alternate view for this reference period is that 50-percent of the days taken over several years will have daily peak winds that are greater than 18.63 knots at least one time within each day. Similarly, 50-percent of the months (30-day period from Table 5.2.3) over several years will have peak winds exceeding 35.23 knots at least one time within each month.

5.2.4.5 Envelope of Distributions.

In the development of the statistics for Table 5.2.3, it was recognized that the probability of hourly, daily, and monthly peak winds exceeding (or not exceeding) specified values varied with time of day and from month to month. In other words, the distributions of like variables were different for the various reference periods. Even so, the Gumbel distribution was an excellent fit to the samples of all hourly, daily, monthly, bimonthly (in two combinations), and trimonthly (in three combinations) periods taken over the complete period of record, justifying the presentation of these distributions; they serve as a basic reference for the statistics of peak wind for the annual reference period. However, in establishing vehicle wind design criteria for the peak winds versus exposure time, it is desired to present a simple set of wind statistics in such a manner that every reference period and exposure time would not have to be examined to determine the probability that the largest peak wind during the exposure time would exceed some specified magnitude. To accomplish this objective, envelopes of the distributions of the largest peak winds for various time increments from which the extremals were taken for the various reference periods were constructed. A brief explanation of the procedure follows.

First, the largest average and largest standard deviation (σ_{x_N}) of hourly, daily, and monthly peak winds for monthly reference periods, the bimonthly and trimonthly peak winds for the respective reference periods, and the mean and standard deviation (σ_{x_N}) for the yearly peak winds, including hurricane winds, were fit by the Gumbel distributions:

$$\Phi(x) = \exp[-e^{-y}] \text{ , where } y = \alpha(x - \mu) \qquad (6)\ 5.2.4$$

where α is a scale parameter, μ is the mode

The computational equations for envelopes of largest mean and standard deviations of the largest peak wind speed at the 10-meter level versus time increments (from which the largest extremals were taken including hurricane winds) are

$$\bar{x}(t) = 18.00 + 1.5733 \ln t \qquad (7)\ 5.2.4$$

$$\sigma_{x_N}(t) = 6.86 + 0.04405 \ln t \quad , \qquad (8)\ 5.2.4$$

valid for 1 hour to 24 hours, and

$$\bar{x}(t) = 23.00 + 4.8755 \ln t \qquad (9)\ 5.2.4$$

$$\sigma_{x_N}(t) = 7.00 + 1.17606 \ln t \quad , \qquad (10)\ 5.2.4$$

valid for 1 day to 365 days where the units for x and σ_{x_N} are in knots.

Equations (7) 5.2.4 and (8) 5.2.4, and Equations (9) 5.2.4 and (10) 5.2.4 are substituted into Equation (5) 5.2.4 and evaluated at various values of t. This procedure gives the envelopes for the Gumbel distributions. Selected envelopes of distributions are shown in Table 5.2.4 It is recommended that the envelope of distributions be used for vehicle wind design considerations. This recommendation is made under the assumption that it is not known what time of day or season of year critical vehicle operations are to be conducted; furthermore, it is not desirable to design a vehicle to operate only during selected hours or months. Should all other design alternatives fail to lead to a functionally engineered vehicle with an acceptable risk of not being over stressed by wind loads, then distributions for peak winds by time of day for monthly reference periods may be considered for limited missions. For vehicle operations, detailed statistics of peak winds for specific

TABLE 5.2.4 ENVELOPE OF GUMBEL DISTRIBUTIONS OF LARGEST PEAK WINDS (10-m level), ANNUAL REFERENCE PERIOD, HURRICANE WINDS INCLUDED, CAPE KENNEDY, FLORIDA

y	Φ	U	1 Hour	1 Day	2 Days	10 Days	15 Days	30 Days	60 Days	90 Days	180 Days	365 Days
0.00000	0.36788	0.63212	14.91	19.85	22.86	29.86	31.62	34.63	37.64	39.41	42.42	45.49
0.08742	0.40	0.60	15.38	20.33	23.39	30.52	32.31	35.38	38.45	40.24	43.31	46.44
0.36651	0.50	0.50	16.87	21.85	25.10	32.63	34.53	37.78	41.02	42.92	46.16	49.47
0.57722	0.57040	0.42960	18.00	23.00	26.38	34.23	36.20	39.58	42.96	44.94	48.32	51.76
0.67173	0.60	0.40	18.51	23.52	26.96	34.94	36.75	40.39	43.83	45.84	49.28	52.79
1.03093	0.70	0.30	20.43	25.48	29.14	37.66	39.81	43.47	47.14	49.29	52.95	56.70
1.49994	0.80	0.20	22.94	28.04	32.00	41.21	43.53	47.50	51.46	53.78	57.75	61.79
2.25037	0.90	0.10	26.95	32.13	36.57	46.89	49.49	53.93	58.38	60.97	65.42	69.95
2.97020	0.95	0.05	30.80	36.06	40.96	52.34	55.21	60.11	65.01	67.87	72.77	77.77
4.60016	0.99	0.01	39.52	44.96	50.89	64.68	68.15	74.09	80.02	83.49	89.43	95.49
6.90726	0.999	0.001	51.86	57.55	64.95	82.14	86.47	93.87	101.28	105.61	113.01	120.56

$1 - \Phi = U$

missions are meaningful for management decisions, in planning the mission, and in establishing mission rules and alternatives to the operational procedures. To present the wind statistics for these purposes is beyond the scope of this document. Each space mission has many facets that make it difficult to generalize and to present the statistics in brief form.

There are three informative graphic presentations of the statistics contained in Tables 5.2.3 and 5.2.4. The first is the distributions of Table 5.2.3, which are shown in Figure 5.2.12, and those of Table 5.2.4 are shown in Figure 5.2.13. From these graphs the probability of the largest peak wind at the 10-meter level, equal to or less than any specified value $\Phi\{W \leq W^*\}$, can be interpolated for the indicated time periods. The probability that the wind will exceed a given value $\Phi\{W > W^*\}$ for the indicated time period is then $1 - \Phi\{W \leq W^*\}$. Note that the slopes of the distributions increase with increased time increments from which the extremals are selected. This observation is also obvious from the empirical Equations, (4) 5.2.4, and (10) 5.2.4. This shows that α decreases and the σ_{x_N} increases

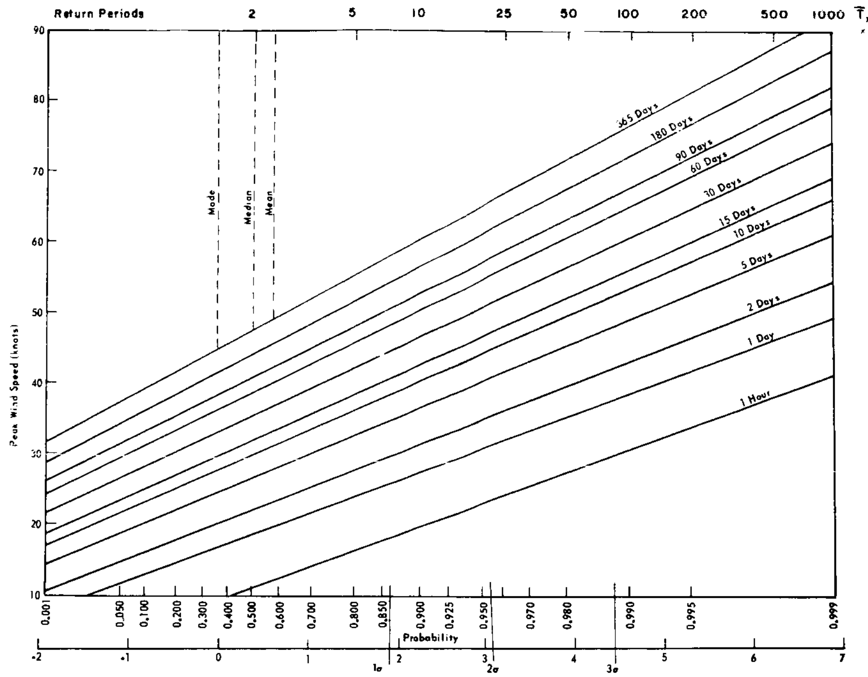

FIGURE 5.2.12 GUMBEL DISTRIBUTIONS OF LARGEST PEAK WINDS (10-m level), ANNUAL REFERENCE PERIOD, HURRICANE WINDS EXCLUDED, CAPE KENNEDY, FLORIDA

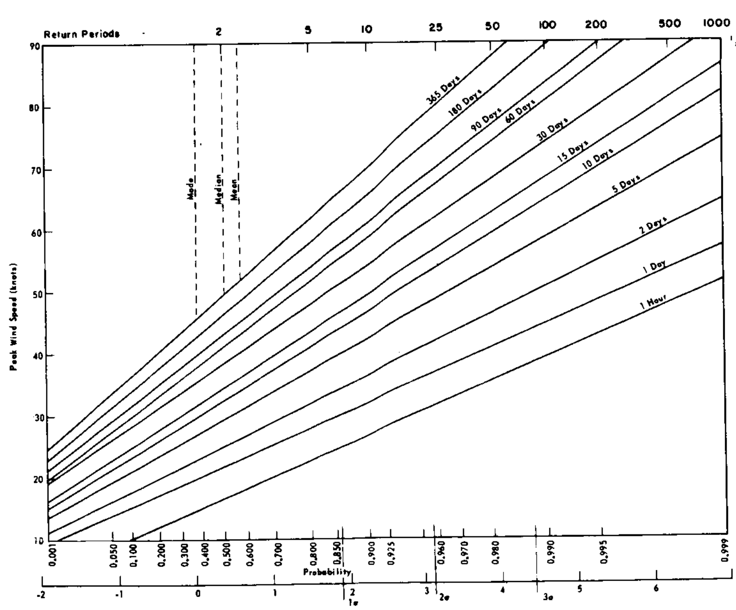

FIGURE 5.2.13 ENVELOPE OF GUMBEL DISTRIBUTIONS OF LARGEST PEAK WINDS (10-m level), ANNUAL REFERENCE PERIOD, HURRICANE WINDS INCLUDED, CAPE KENNEDY, FLORIDA

with the selection of extremals from larger time bases. From the calculated risk concept, $U = 1 - [P]^N$, discussed in Section 5.2.4.3, the slopes of all these curves would be the same.

The second graphic presentations of Table 5.2.3 and 5.2.4 are shown in Figures 5.2.14 and 5.2.15, where the probability of the winds exceeding the given percentiles versus the time increment from which the extremals are taken is plotted. Here we will depart from the original concept of empirical exposure period probabilities and refer to these statistics as fixed risk probabilities (U) versus exposure time. Here U is simply $(1 - \Phi)100$ taken from Tables 5.2.3 or 5.2.4. From Figure 5.2.15, taken from the envelope of the distributions (Table 5.2.4), it becomes immediately obvious that to hold the exceedance probability fixed, then as the exposure time increases the $\Phi\{W>W^*\}$ increases as a function of the logarithm of exposure time. Suppose the design risk for the vehicle is set at U = 10 percent, then as the exposure time increases from 1 day to 90 days, the design wind must be 32.13 knots (taken from Table 5.2.3) for one day exposure and must increase to 60.97 knots (taken from Table 5.2.4) for 90 days exposure.

The third interesting graphic presentation is a cross-plot from Figures 5.2.12 and 5.2.13, obtained by holding the wind speed of interest fixed and interpolating for the exceedance probability versus the time increment from which the extremals are taken (or exposure time).

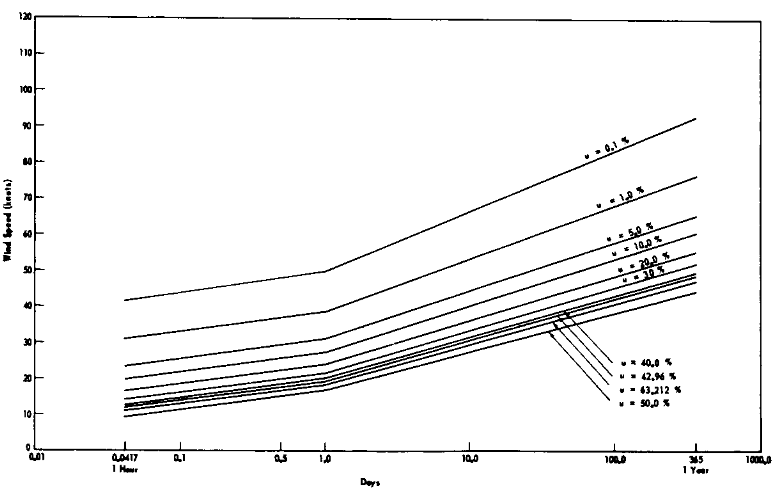

FIGURE 5.2.14 EXCEEDANCE PROBABILITIES OF PEAK WINDS (10-m level) VERSUS EXPOSURE TIME, HURRICANE WINDS EXCLUDED, CAPE KENNEDY, FLORIDA

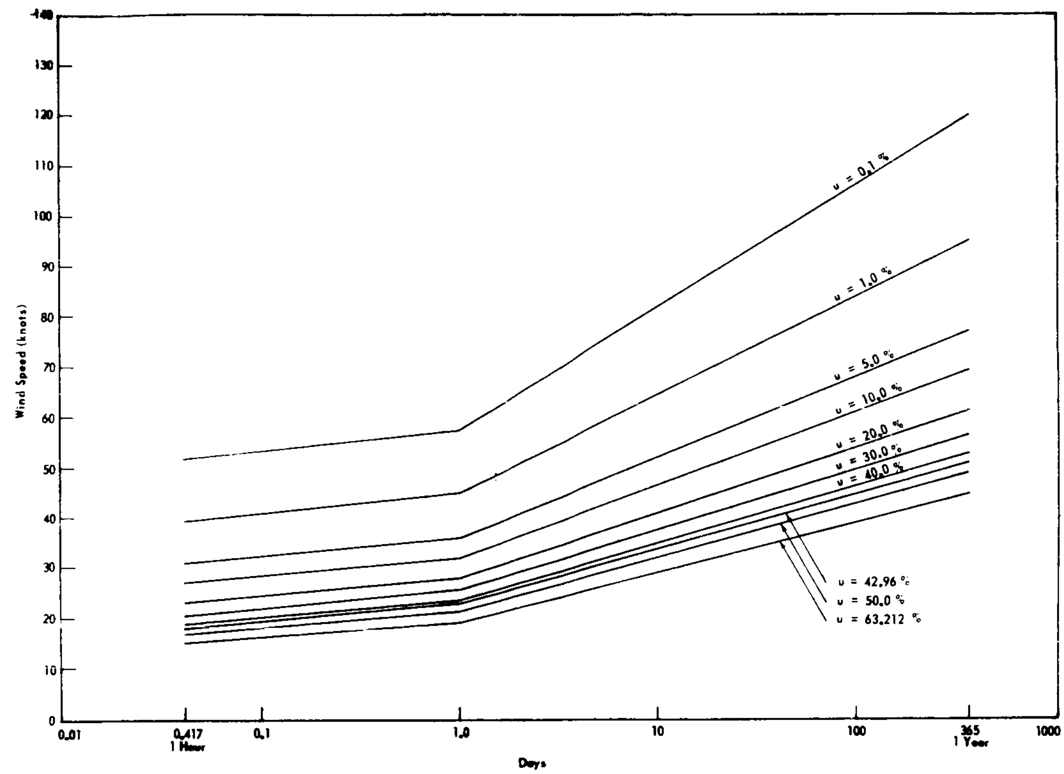

FIGURE 5.2.15 EXCEEDANCE PROBABILITIES OF PEAK WINDS (10-m level) VERSUS EXPOSURE TIME, HURRICANE WINDS INCLUDED, CAPE KENNEDY, FLORIDA

A further evaluation for selected values of peak wind speeds versus exposure time is shown in Table 5.2.5 for the distribution of peak winds, annual reference period, excluding hurricane winds and in Table 5.2.6 for the envelope of distributions, annual reference period, including hurricane winds. These statistics are also illustrated graphically in Figures 5.2.16 and 5.2.17. By inspecting Table 5.2.5 or Figure 5.2.16, it becomes obvious that the probability of exceeding a given wind speed increases with exposure time. Thus, we have a measure in terms of probability for the simple notion set forth in Section 5.2.4.3: the longer a vehicle is exposed on the pad to ground winds, the higher the probability becomes that the vehicle will experience a high wind.

By applying the fundamental principles of extreme value statistics to the analysis of peak wind samples for Cape Kennedy, and a set of empirical functions to simplify the necessary computations, a unified approach for establishing the basic peak wind statistics at the 10-meter level for aerospace vehicle design winds has been derived. The procedure gives consistent results in excellent agreement with the sample statistics and an objective technique to derive the required wind statistics. It is all-important for the design engineering group to consider the probability that the largest peak wind will be exceeded during the time the vehicle is to be exposed on the pad. The statistics of peak wind speeds at the 10-meter level versus exposure times developed in this section for Cape Kennedy are used in Section 5.2.5 to depict the peak wind profile for various risks versus exposure time.

TABLE 5.2.5 EXCEEDANCE PROBABILITIES FROM GUMBEL DISTRIBUTIONS OF LARGEST PEAK WINDS (10-m level), ANNUAL REFERENCE PERIOD, HURRICANE WINDS EXCLUDED, CAPE KENNEDY, FLORIDA

Exposure Time	Peak Wind Speed (knots)								
	15	20	25	30	35	40	45	50	55
1 Hour	0.26071	0.09854	0.03500	0.01216	0.00419	0.00144	0.00050	0.00017	0.00006
1 Day		0.40524	0.16644	0.06179	0.02209	0.00780	0.00274	0.00096	0.00034
2 Days			0.31762	0.13170	0.05085	0.01910	0.00710	0.00263	0.00097
5 Days			0.59900	0.30200	0.13191	0.05414	0.02166	0.00858	0.00338
10 Days				0.49164	0.24251	0.10776	0.04573	0.01903	0.00786
15 Days				0.61488	0.33026	0.15499	0.06830	0.02928	0.01241
30 Days					0.51305	0.26922	0.12777	0.05784	0.02563
60 Days						0.42609	0.22147	0.10673	0.04961
90 Days						0.53207	0.29446	0.14802	0.07093
180 Days							0.44793	0.24504	0.12453
365 Days							0.62551	0.37996	0.20753

5.2.4.6 Hourly Peak Winds 10-Meter Reference Height for Huntsville, New Orleans, Western Test Range, Wallops Island, and White Sands.

The basic reference for the hourly peak wind statistics for these five stations are from TM X-53328 (Ref. 5.18). The hourly peak wind statistics for the percentiles given in Tables 5.3A - 5.5B and 5.7A - 5.8B of Reference 5.18 were derived by applying a 1.4 gust factor to the percentiles derived from standard meteorological hourly wind measurements, which are approximately 2-minute mean winds. The resulting hourly peak wind percentiles were plotted on Gumbel probability graph paper and the parameters, α, and u, for the Gumbel distribution were estimated. These parameters are presented in Table 5.2.7 along with selected percentiles. The percentile values give the $P\{W \leq W^*\}$, which is the probability expressed in percent that the hourly peak wind speed for the annual reference period will be less than or equal to the tabulated values, and $[1 - P]\ 100 = U\%$ gives the $P\{W > W^*\}$, which

TABLE 5.2.6 EXCEEDANCE PROBABILITIES FROM ENVELOPE OF GUMBEL DISTRIBUTIONS OF LARGEST PEAK WINDS (10-m level), ANNUAL REFERENCE PERIOD, HURRICANE WINDS INCLUDED, CAPE KENNEDY, FLORIDA

Exposure	Peak Wind Speed (knots)								
Time	15	20	25	30	35	40	45	50	55
1 Hour	0.62611	0.32043	0.14074	0.05782	0.02312	0.00914	0.00360	0.00141	0.00056
1 Day		0.62198	0.32240	0.14419	0.06039	0.02461	0.00992	0.00398	0.00159
2 Days			0.49291	0.25838	0.12329	0.05627	0.02517	0.01116	0.00493
5 Days				0.44524	0.24910	0.13002	0.06548	0.03239	0.01588
10 Days				0.58965	0.36879	0.21155	0.11554	0.06145	0.03223
15 Days					0.44351	0.26821	0.15327	0.08483	0.04613
30 Days					0.57018	0.37585	0.23136	0.13661	0.07873
60 Days						0.48943	0.32339	0.20311	0.12361
90 Days						0.55492	0.38149	0.24810	0.15569
180 Days							0.48358	0.33312	0.21994
365 Days							0.58533	0.42630	0.29584

is the probability that the hourly peak winds will be exceeded at least one time in an hour based upon the annual reference period; U is also referred to as risk. The Gumbel distributions for the hourly peak winds for these stations are presented in Figure 5.2.18.

5.2.5 Design Wind Profiles (Vehicles).

To calculate ground wind loads on space vehicles, the engineer requires specific information about the wind profile. The earth's surface is a rigid boundary that exerts a frictional force on the lower layers of the atmosphere, causing the wind to vanish on the boundary. In addition, the characteristic length and velocity scales of the mean (steady-state) flow in the first 150 meters (boundary layer) of the atmosphere combine to yield extremely high Reynolds numbers with values that range between approximately 10^6 and 10^8, so that for most conditions (wind speeds > 1 ms^{-1}) the flow is turbulent. The lower boundary condition, the thermal and dynamic stability properties of the boundary layer, the distributions of the large scale pressure and Coriolis forces, and the structure of the turbulence combine to yield an infinity of wind profiles.

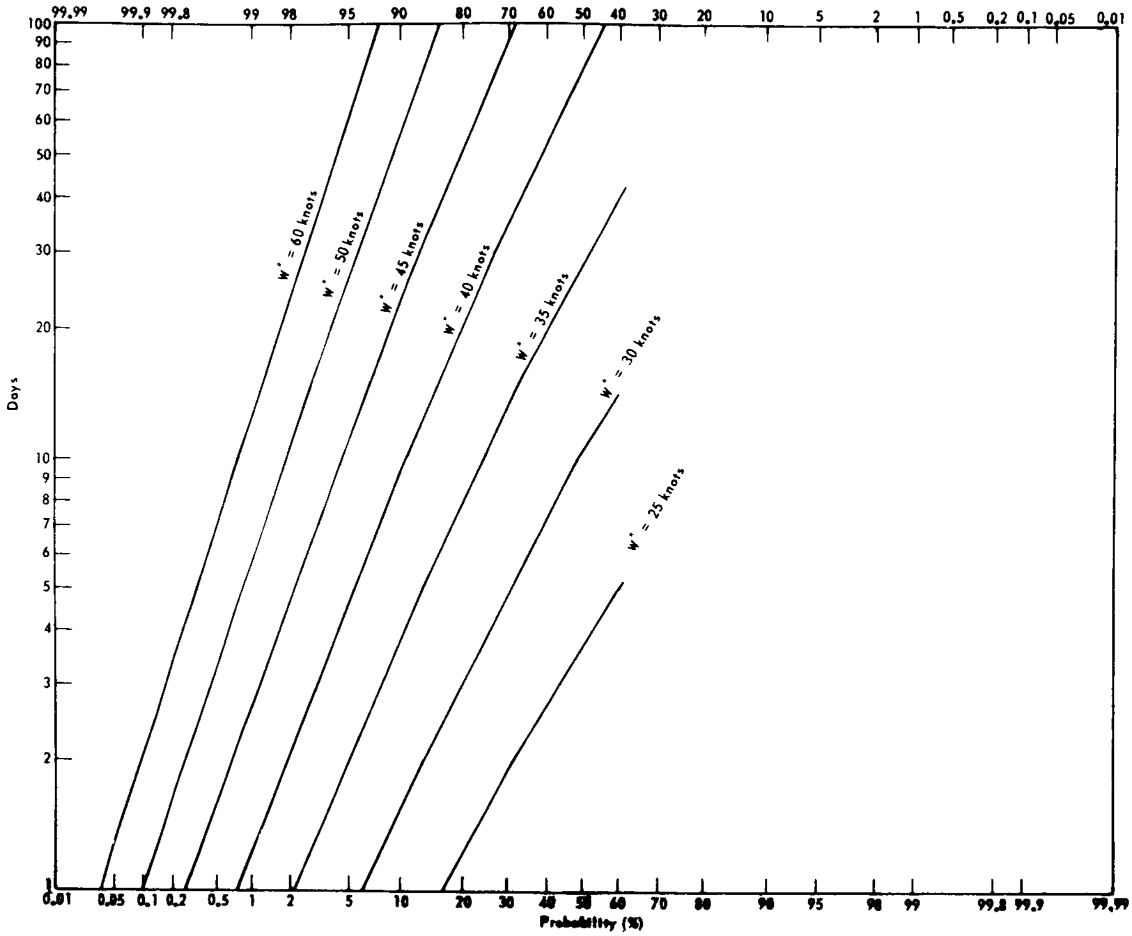

FIGURE 5.2.16 PROBABILITY THAT SPECIFIED VALUES OF PEAK WINDS (10-m level) WILL BE EXCEEDED AS A FUNCTION OF EXPOSURE TIME AT A FIXED RISK (U%), HURRICANE WINDS EXCLUDED, CAPE KENNEDY, FLORIDA

In the past, most formulations from an engineering viewpoint have been concerned with prescribing a mean wind profile from which a peak wind profile is obtained by applying a gust factor. The mean wind profiles that have been used include the logarithmic profile, the power law, the modified power law, and the extended logarithmic profile (Ref. 5.19). These profile "laws" are used to extrapolate known mean wind statistics at a single level to other levels. A gust factor is applied to obtain a peak wind profile.

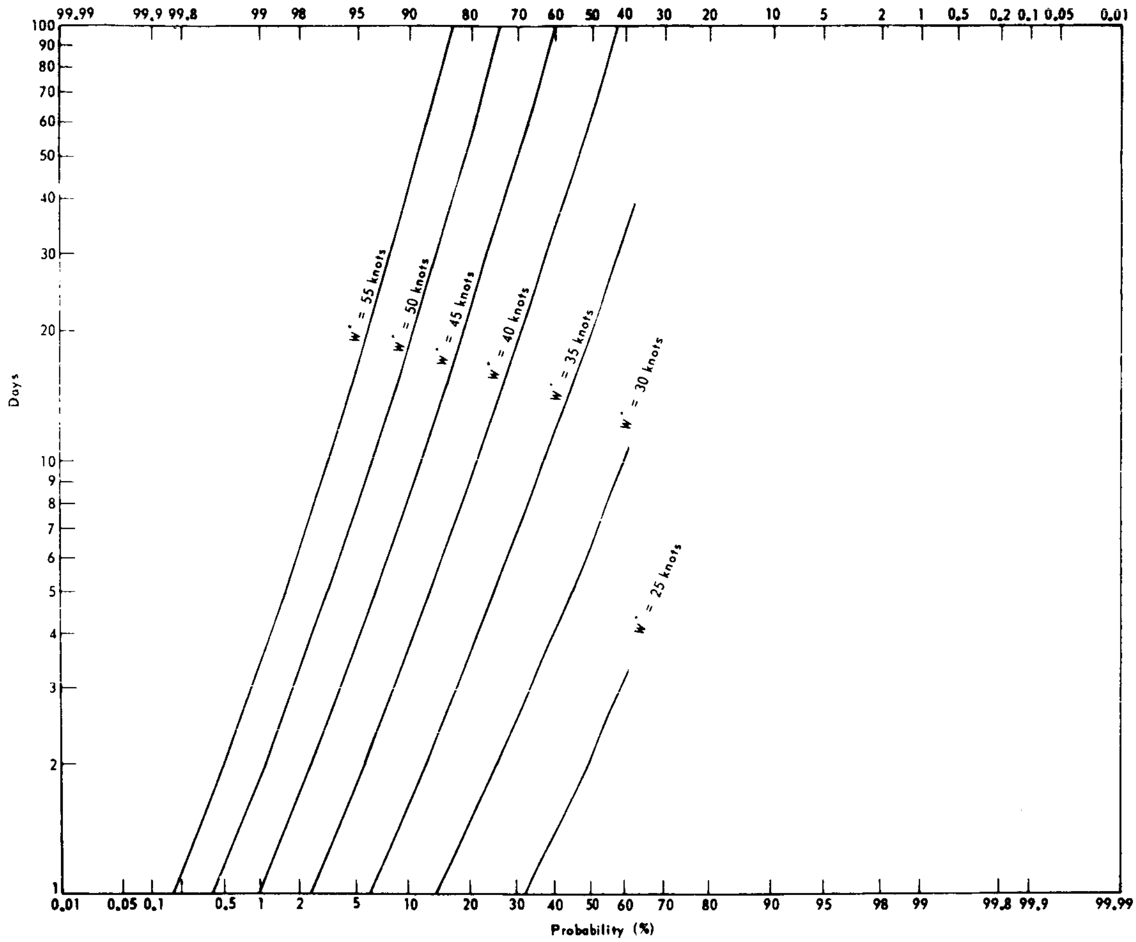

FIGURE 5.2.17 PROBABILITY THAT SPECIFIED VALUES OF PEAK WINDS (10-m level) WILL BE EXCEEDED AS A FUNCTION OF EXPOSURE TIME AT A FIXED RISK (U%), HURRICANE WINDS INCLUDED, CAPE KENNEDY, FLORIDA

In the usual situation, one has a reasonably long record (greater than 5 years) of wind speed data at a single level with which to compile wind statistics and very little, if any, information about the behavior of the vertical variation of wind speed. Accordingly, in many cases the profile that is used to extrapolate wind statistics to various levels is a hypothesis based upon meteorological, design, and operational considerations. To circumvent these problems, an 150-meter meteorological tower was constructed in the vicinity of launch complex 39 at Kennedy Space Center/Eastern Test Range. The tower provides wind speed and direction data at the 18-, 30-, 60-, 90-, 120-, and 150-meter levels. A discussion of the tower and the instrumentation can be found in Reference 5.20. The availability of low level wind

TABLE 5.2.7 PARAMETERS FOR THE GUMBEL DISTRIBUTION AND SELECTED PERCENTILE VALUES FOR HOURLY PEAK WIND SPEED (10-m reference height), ANNUAL REFERENCE PERIOD, FOR THE INDICATED STATIONS

Station	α (knots)$^{-1}$	μ (knots)	Percentiles 80th U=20% (knots)	90th U=10% (knots)	95th U=5% (knots)	99th U=1% (knots)	99.9th U=0.1% (knots)
Huntsville	0.3296	21.04	26	28	30	35	42
New Orleans	0.1735	5.68	15	19	23	32	45
Western Test Range	0.2329	15.14	22	25	28	35	45
Wallops Island	0.2063	15.80	23	27	30	38	39
White Sands	0.1771	16.04	24	29	33	42	55

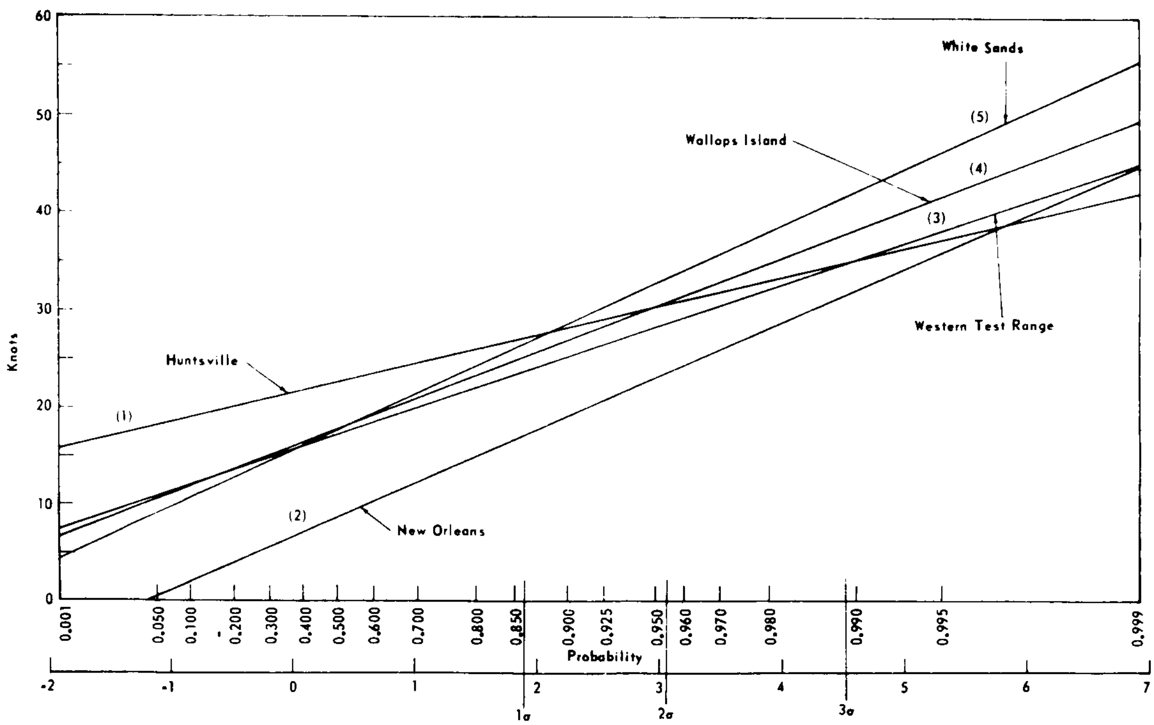

FIGURE 5.2.18 GUMBEL DISTRIBUTIONS FOR HOURLY PEAK WINDS AT THE 10-METER LEVEL FOR STATIONS SPECIFIED

profile data has permitted the atmospheric scientists at NASA's George C. Marshall Space Flight Center to modify and improve this procedure of specifying design wind profiles.

5.2.5.1 Philosophy.

The fundamental wind statistics for the Kennedy Space Center are based upon an 8-year sample of hourly peak wind speeds measured at the 10-meter level with a period of record from September 1958 through June 1967 and a 17-year sample of monthly and yearly peak winds with a period of record from 1950 through 1967. The sample was constructed at the National Weather Records Center, Asheville, North Carolina, by selecting the peak wind speed that occurred in each hour of record read from original wind records. An example of a peak wind speed is given in Figure 5.2.19. Peak wind statistics have three advantages over mean wind statistics. First, peak wind statistics do not depend upon an averaging operation as do mean wind statistics. Second, to construct a mean wind sample, a chart reader or weather observer must perform an "eyeball" average of the wind data, causing the averaging process to vary from day to day, according to the mood of the observer, and from observer to observer. Hourly peak wind speed readings avoid this subjective averaging process. Third, to monitor winds during the countdown phase of a space vehicle launch, it is easier to monitor the peak wind speed rather than the mean wind speed.

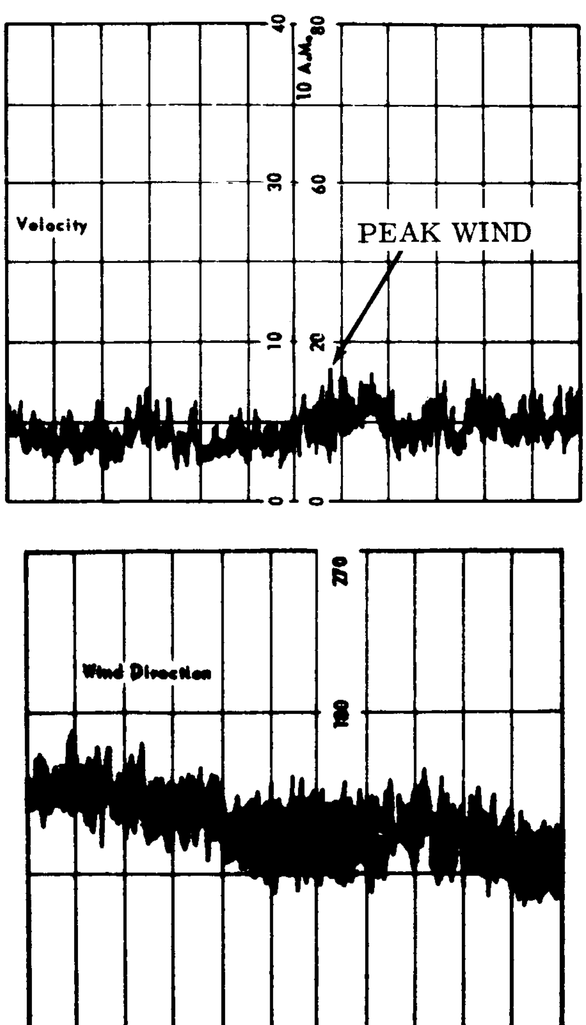

FIGURE 5.2.19 EXAMPLE OF PEAK WIND SPEED RECORDS

Smith et al. (Ref. 5.21) have performed extensive statistical analyses with the Kennedy Space Center and Cape Kennedy peak wind speed sample. In the course of the work, he and collaborators have introduced the concept of exposure period probabilities into the design and operation of space vehicles. By determining the distribution functions of peak wind speeds for various periods of exposure (hour, day, month, year, etc.), it is possible to determine the probability of occurrence of a certain wind speed magnitude occurring during a prescribed period of exposure of a space vehicle to the natural environment. Thus, if an operation requires, for example, one hour to complete, and if the critical wind loads on the space vehicle can be defined in terms of the peak wind speed, then it is the probability of occurrence of the peak wind speed during a 1-hour period that gives a measure of the probable risk of the occurrence of structural failure. Similarly, if an operation requires one day to complete, then it is the probability of occurrence of the peak wind speed during a 1-day period that gives a measure of the probable risk of structural failure.

All probability statements concerning the capabilities of the space vehicles that are launched at NASA's Kennedy Space Center are prescribed in terms of Smith's peak wind speed exposure statistics. The statistics are valid at the 10-meter level* . However, to perform loading and response calculations resulting from steady-state and random turbulence drag loads and von Karman vortex shedding loads, the engineer requires information about the vertical variation of the mean wind and the structure of turbulence in the atmospheric boundary layer. The philosophy at the George C. Marshall Space Flight Center is to extrapolate the peak wind statistics up into the atmosphere via a peak wind profile, and the associated steady-state or mean wind speed profile is obtained by applying a gust factor that is a function of wind speed and height.

5.2.5.2 Peak Wind Profile Shapes for Eastern Test Range.

To develop a peak wind profile model for the Eastern Test Range, approximately 6000 hourly peak wind speed profiles measured during the year of 1967 at the NASA/Kennedy Space Center tower facility were analyzed. The sample was comprised of profiles of hourly peak wind speeds measured at the 18-, 30-, 60-, 90-, 120-, and 150-meter levels. The data appeared to show that the variation of the peak wind speed in the vertical, below 150 meters, could be described with a power law relationship given by

$$u(z) = u_{18.3}\left(\frac{z}{18.3}\right)^{k} , \qquad (1)\ 5.2.5$$

where u(z) is the peak wind speed at height z in meters above natural grade and $u_{18.3}$ is a known peak wind speed at z = 18.3 meters. The peak wind is referenced to the 18.3-meter level because this level has been selected as the standard reference for the launch area, Kennedy Space Center. The parameter k was determined for each profile by a least squares analysis of the data.

* A transformation to the 18.3 meter reference level is made for Kennedy Space Center applications of risk statements. See Section 5.2.5.5.1.

A statistical analysis of the ETR peak wind speed profile data revealed that for engineering purposes, k is distributed normally for any particular value of the peak wind speed at the 18.3-meter level. Thus, for a given percentile level of occurrence, it was found that for peak wind speeds at the 18.3-meter level less than approximately 2 ms^{-1}, k is approximately equal to a constant, while for peak wind speeds greater than approximately 2 ms^{-1}

$$k = cu_{18.3}^{-3/4} , \qquad (2)\ 5.2.5$$

where $u_{18.3}$ has the units of meter per second. The parameter, c, for engineering purposes, is distributed normally with mean value 0.52 and standard deviation 0.36. The distribution of k as a function $u_{18.3}$ is depicted in Figure 5.2.20. The $\bar{k} + 3\sigma$ values are used in design studies.

5.2.5.3 Instantaneous Extreme Wind Profiles.

The probability that the hourly peak wind speeds at all levels occur simultaneously is small. Accordingly, the practice of using peak wind profiles introduces some conservatism into the design criteria.

To gain some insight into this question, approximately 35 hours of digitized magnetic tape data were analyzed. The data were digitized at 0.1-second intervals in real time and partitioned into 0.5-, 2-, 5-, and 10-minute samples. The vertical average peak wind speed $\bar{u}_P$ and the 18-meter mean wind $\bar{u}_{18}$ were calculated for each sample. In addition, the instantaneous vertical average wind speed time history at 0.1-second intervals was calculated for each sample, and the peak instantaneous vertical average wind speed $\bar{u}_I$ was selected from each sample. The quantity $\bar{u}_I/\bar{u}_P$ was then interpreted to be a measure of how well the peak wind profile approximates the instantaneous extreme wind profile. Figure 5.2.21 is a plot of $\bar{u}_I/\bar{u}_P$ as a function of $\bar{u}_{18}$. The data points tend to scatter about a mean value of $\bar{u}_I/\bar{u}_P \simeq 0.93$, which could mean that the peak wind profile will result in an overestimate of ground wind loads by approximately 14 percent. However,

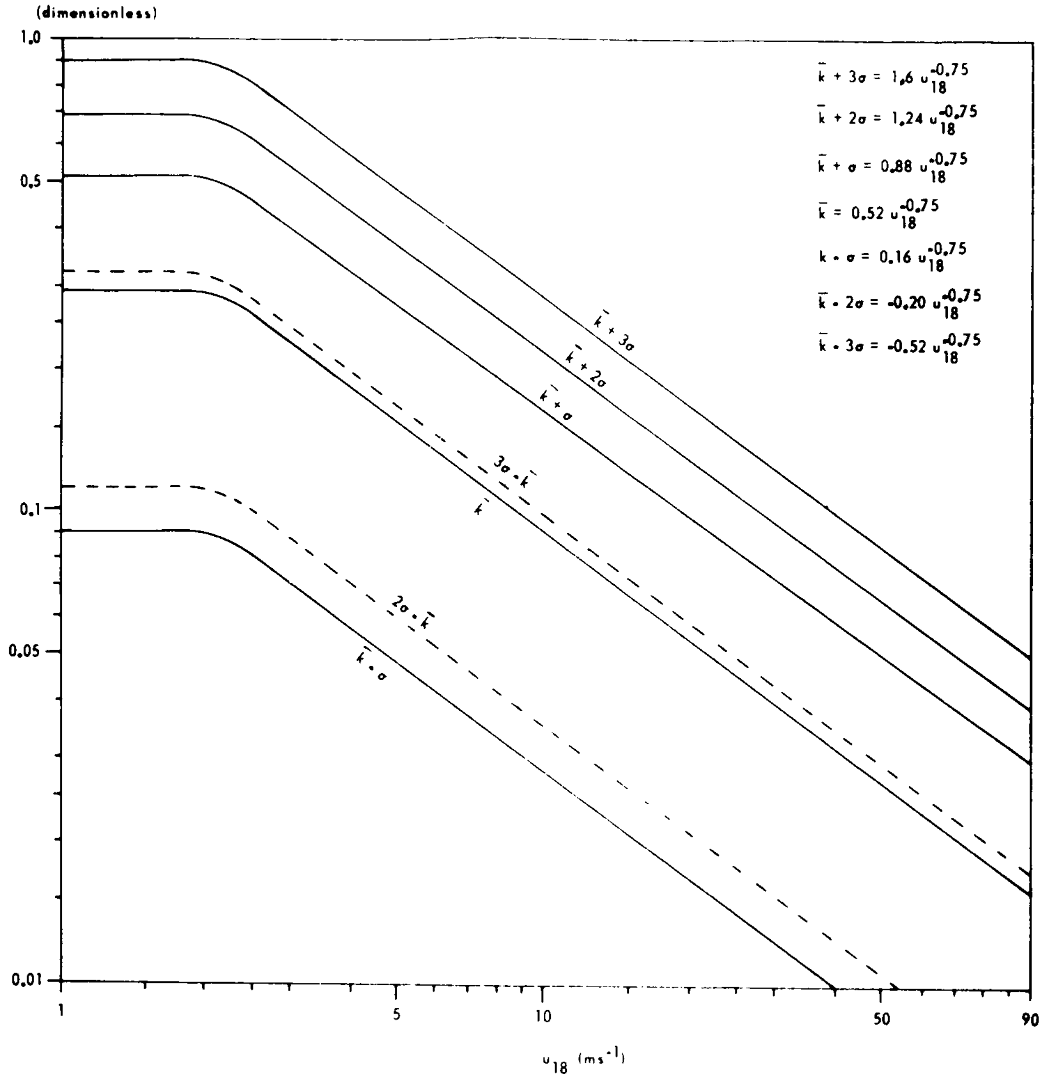

FIGURE 5.2.20 DISTRIBUTION OF THE PEAK WIND PROFILE PARAMETER k FOR VARIOUS WIND SPEEDS AT THE 18.3-METER LEVEL FOR THE EASTERN TEST RANGE

some of the data points have values equal to 0.98, which could mean an over-estimate of the loads by only 4 percent. Figure 5.2.22 gives the average values of $\bar{u}_I/\bar{u}_P$ as a function of $\bar{u}_{18}$ for different averaging times (0.5, 2, 5, and 10 minutes).

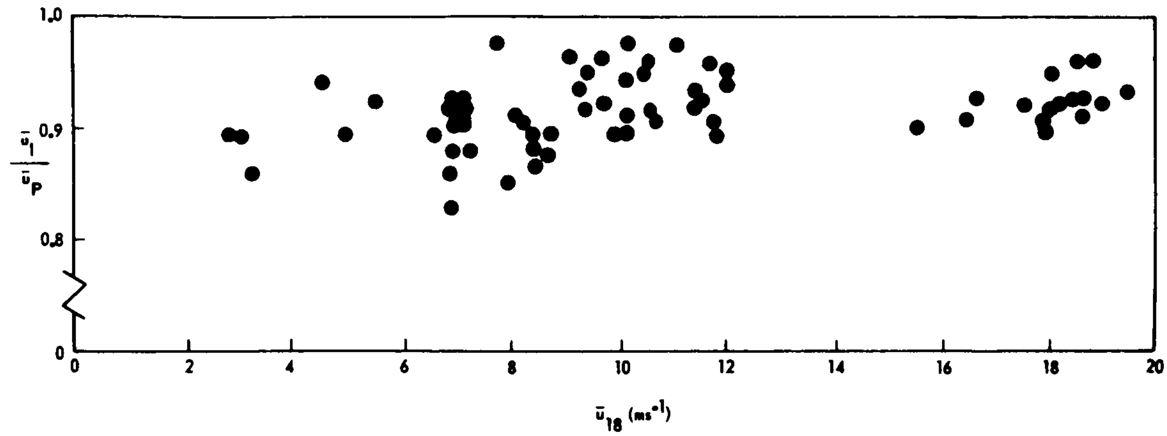

FIGURE 5.2.21 THE RATIO $\bar{u}_I/\bar{u}_P$ AS A FUNCTION OF THE 18.3 METER MEAN WIND SPEED ($\bar{u}_{18}$) FOR A 10-MINUTE SAMPLING PERIOD

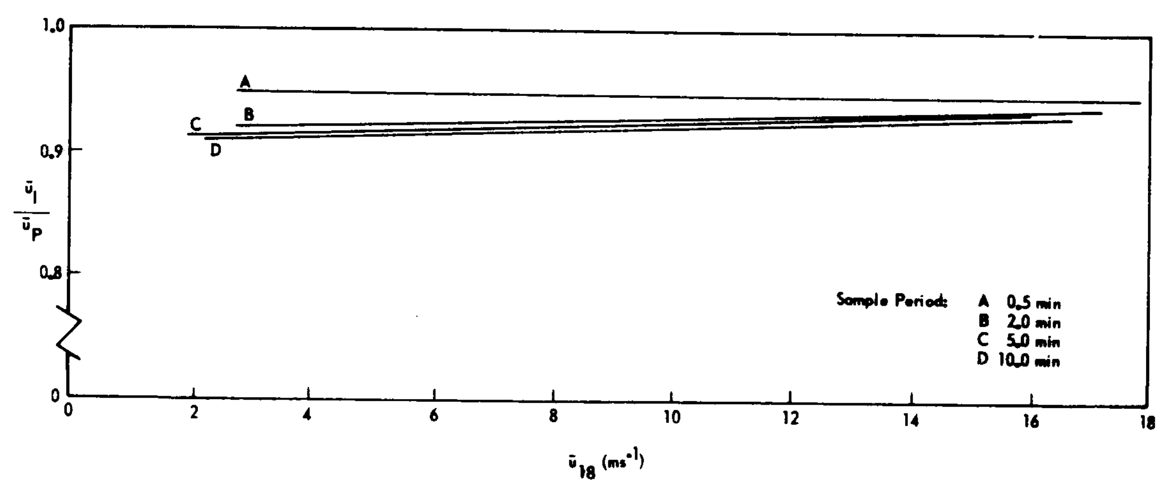

FIGURE 5.2.22 THE RATIO $\bar{u}_I/\bar{u}_P$ AS A FUNCTION OF THE 18.3 METER MEAN WIND SPEED ($\bar{u}_{18}$) FOR VARIOUS SAMPLING PERIODS

5.2.5.4 Peak Wind Profile Shapes for Other Test Ranges and Sites.

Wind profile statistics like those presented in Section 5.2.5.2 are not available for other test ranges and sites. However, the exponent k in

Equation (1) 5.2.5 is a function of wind speed, surface roughness, etc. For moderate surface roughness conditions, the extreme value of k is usually equal to 0.2 or less during high winds ($\sim 15\ ms^{-1}$). For design and planning purposes for test ranges and sites other than the Eastern Test Range, it is recommended that the values of k given in Table 5.2.8 be used:

TABLE 5.2.8 VALUES OF k TO USE FOR TEST RANGES OTHER THAN THE EASTERN TEST RANGE

k Value	18.3-Meter Level Peak Wind Speed (ms^{-1})
k = 0.2	$7 \leq u_{18.3} < 22$
k = 0.14	$22 \leq u_{18.3}$

The above values of k are the only values used in this report for sites other than the Eastern Test Range and represent estimates for 99.87 percentile-mean + 3σ (0.13 percent risk) values for the profile shape.

5.2.5.5 Design Wind Profiles.

The data presented in this section provide basic wind speed profile (envelope) information for use in studies to determine load factors for test, free-standing, launch, and lift-off conditions to ensure satisfactory performance of the space vehicle. To establish vehicle design requirements, the surface winds are assumed to act normal to the longitudinal axis of the vehicle on the launch pad and to be from the most critical direction.

5.2.5.5.1 Design Wind Profiles for the Eastern Test Range.

Peak wind profiles are characterized by two parameters, the peak wind speed at the 18.3-meter level and the shape parameter k. Once these two quantities are defined, the peak wind speed profile is completely specified. Accordingly, to construct a peak wind profile for the Eastern Test Range, in the context of launch vehicle loading and response calculations, two pieces of information are required. First, the risk value acceptable for exposing the vehicle for a given period must be specified. Once this quantity is given, the design peak wind speed at the 10-meter reference level is automatically specified (See section 5.2.4). Second, the risk associated with losing the vehicle once the 10-meter reference level design wind occurs must be specified. This second quantity and the 10-meter peak wind speed will determine the value of k that is to be used in Equation (1) 5.2.5. To apply Equations (1) 5.2.5 and (2) 5.2.5 to the peak wind statistics valid at 10 meters, Equation (1) 5.2.5 is evaluated at z = 10 meters, and it is assumed that the resulting relationship can be inverted to yield $u_{18.3}$ as a function of the 10-meter level peak wind speed u_{10} for a fixed value of c. This function is then combined with Equation (2) 5.2.5 to yield k as a function of u_{10} for a given value of c. The validity of this inversion process is open to question because Equation (1) 5.2.5 is a stochastic relationship. However, preliminary analyses of profiles that include peak wind information obtained at the 10-meter level appear to show that this inversion is valid.

It is recommended that the $\bar{k} + 3\sigma$ value of k be used for the design and operation of space vehicles. Thus, if a space vehicle, designed to withstand a particular value of the peak wind speed at the 10-meter level, is exposed to that peak wind speed, the vehicle has at least a 99.87-percent chance of withstanding possible peak wind speed profile conditions.

Table 5.2.9 contains peak wind speed profiles associated with the 3σ values of k for various values of risk of exceeding the indicated 10-meter level peak wind speeds for 1-hour exposure period based upon an annual reference period. Thus, for example, there is a 20-percent risk that the peak wind speed, at the 10-meter (33-ft) level, will exceed 16.43 knots if the vehicle is exposed to the natural environment during any arbitrary hour of the year, and if the peak wind speed of 16.43 knots occurs at the 10-meter level, then there is only a 0.135-percent chance of the peak wind speed exceeding 35.55 knots at the 152.4-meter (500-ft) level. Similar comments can be made about the other levels given in Table 5.2.9.

Tables 5.2.10 through 5.2.12 contain peak wind speed profiles associated with the 3σ values of k for various periods of exposure for 10-, 5-, and 1-percent risk values of exceeding the indicated 10-meter level peak wind speeds based upon an annual period of reference. Thus, for example, according to Table 5.2.11, there is a 5-percent risk that the peak wind speed, at the 10-meter level, will exceed 50.9 knots during any arbitrary 30-day period of the year, and if the wind speed of 50.9 knots occurs at the 10-meter level, then there is only a 0.135-percent chance that the 152.4-meter level peak wind speed will exceed 72.5 knots.

Tables 5.2.9 through 5.2.12 are valid for an annual reference period; however, the risks of encountering the indicated peak wind speeds at the 10-meter level will be larger or smaller in some months than in other months. For example, the month of February has higher hourly peak wind

TABLE 5.2.9* PEAK WIND SPEED PROFILES FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED FOR 1-HOUR EXPOSURE (annual reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	16.4	8.5	19.9	10.3	23.3	12.0	30.9	15.9	41.7	21.5
18.3	60	19.5	10.0	23.2	11.9	26.7	13.7	34.6	17.8	45.7	23.5
30.5	100	22.5	11.6	26.3	13.5	29.9	15.4	38.0	19.5	49.3	25.4
61.0	200	27.4	14.1	31.3	16.1	34.9	18.0	43.2	22.2	54.7	28.1
91.4	300	30.8	15.8	34.6	17.8	38.2	19.7	46.5	23.9	58.1	29.9
121.9	400	33.4	17.2	37.2	19.1	40.8	21.0	49.0	25.2	60.6	31.2
152.4	500	35.6	18.3	39.3	20.2	42.9	22.1	51.1	26.3	62.7	32.3

TABLE 5.2.10* PEAK WIND SPEED PROFILES FOR A 10-PERCENT RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE (annual reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	27.6	14.2	40.4	20.8	46.6	24.0	52.7	27.1	60.5	31.1
18.3	60	31.1	16.0	44.4	22.8	50.6	26.0	56.9	29.3	64.9	33.4
30.5	100	34.5	17.7	48.0	24.7	54.3	28.0	60.7	31.2	68.8	35.4
61.0	200	39.6	20.4	53.3	27.4	59.8	30.8	66.3	34.1	74.5	38.3
91.4	300	42.9	22.1	56.7	29.2	63.3	32.6	69.8	35.9	78.0	40.1
121.9	400	45.5	23.4	59.3	30.5	65.8	33.9	72.3	37.2	80.6	41.5
152.4	500	47.5	24.4	61.3	31.5	67.9	34.9	74.4	38.3	82.7	42.5

* NOT RECOMMENDED FOR DESIGN APPLICATIONS--INFORMATION ONLY.

TABLE 5.2.11* PEAK WIND SPEED PROFILES FOR A 5-PERCENT RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE (annual reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	31.0	15.9	44.5	22.9	50.9	26.2	57.3	29.5	65.5	33.7
18.3	60	34.7	17.9	48.5	25.0	55.1	28.4	61.6	31.7	69.9	36.0
30.5	100	38.1	19.6	52.2	26.9	58.8	30.3	65.5	33.7	73.9	38.0
61.0	200	43.3	22.3	57.7	29.7	64.4	33.1	71.1	36.6	79.7	41.0
91.4	300	46.6	24.0	61.0	31.4	67.9	34.9	74.7	38.4	83.3	42.9
121.9	400	49.2	25.3	63.6	32.7	70.5	36.3	72.3	37.2	85.9	44.2
152.4	500	51.2	26.3	65.7	33.8	72.5	37.3	79.4	40.8	88.0	45.3

TABLE 5.2.12* PEAK WIND SPEED PROFILES FOR A 1-PERCENT RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE (annual reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	38.8	20.0	53.6	27.6	60.7	31.2	67.8	34.9	76.8	39.5
18.3	60	42.7	22.0	57.9	29.8	65.1	33.5	72.3	37.2	81.4	41.9
30.5	100	46.3	23.8	61.7	31.7	69.0	35.5	76.3	39.3	85.6	44.0
61.0	200	51.6	26.5	67.3	34.6	74.7	38.4	82.2	42.3	91.5	47.1
91.4	300	55.0	28.3	70.8	36.4	78.3	40.3	85.7	44.1	95.2	49.0
121.9	400	57.5	29.6	73.4	37.8	80.9	41.6	88.4	45.5	97.9	50.4
152.4	500	59.6	30.7	75.5	38.8	83.0	42.7	90.5	46.6	100.0	51.4

* NOT RECOMMENDED FOR DESIGN APPLICATIONS--INFORMATION ONLY.

speeds at the 10-meter level than the peak wind speeds given in Table 5.2.9 for the quoted values of risk, whereas May is characterized by lower hourly peak wind speeds for the same values of risk. In addition, the peak wind speed associated with a given risk is also a function of time of day. Thus, for a given value of risk, the peak wind speed in the afternoon is greater than the peak wind speed in the early morning hours. For design purposes these effects have been taken into account in constructing Tables 5.2.13 through 5.2.16 by introducing the concept of the envelope of distribution functions.

Table 5.2.13 contains peak wind speed profiles for various envelope values of peak wind speed at the 10-meter level for fixed values of risk for the worst monthly-hourly reference periods of the year for a 1-hour exposure. To construct these profiles, the 1-hour exposure period statistics for each hour in each month were constructed. This exercise yielded 288 distribution functions (12 months times 24 hours), which were enveloped to yield the largest or "worst" 10-meter level peak wind speed associated with a given level of risk for all monthly-hourly reference periods. Thus, for example, according to Table 5.2.13, there is at most a 10-percent risk that the peak wind speed will exceed 26.9 knots during any particular hour in any particular month at the 10-meter level, and if 26.9 knots occur at the 10-meter level, then there is only a 0.135-percent chance that the peak wind speed will exceed 46.8 knots at the 152.4-meter level or the corresponding values given at the other heights.

Table 5.2.14 through 5.2.16 contain peak wind profiles for various envelope values of the peak wind speed at the 10-meter level for fixed values of risk for various exposure periods. The 1-day exposure values of peak wind speed were obtained by constructing the daily peak wind statistics for each month and then enveloping these distributions to yield the worst 1-day exposure, 10-meter level peak wind speed for a specified value of risk. The 30-day exposure envelope peak wind speeds were obtained by constructing the monthly peak wind statistics for each month and then constructing the envelope of the distributions. The 10-day exposure statistics were obtained by interpolating between the 1- and 30-day exposure period results. The envelopes of the 90-day exposure period statistics were the 90-day exposure statistics associated with the 12 trimonthly periods (January-February-March, February-March-April, March-April-May, and so forth). Finally, the 365-day exposure period statistics were calculated with the annual peak wind sample (17 data points) to yield one distribution. Tables 5.2.14 through 5.2.16 contain the largest or "worst" 10-meter level peak wind speed associated with a given level of risk for the stated exposure periods.

TABLE 5.2.13* PEAK WIND SPEED PROFILES FOR VARIOUS ENVELOPE VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED FOR 1-HOUR EXPOSURE BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	22.9	11.8	27.0	13.9	30.8	15.8	39.5	20.3	51.9	26.7
18.3	60	26.3	13.5	30.5	15.7	34.5	17.7	43.4	22.3	56.0	28.8
30.5	100	29.5	15.2	33.8	17.4	37.9	19.5	47.0	24.2	59.8	30.8
61.0	200	34.5	17.8	38.9	20.0	43.0	22.1	52.3	26.9	65.4	33.6
91.4	300	37.8	19.5	42.2	21.7	46.4	23.9	55.7	28.7	68.9	35.4
121.9	400	40.4	20.8	44.7	23.0	48.9	25.2	58.3	30.0	71.5	36.8
152.4	500	42.5	21.9	46.8	24.1	51.0	26.2	60.3	31.0	73.6	37.8

TABLE 5.2.14* PEAK WIND SPEED PROFILES FOR A 10-PERCENT ENVELOPE RISK VALUE OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	32.1	16.5	46.9	24.1	53.9	27.7	61.0	31.4	70.0	36.0
18.3	60	35.8	18.4	51.0	26.2	58.2	29.9	65.3	33.6	74.5	38.3
30.5	100	39.2	20.2	54.7	28.1	62.0	31.9	69.3	35.7	78.5	40.4
61.0	200	44.4	22.8	60.2	31.0	67.6	34.8	75.0	38.6	84.4	43.4
91.4	300	47.8	24.6	63.6	32.7	71.1	36.6	78.5	40.4	88.0	45.3
121.9	400	50.3	25.9	66.2	34.1	73.7	37.9	81.1	41.7	90.6	46.6
152.4	500	52.4	27.0	68.3	35.1	75.8	39.0	83.2	42.8	92.8	47.7

* RECOMMENDED FOR DESIGN APPLICATIONS

TABLE 5.2.15* PEAK WIND SPEED PROFILES FOR A 5-PERCENT ENVELOPE RISK VALUE OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	36.1	18.5	52.3	26.9	60.1	30.9	67.8	34.9	77.7	40.0
18.3	60	39.8	20.5	56.5	29.1	64.4	33.1	72.3	37.2	82.4	42.4
30.5	100	43.3	22.3	60.3	31.0	68.3	35.1	76.3	39.3	86.5	44.5
61.0	200	48.6	25.0	65.9	33.9	74.0	38.1	82.1	42.2	92.5	47.6
91.4	300	52.0	26.8	69.4	35.7	77.6	40.0	85.7	44.1	96.1	49.4
121.9	400	54.5	28.0	72.0	37.0	80.2	41.3	88.4	45.5	98.8	50.8
152.4	500	56.6	29.1	74.1	38.1	82.3	42.3	91.0	46.8	101.0	52.0

TABLE 5.2.16* PEAK WIND SPEED PROFILES FOR A 1-PERCENT ENVELOPE RISK VALUE OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	45.0	23.1	65.4	33.6	74.0	38.1	83.4	42.9	95.4	49.1
18.3	60	49.0	25.2	69.9	36.0	78.6	40.4	88.2	45.4	100.3	51.6
30.5	100	52.6	27.1	73.9	38.0	82.8	42.6	92.4	47.5	104.7	53.9
61.0	200	58.1	30.0	79.7	41.0	88.6	45.6	98.4	50.6	110.9	57.1
91.4	300	61.5	31.6	83.2	42.8	92.3	47.5	102.1	52.5	114.6	59.0
121.9	400	64.1	33.0	85.9	44.2	95.0	48.9	104.8	53.9	117.4	60.4
152.4	500	66.1	34.0	88.0	45.3	97.1	50.0	107.0	55.0	119.6	61.5

* RECOMMENDED FOR DESIGN APPLICATIONS

It is recommended that the data in Tables 5.2.13 through 5.2.16 be used as the basis for space vehicle design for Cape Kennedy — Kennedy Space Center Operations. Wind profile statistics for the design of permanent ground support equipment are discussed in Section 5.2.6.

Mean wind profiles or steady-state wind profiles can be obtained from the peak wind profiles by dividing the peak wind by the appropriate gust factor (see Section 5.2.7). It is recommended that the 10-minute gust factors be used for structural design purposes. Application of the 10-minute gust factors to the peak wind profile corresponds to averaging the wind speed over a 10-minute period. This averaging period appears to result in a stable mean value of the wind speed. Within the range of variation of the data, the 1-hour and 10-minute gust factors are approximately equal for sufficiently high wind speed. This occurs because the spectrum of the horizontal wind speed near the ground is characterized by a broad energy gap centered at a frequency approximately equal to 1 cycle hr^{-1} and typically extends over the frequency domain 0.5 cycles $hr^{-1} < \omega < 5$ cycles hr^{-1} (Ref. 5.22). The Fourier spectral components associated with frequencies less than 1 cycles hr^{-1} correspond to the meso- and synoptic-scale motions, while the remaining high frequency spectral components correspond to mechanically and thermally produced turbulence. Thus, a statistically stable estimate of the mean or steady-state wind speed can be obtained by averaging over a period in the range from 10-minutes to an hour. Davenport (Ref. 5.5) points out that this period for averaging is also suitable for structural analysis. Since this period is far longer than any natural period of structural vibration, it assures that effects caused by the mean wind properly represent steady-state, nontransient effects. The steady-state wind profiles, calculated with the 10-minute gust factors, that correspond to those in Tables 5.2.9 through 5.2.16 are given in Tables 5.2.17 through 5.2.24.

5.2.5.5.2 Design Wind Profiles for Other Test Ranges.

At the present time, only estimates of the 1-hour exposure period peak wind speed statistics for an annual reference period are available for Huntsville, Alabama, Wallops Island, Virginia, White Sands Missile Range, New Mexico, and the Western Test Range (WTR), Point Arguello, California. The peak wind statistics were constructed from mean wind data obtained from standard hourly weather observations. These data correspond to approximately a 2-minute mean wind speed measured at the 10-meter level. The associated peak wind sample was constructed by applying a 1.4 gust factor. The surface peak and mean wind speed profiles for the above sites for various values of risk of exceeding the indicated 10-meter level peak or mean wind speed, calculated with the values of k given in Section 5.2.5.5, are given in Tables 5.2.25 through 5.2.34.

TABLE 5.2.17 MEAN WIND SPEED PROFILES FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED FOR 1-HOUR EXPOSURE (annual reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Risk (%)									
		20		10		5				0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots 1	ms^{-1}	knots	ms^{-1}
10.0	33	9.8	5.1	12.1	6.3	14.3	7.4	19.2	9.9	26.0	13.4
18.3	60	12.3	6.3	14.9	7.7	17.3	8.9	22.7	11.7	30.2	15.6
30.5	100	14.8	7.6	17.6	9.1	20.3	10.4	26.1	13.5	34.2	17.6
61.0	200	19.0	9.8	22.1	11.4	25.0	12.9	31.4	16.1	40.1	20.6
91.4	300	21.9	11.3	25.1	12.9	28.1	14.5	34.8	17.9	43.8	22.5
121.9	400	24.2	12.4	27.5	14.2	30.6	15.8	37.4	19.2	46.6	24.0
152.4	500	26.1	13.4	29.5	15.1	32.6	16.8	39.5	20.3	48.9	25.2

TABLE 5.2.18 MEAN WIND SPEED PROFILES FOR A 10-PERCENT RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE (annual reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		**Exposure (days)**									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	17.1	8.8	25.2	13.0	29.1	15.0	32.9	16.9	37.8	19.4
18.3	60	20.4	10.5	29.4	15.1	33.6	17.3	37.8	19.4	43.1	22.2
30.5	100	23.6	12.1	33.3	17.1	37.7	19.4	42.2	21.7	47.8	24.6
61.0	200	28.7	14.8	39.1	20.1	43.9	22.6	48.7	25.1	54.8	28.2
91.4	300	32.0	16.5	42.8	22.0	47.8	24.6	52.8	27.2	59.1	30.4
121.9	400	34.5	17.7	45.6	23.5	50.7	26.1	55.8	28.7	62.2	32.0
152.4	500	36.6	18.8	47.8	24.6	53.0	27.3	58.2	29.9	64.7	33.3

TABLE 5.2.19 MEAN WIND SPEED PROFILES FOR A 5-PERCENT RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE (annual reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	19.3	9.9	27.8	14.3	31.8	16.4	35.8	18.4	40.9	21.0
18.3	60	22.8	11.7	32.2	16.6	36.5	18.8	40.9	21.0	46.5	23.9
30.5	100	26.3	13.5	36.2	18.6	40.9	21.0	45.5	23.4	51.4	26.4
61.0	200	31.4	16.2	42.3	21.8	47.3	24.3	52.3	26.9	58.6	30.1
91.4	300	34.9	18.0	46.1	23.7	51.3	26.4	56.5	29.1	63.0	32.4
121.9	400	37.5	19.3	49.0	25.2	54.3	27.9	59.6	30.7	66.3	34.1
152.4	500	39.7	20.4	51.3	26.4	56.7	29.2	62.1	31.9	68.9	35.4

TABLE 5.2.20 MEAN WIND SPEED PROFILES FOR A 1-PERCENT RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE (annual reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	24.2	12.4	33.5	17.2	38.0	19.5	42.4	21.8	48.0	24.7
18.3	60	28.2	14.5	38.4	19.8	43.2	22.2	48.0	24.7	54.1	27.8
30.5	100	32.0	16.5	42.9	22.1	48.0	24.7	53.1	27.3	59.6	30.7
61.0	200	37.8	19.4	49.4	25.4	54.9	28.2	60.4	31.1	67.3	34.6
91.4	300	41.4	21.3	53.5	27.5	59.2	30.5	64.9	33.4	72.1	37.1
121.9	400	44.2	22.7	56.5	29.1	62.4	32.1	68.2	35.1	75.6	38.9
152.4	500	46.4	23.9	59.0	30.3	64.9	33.4	70.8	36.4	78.3	40.3

TABLE 5.2.21 MEAN WIND SPEED PROFILES FOR VARIOUS ENVELOPE VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED FOR A 1-HOUR EXPOSURE (monthly-hourly reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	14.1	7.2	16.6	8.6	19.1	9.8	24.6	12.7	32.4	16.7
18.3	60	17.1	8.8	19.9	10.3	22.6	11.7	28.7	14.8	37.2	19.1
30.5	100	20.0	10.3	23.1	11.9	26.0	13.4	32.6	16.8	41.6	21.4
61.0	200	24.7	12.7	28.1	14.5	31.3	16.1	38.3	19.7	48.1	24.7
91.4	300	27.8	14.3	31.3	16.1	34.7	17.9	42.0	21.6	52.1	26.8
121.9	400	30.3	15.6	33.9	17.4	37.3	19.2	44.8	23.0	55.1	28.3
152.4	500	32.3	16.6	35.9	18.5	39.4	20.3	47.0	24.2	57.5	29.6

TABLE 5.2.22 MEAN WIND SPEED PROFILES FOR A 10-PERCENT ENVELOPE RISK VALUE OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE (monthly-hourly reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	20.0	10.3	29.3	15.1	33.7	17.3	38.1	19.6	43.8	22.5
18.3	60	23.6	12.1	33.8	17.4	38.7	19.9	43.3	22.3	49.5	25.5
30.5	100	27.1	13.9	38.0	19.5	43.1	22.2	48.2	24.8	54.6	28.1
61.0	200	32.4	16.7	44.2	22.7	49.6	25.5	55.1	28.3	62.1	31.9
91.4	300	35.8	18.4	48.1	24.7	53.8	27.7	59.4	30.6	66.6	34.3
121.9	400	38.5	19.8	51.0	26.2	56.8	29.2	62.6	32.2	69.9	36.0
152.4	500	40.6	20.9	53.3	27.4	59.2	30.5	65.1	33.5	72.6	37.3

TABLE 5.2.23 MEAN WIND SPEED PROFILES FOR A 5-PERCENT ENVELOPE RISK VALUE OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE (monthly-hourly reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	22.5	11.6	32.7	16.8	37.6	19.3	42.5	21.9	48.6	25.0
18.3	60	26.3	13.5	37.5	19.3	42.8	22.0	48.1	24.7	54.8	28.2
30.5	100	30.0	15.4	41.9	21.6	47.5	24.4	53.2	27.4	60.2	31.0
61.0	200	35.5	18.3	48.4	24.9	54.5	28.0	60.4	31.1	68.1	35.0
91.4	300	39.2	20.2	52.5	27.0	58.7	30.2	64.9	33.4	72.9	37.5
121.9	400	41.9	21.6	55.5	28.6	61.9	31.8	68.2	35.1	76.3	39.3
152.4	500	44.0	22.6	57.9	29.8	64.4	33.1	70.9	36.4	79.1	40.7

TABLE 5.2.24 MEAN WIND SPEED PROFILES FOR A 1-PERCENT ENVELOPE RISK VALUE OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED FOR VARIOUS PERIODS OF EXPOSURE (annual reference period) BASED UPON 3σ VALUES OF k, CAPE KENNEDY, FLORIDA

Height		Exposure (days)									
		1		10		30		90		365	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	28.1	14.5	40.9	21.0	46.3	23.8	52.2	26.9	59.7	30.7
18.3	60	32.5	16.7	46.5	23.9	52.2	26.9	58.6	30.1	66.7	34.3
30.5	100	36.6	18.8	51.4	26.4	57.6	29.6	64.3	33.1	72.9	37.5
61.0	200	42.6	21.9	58.6	30.1	65.2	33.5	72.5	37.3	81.6	42.0
91.4	300	47.2	24.3	63.0	32.4	69.9	36.0	77.4	39.8	86.9	44.7
121.9	400	49.4	25.4	66.3	34.1	73.4	37.8	81.0	41.7	90.7	46.7
152.4	500	51.7	26.6	68.9	35.4	76.1	39.1	83.8	43.1	93.7	48.2

TABLE 5.2.25 SURFACE PEAK WIND SPEED PROFILE ENVELOPES FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED (annual reference period) FOR HUNTSVILLE, ALABAMA

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	26.0	13.4	28.0	14.4	30.0	15.4	35.0	18.0	42.0	21.6
18.3	60	29.4	15.1	31.6	16.3	33.9	17.4	39.5	20.3	47.4	24.4
30.5	100	32.5	16.7	35.0	18.0	37.5	19.3	43.7	22.5	52.5	27.0
61.0	200	37.3	19.2	40.2	20.7	43.1	22.2	50.2	25.8	60.3	31.0
91.4	300	40.5	20.8	43.6	22.4	46.8	24.1	54.5	28.0	65.4	33.4
121.9	400	43.0	22.1	46.2	23.8	49.5	25.5	57.7	29.7	69.3	35.7
152.4	500	44.9	23.1	48.3	24.8	51.8	26.6	60.4	31.1	72.4	37.2

TABLE 5.2.26 SURFACE MEAN WIND SPEED PROFILE ENVELOPES FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED (annual reference period) FOR HUNTSVILLE, ALABAMA

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	18.6	9.6	20.0	10.3	21.4	11.0	25.0	12.9	30.0	15.4
18.3	60	21.0	10.8	22.6	11.6	24.2	12.4	28.2	14.5	33.9	17.4
30.5	100	23.2	11.9	25.0	12.9	26.8	13.8	31.2	16.1	37.5	19.3
61.0	200	26.6	13.7	28.7	14.8	30.8	15.8	35.9	18.5	43.1	22.2
91.4	300	28.9	14.9	31.1	16.0	33.4	17.2	38.9	20.0	46.7	24.0
121.9	400	30.7	15.8	33.0	17.0	35.4	18.2	41.2	21.2	49.5	25.5
152.4	500	32.1	16.5	34.5	17.7	37.0	19.0	43.1	22.2	51.7	26.6

TABLE 5.2.27 SURFACE PEAK WIND SPEED PROFILE ENVELOPES (in knots) FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED (annual reference period) FOR NEW ORLEANS AND FOR RIVER, GULF, AND PANAMA CANAL TRANSPORTATION

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	15.0	7.7	19.0	9.8	23.0	11.8	32.0	16.5	45.0	23.1
18.3	60	17.0	8.7	21.5	11.1	26.0	13.4	36.2	18.6	49.0	25.2
30.5	100	18.8	9.7	23.8	12.2	28.8	14.8	40.1	20.6	52.6	27.1
61.0	200	21.6	11.1	27.4	14.1	33.1	17.0	46.1	23.7	58.0	29.8
91.4	300	23.5	12.1	29.7	15.3	35.9	18.5	49.9	25.7	61.4	31.6
121.9	400	24.8	12.8	31.4	16.2	38.0	19.5	52.9	27.2	63.9	32.9
152.4	500	26.0	13.4	32.9	16.9	39.7	20.4	55.3	28.4	65.9	33.9

TABLE 5.2.28 SURFACE MEAN WIND SPEED PROFILE ENVELOPES (in knots) FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED (annual reference period) FOR NEW ORLEANS AND FOR RIVER, GULF, AND PANAMA CANAL TRANSPORTATION

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	10.7	5.5	13.6	7.0	16.4	8.4	22.9	11.8	32.1	16.5
18.3	60	12.1	6.2	15.4	7.9	18.6	9.6	25.9	13.3	35.0	18.0
30.5	100	13.4	6.9	17.0	8.7	20.6	10.6	28.6	14.7	37.6	19.3
61.0	200	15.4	7.9	19.6	10.1	23.6	12.1	32.9	16.9	41.4	21.3
91.4	300	16.8	8.6	21.2	10.9	26.4	13.6	35.6	18.3	43.9	22.6
121.9	400	17.7	9.1	22.4	11.5	27.1	13.9	37.8	19.4	45.6	23.5
152.4	500	18.6	9.6	23.5	12.1	28.4	14.6	39.5	20.3	47.1	24.2

TABLE 5.2.29 SURFACE PEAK WIND SPEED PROFILE ENVELOPES (in knots) FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED (annual reference period) FOR THE WESTERN TEST RANGE, WEST COAST TRANSPORTATION, AND SACRAMENTO

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	22.0	11.3	25.0	12.9	28.0	14.4	35.0	18.0	45.0	23.1
18.3	60	24.9	12.8	28.3	14.6	31.6	16.3	39.5	20.3	50.8	26.1
30.5	100	27.6	14.2	31.3	16.1	35.0	18.0	43.7	22.5	56.3	29.0
61.0	200	31.7	16.3	36.0	18.5	40.2	20.7	50.2	25.8	64.6	33.2
91.4	300	34.3	17.6	39.0	20.1	43.6	22.4	54.5	28.0	70.1	36.1
121.9	400	36.4	18.7	41.4	21.3	46.2	23.8	57.7	29.7	74.2	38.2
152.4	500	38.0	19.5	43.2	22.2	48.3	24.8	60.4	31.1	77.6	39.9

TABLE 5.2.30 SURFACE MEAN WIND SPEED PROFILE ENVELOPES (in knots) FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED (annual reference period) FOR THE WESTERN TEST RANGE, WEST COAST TRANSPORTATION, AND SACRAMENTO

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	15.7	8.1	17.9	9.2	20.0	10.3	25.0	12.9	32.1	16.5
18.3	60	17.8	9.2	20.2	10.4	22.6	11.6	28.2	14.5	36.3	18.7
30.5	100	19.7	10.1	22.4	11.5	25.0	12.9	31.2	16.1	40.2	20.7
61.0	200	22.6	11.6	25.7	13.2	28.7	14.8	35.9	18.5	46.1	23.7
91.4	300	24.5	12.6	27.9	14.4	31.1	16.0	38.9	20.0	50.1	25.8
121.9	400	26.0	13.4	29.6	15.2	33.0	17.0	41.2	21.2	53.0	27.3
152.4	500	27.1	13.9	30.9	15.9	34.5	17.7	43.1	22.2	55.4	28.5

TABLE 5.2.31 SURFACE PEAK WIND SPEED PROFILE ENVELOPES (in knots) FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED (annual reference period) FOR WALLOPS TEST RANGE

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	23.0	11.8	27.0	13.9	30.0	15.4	38.0	19.5	39.0	20.1
18.3	60	26.0	13.4	30.5	15.7	33.9	17.4	42.9	22.1	44.1	22.7
30.5	100	28.8	14.8	33.8	17.4	37.5	19.3	47.5	24.4	48.8	25.1
61.0	200	33.1	17.0	38.8	20.0	43.1	22.2	54.6	28.1	56.1	28.9
91.4	300	35.9	18.5	42.1	21.6	46.8	24.1	59.2	30.5	60.8	31.3
121.9	400	38.0	19.5	44.7	23.0	49.5	25.5	62.7	32.3	64.4	33.1
152.4	500	39.7	20.4	46.6	24.0	51.8	26.6	65.5	33.7	67.4	34.7

TABLE 5.2.32 SURFACE MEAN WIND SPEED PROFILE ENVELOPES (in knots) FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED (annual reference period) FOR WALLOPS TEST RANGE

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	16.4	8.4	19.3	9.9	21.4	11.0	27.1	13.9	27.9	14.4
18.3	60	18.6	9.6	21.8	11.2	24.2	12.4	30.6	15.7	31.5	16.2
30.5	100	20.6	10.6	24.1	12.4	26.8	13.8	33.9	17.4	34.9	18.0
61.0	200	23.6	12.1	27.7	14.2	30.8	15.8	39.0	20.1	40.1	20.6
91.4	300	25.6	13.2	30.1	15.5	33.4	17.2	42.3	21.8	43.4	22.3
121.9	400	27.1	13.9	31.9	16.4	35.3	18.2	44.8	23.0	46.0	23.7
152.4	500	28.4	14.6	33.3	17.1	37.0	19.0	46.8	24.1	48.1	24.7

TABLE 5.2.33 SURFACE PEAK WIND SPEED PROFILE ENVELOPES (in knots) FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL PEAK WIND SPEED (annual reference period) FOR WHITE SANDS MISSILE RANGE

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	24.0	12.3	29.0	14.9	33.0	17.0	42.0	21.6	55.0	28.3
18.3	60	27.1	13.9	32.8	16.9	37.3	19.2	47.5	24.4	59.9	30.8
30.5	100	30.0	15.4	36.3	18.7	41.3	21.2	52.6	27.1	64.3	33.1
61.0	200	34.5	17.7	41.7	21.5	47.5	24.4	60.4	31.1	70.9	36.5
91.4	300	37.4	19.2	45.2	23.3	51.4	26.4	65.5	33.8	75.0	38.6
121.9	400	39.6	20.4	47.9	24.6	54.5	28.0	69.4	35.7	78.1	40.2
152.4	500	41.4	21.3	50.1	25.8	57.0	29.3	72.6	37.3	80.6	41.5

TABLE 5.2.34 SURFACE MEAN WIND SPEED PROFILE ENVELOPES (in knots) FOR VARIOUS VALUES OF RISK OF EXCEEDING THE 10-METER LEVEL 10-MINUTE MEAN WIND SPEED (annual reference period) FOR WHITE SANDS MISSILE RANGE

Height		Risk (%)									
		20		10		5		1		0.1	
(m)	(ft)	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}	knots	ms^{-1}
10.0	33	17.1	8.8	20.7	10.6	23.6	12.1	30.0	15.4	39.3	20.2
18.3	60	19.4	10.0	23.4	12.0	26.7	13.7	33.9	17.4	42.8	22.0
30.5	100	21.4	11.0	25.9	13.3	29.5	15.2	37.6	19.3	45.9	23.6
61.0	200	24.6	12.7	29.8	15.3	33.9	17.4	43.1	22.2	50.1	25.8
91.4	300	26.7	13.7	32.3	16.6	36.7	18.9	46.8	24.1	53.6	27.6
121.9	400	28.3	14.6	34.2	17.6	38.9	20.0	49.6	25.5	55.8	28.7
152.4	500	29.6	15.2	35.8	18.4	40.7	20.9	51.9	26.7	57.6	29.6

5.2.6 Spectral Ground Wind Turbulence Model.

Under most conditions ground winds are fully developed turbulent flows. This is particularly true when the wind speed is greater than a few knots, the atmosphere is unstable, or when both conditions exist. During nighttime conditions when the wind speed is low and the stratification is stable, the intensity of turbulence is small if not nil. Spectral methods are a particularly useful way of representing the turbulent portion of the ground wind environment for launch vehicle design purposes, as well as for use in diffusion calculations of toxic fuels and atmospheric pollutents. At the present time, a spectral turbulence model of the longitudinal and horizontal lateral components of turbulence that is valid for all conditions, except for the case of a nighttime stable stratification, is available. The model will be presented in this section.

5.2.6.1 Introduction.

At a fixed point in the atmospheric boundary layer, the instantaneous wind vector fluctuates in time about the horizontal quasi-steady wind vector. The vector departure of the horizontal component of the instantaneous wind vector from the quasi-steady wind vector is the horizontal vector component of turbulence. This vector departure can be represented by two components, the longitudinal and the lateral components of turbulence that are parallel and perpendicular to the quasi-steady wind vector in the horizontal plane (see Fig. 5.2.23). The model contained herein is a spectral representation of the characteristics of the longitudinal and lateral components of turbulence. The model analytically defines the spectra of these components of turbulence for the first 200 meters of the boundary layer. In addition, it defines the longitudinal and lateral cospectra, quadrature spectra, and the corresponding coherence functions associated with any pair of levels in the boundary layer.

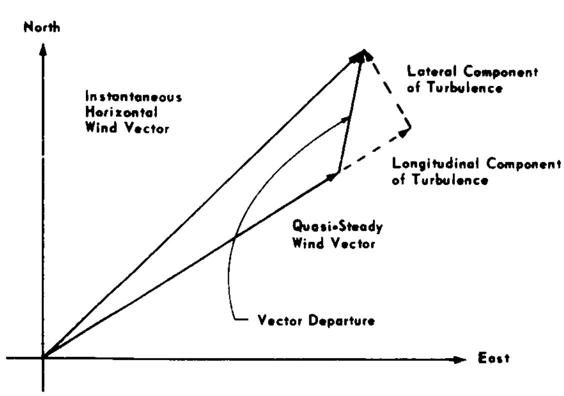

FIGURE 5.2.23 THE RELATIONSHIP BETWEEN THE QUASI-STEADY AND THE HORIZONTAL INSTANTANEOUS WIND VECTORS AND THE LONGITUDINAL AND LATERAL COMPONENTS OF TURBULENCE

To determine this turbulence model, approximately 50-hour cases of turbulence observed at the NASA 150-meter meteorological tower facility discussed in Reference 5.20 were analyed. Each case consisted of horizontal wind speed and direction data obtained at the 18-, 30-, 60-, 90-, 120-, and 150-meter levels. The procedure for calculating the longitudinal components of turbulence consisted of the following: (1) converting the digitized wind speeds and directions (10 points per second) into the associated north-south and east-west components and averaging these components over the duration of each test; (2) calculating the quasi-steady wind speed and direction; and (3) projecting the original digitized data on this quasi-steady wind vector and subtracting the quasi-steady wind vector to yield the longitudinal and lateral components of turbulence. Long term trends contained within the data were removed by fitting the longitudinal and lateral component time histories to second-order polynomials and in turn subtracting these polynomials from the time histories. To reduce computation time, the resulting data, with trend removed, were block averaged over 0.5-second intervals. The longitudinal and lateral spectra, cospectra and quadrature spectra were calculated from these processed data by employing the standard correlation-Fourier transform methods outlines in a book by Blackman and Tukey (Ref. 5.23). The spectral estimates were corrected for the 0.5-second block-averaging operation, as well as for the response properties of the wind sensors. A discussion of the response properties of the wind sensing instrumentation on the NASA 150-meter meteorological tower can be found in Reference 5.7.

Longitudinal and lateral spectra were calculated for each level, thus yielding approximately 300 spectra for each component of turbulence. Interlevel longitudinal and lateral cospectra and quadrature spectra were calculated for all possible combinations of pairs of levels, yielding a net total of 30 cospectra and quadrature spectra for each case for each component of turbulence. All the longitudinal and lateral spectra for each level were used in the development of the model, while only 16 representative cases were analyzed to develop the cospectrum and quadrature spectrum models. The models contained herein were determined using dimensional analysis based upon sound physical reasoning and insight gained from the open literature and from discussions with authorities in the field of atmospheric turbulence. The model was developed in a joint effort by scientists at the Cornell Aeronautical Laboratories, the Pennsylvania State University, and the NASA Marshall Space Flight Center. The details of their investigations appear in NASA Technical Reports and Contractor Reports. (See references 5.58, 5.59, and 5.60).

5.2.6.2 Turbulence Spectra.

The longitudinal and lateral spectra of turbulence at frequency ω and height z can be represented by a dimensionless function of the form

$$\frac{\omega\, S(\omega)}{\beta\, u_*^2} = \frac{c_1\, f/f_m}{\left[1 + 1.5(f/f_m)^{c_2}\right]^{5/3c_2}} , \qquad (1)\ 5.2.6$$

where

$$f = \frac{\omega z}{\bar{u}(z)} , \qquad (2)\ 5.2.6$$

$$f_m = c_3 \left(\frac{z}{z_r}\right)^{c_4} , \qquad (3)\ 5.2.6$$

$$\beta = \left(\frac{z}{z_r}\right)^{c_5} , \qquad (4)\ 5.2.6$$

and

$$u_* = c_6\, u\,(z_r) \quad . \qquad (5)\ 5.2.6$$

In these equations z_r is a reference height equal to 18.3 meters or 60 feet, depending upon the desired units; $\bar{u}\,(z)$ is the quasi-steady wind speed at height z; and the quantities c_i (i = 1, 2, 3, 4, 5) are dimensionless constants that depend upon the site and the stability. The spectrum $S(\omega)$ is defined so that integration over the domain $0 \leq \omega \leq \infty$ yields the variance of the turbulence. For the launch sites at the Eastern Test Range*, it is permissible for engineering purposes to use the values of c_i given in Table 5.2.35 for the longitudinal spectrum and Table 5.2.36 for the lateral spectrum.

TABLE 5.2.35 DIMENSIONLESS CONSTANTS FOR THE LONGITUDINAL SPECTRUM OF TURBULENCE FOR THE EASTERN TEST RANGE, FLORIDA

Condition	c_1	c_2	c_3	c_4	c_5
Light Wind Daytime Conditions	2.905	1.235	0.04	0.87	-0.14
Strong Winds	6.198	0.845	0.03	1.00	-0.63

* Eastern Test Range, Kennedy Space Center, and Cape Kennedy are used with same meaning in this section.

TABLE 5.2.36 DIMENSIONLESS CONSTANTS FOR THE LATERAL SPECTRUM OF TURBULENCE FOR THE EASTERN TEST RANGE, FLORIDA

Condition	c_1	c_2	c_3	c_4	c_5
Light Wind Daytime Conditions	4.599	1.144	0.033	0.72	-0.04
Strong Winds	3.954	0.781	0.1	0.58	-0.35

The constant c_6 can be estimated with the equation

$$c_6 = \frac{0.4}{\ln\left(\frac{z_r}{z_0}\right) - \Psi} , \qquad (6)\ 5.2.6$$

where z_0 is the surface roughness length of the site and Ψ is a parameter that depends upon the stability. If z_0 is not available for a particular site, then an estimate of z_0 can be obtained by taking 10 percent of the typical height of the surface obstructions (gross, shrubs, trees, rocks, etc.) over a fetch from the site with length equal to approximately 1500 meters. The parameter Ψ vanishes for strong wind conditions and is of order unity for light wind unstable daytime conditions at the Kennedy Space Center. Typical values of Z_0 for various surfaces are given in Table 5.2.37. The value of Z_0 given for Palmetto is recommended for Kennedy Space Center design studies.

The functions given by equations (1) 5.2.6, (3) 5.2.6 and (4) 5.2.6 are depicted in Figures 5.2.24 through 5.2.29. Upon prescribing the steady-state wind profile $\bar{u}(z)$ and the site (z_0), the longitudinal and lateral spectra are completely specified functions of height z and frequency ω. A discussion of the units of the various parameters mentioned above is given in Section 5.2.6.4.

TABLE 5.2.37 TYPICAL VALUES OF SURFACE ROUGHNESS LENGTH (z_0) FOR VARIOUS TYPES OF SURFACES

Type of Surface	z_0 (m)	z_0 (ft)
Mud flats, ice	10^{-5} - $3 \cdot 10^{-5}$	$3 \cdot 10^{-5}$ - 10^{-4}
Smooth sea	$2 \cdot 10^{-4}$ - $3 \cdot 10^{-4}$	$7 \cdot 10^{4}$ - 10^{-3}
Sand	10^{-4} - 10^{-3}	$3 \cdot 10^{-4}$ - $3 \cdot 10^{-3}$
Snow surface	10^{-3} - $6 \cdot 10^{-3}$	$3 \cdot 10^{-4}$ - $2 \cdot 10^{-2}$
Mown grass (~ 0.01 m)	10^{-3} - 10^{-2}	$3 \cdot 10^{-3}$ - $3 \cdot 10^{-2}$
Low grass, steppe	10^{-2} - $4 \cdot 10^{-2}$	$3 \cdot 10^{-2}$ - 10^{-1}
Fallow field	$2 \cdot 10^{-2}$ - $3 \cdot 10^{-2}$	$6 \cdot 10^{-2}$ - 10^{-1}
High grass	$4 \cdot 10^{-2}$ - 10^{-1}	10^{-1} - $3 \cdot 10^{-1}$
Palmetto	10^{-1} - $3 \cdot 10^{-1}$	$3 \cdot 10^{-1}$ - 1
Suburbia	1 - 2	3 - 6
City	1 - 4	3 - 13

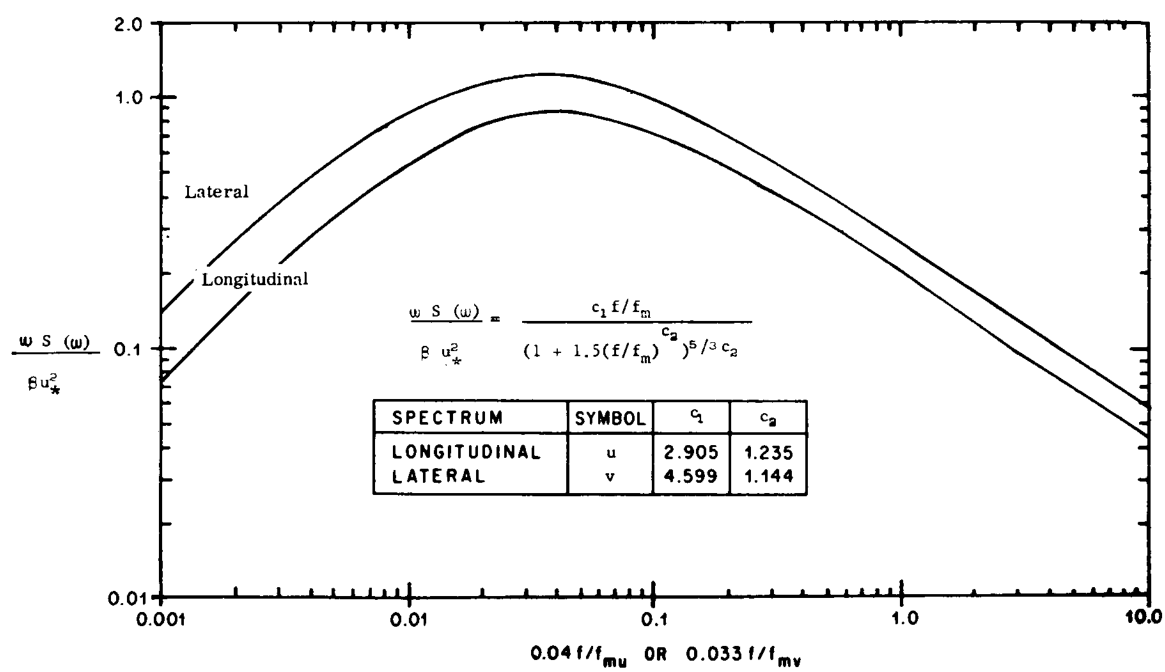

FIGURE 5.2.24 $\frac{\omega S(\omega)}{\beta u_*^2}$ VERSUS $\frac{0.04f}{f_m}$ (longitudinal) AND $\frac{0.033f}{f_m}$ (lateral) FOR LIGHT WIND DAYTIME CONDITIONS, CAPE KENNEDY, FLORIDA

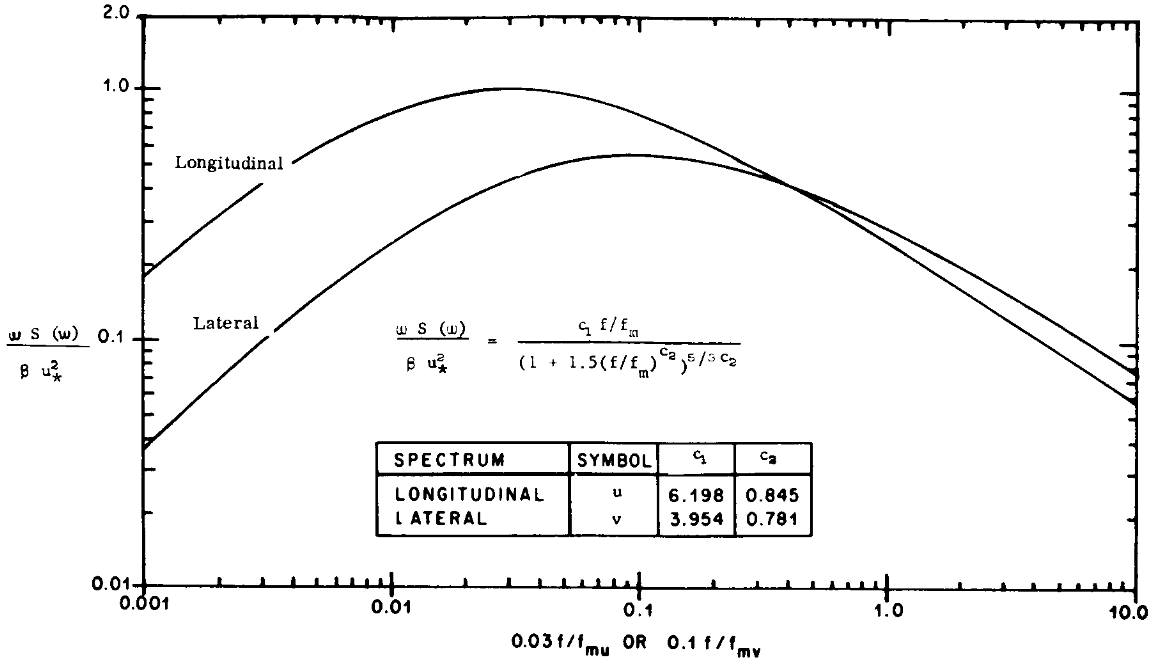

FIGURE 5.2.25 $\frac{\omega S(\omega)}{\beta u_*^2}$ VERSUS $\frac{0.03f}{f_m}$ (longitudinal) AND $\frac{0.1f}{f_m}$ (lateral) FOR STRONG WIND CONDITIONS, CAPE KENNEDY, FLORIDA

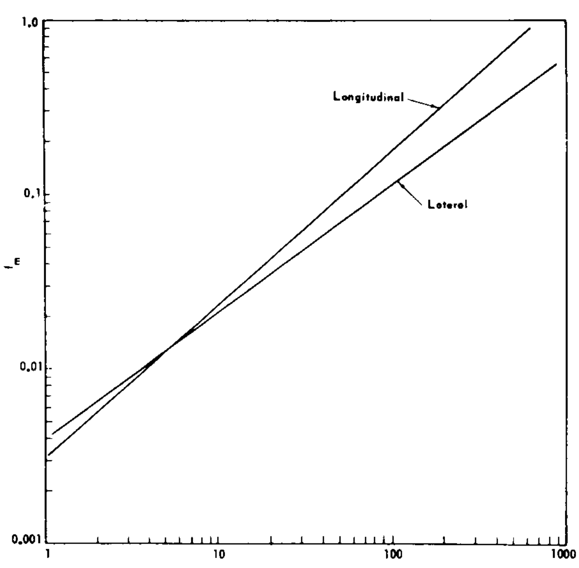

FIGURE 5.2.26 f_m VERSUS z FOR LIGHT WIND DAYTIME CONDITIONS, CAPE KENNEDY, FLORIDA

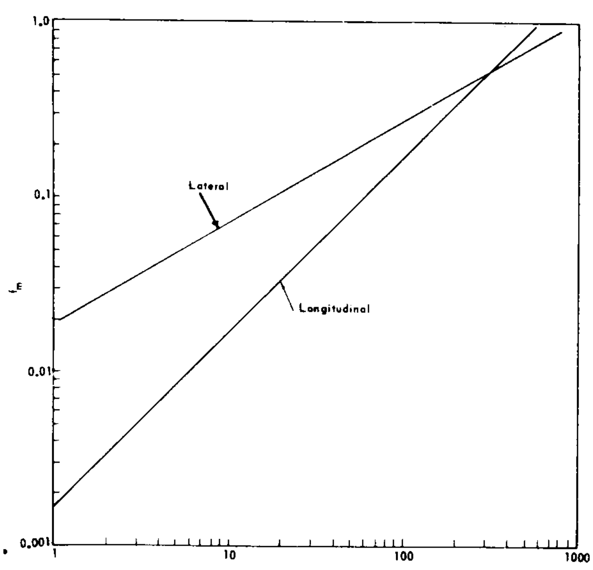

FIGURE 5.2.27 f_m VERSUS z FOR STRONG WIND CONDITIONS, CAPE KENNEDY, FLORIDA

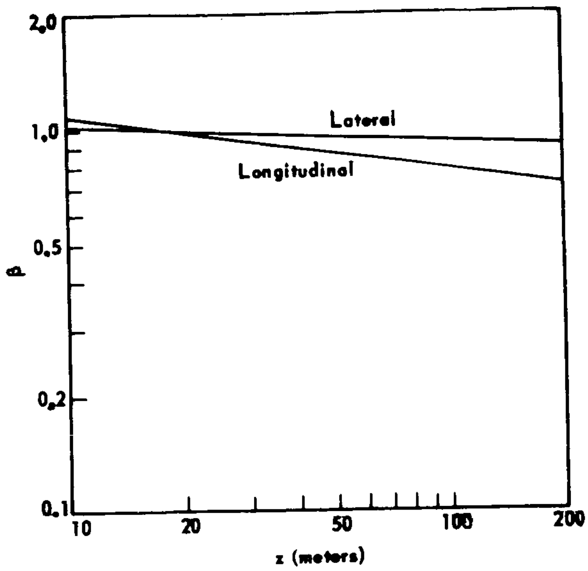

FIGURE 5.2.28 β VERSUS z FOR LIGHT WIND DAYTIME CONDITIONS

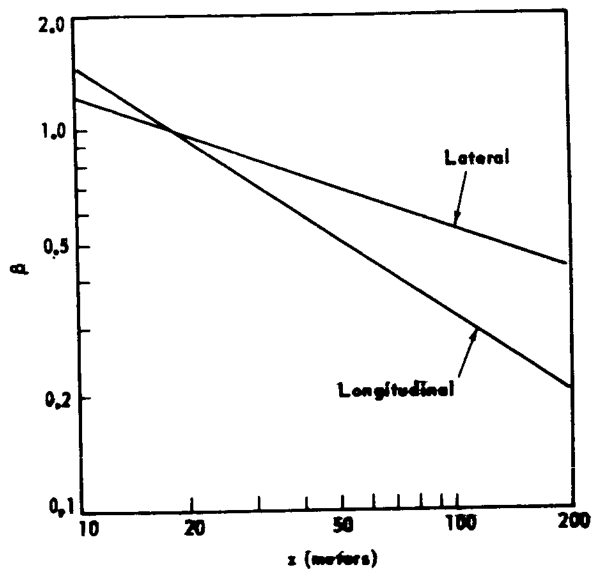

FIGURE 5.2.29 β VERSUS z FOR STRONG WIND CONDITIONS

5.2.6.3 The Cospectrum and Quadrature Spectrum.

The cospectrum and the quadrature spectrum associated with either the longitudinal or lateral components of turbulence at levels z_1 and z_2 can be represented by the following:

$$C(\omega, z_1, z_2) = \sqrt{S_1 S_2}\ \exp\left(-0.3465\,\frac{\Delta f}{\Delta f_{0.5}}\right)\cos(2\pi\gamma\Delta f) \qquad (7)\ 5.2.6$$

and

$$Q(\omega, z_1, z_2) = \sqrt{S_1 S_2}\ \exp\left(-0.3465\,\frac{\Delta f}{\Delta f_{0.5}}\right)\sin(2\pi\gamma\Delta f)\ , \qquad (8)\ 5.2.6$$

where

$$\Delta f = \frac{\omega z_2}{\bar{u}(z_2)} - \frac{\omega z_1}{\bar{u}(z_1)}\ . \qquad (9)\ 5.2.6$$

S_1 and S_2 are the longitudinal or lateral spectra at levels z_1 and z_2, respectively, and $u(z_1)$ and $u(z_2)$ are the steady-state wind speeds at levels z_1 and z_2. The quantity $\Delta f_{0.5}$ is a dimensionless function of stability, and values of this parameter for the Eastern Test Range are given in Table 5.2.38.

TABLE 5.2.38 TABLE OF VALUES OF THE PARAMETER $\Delta f_{0.5}$ FOR THE EASTERN TEST RANGE

Turbulence Component	Light Wind Daytime Conditions	Strong Winds
Longitudinal	0.04	0.036
Lateral	0.06	0.045

The dimensionless quantity γ should depend upon height and stability. However, it has only been possible to detect a dependence on height at the Eastern Test Range. Based upon an analysis of turbulence data measured at the NASA 150-meter meteorological tower facility, the values of γ in Table 5.2.39 are suggested for the Eastern Test Range.

TABLE 5.2.39 TABLE OF VALUES OF THE PARAMETER γ FOR THE EASTERN TEST RANGE

Turbulence Component	$(z_1 + z_2)/2 \leq 100m$	$(z_1 + z_2)/2 > 100m$
Longitudinal	0.7	0.3
Lateral	1.4	0.5

The quantity $\Delta f_{0.5}$ can be interpreted by constructing the coherence function, which is defined to be

$$\mathrm{coh}(\omega, z_1, z_2) = \frac{C^2 + Q^2}{S_1 S_2} \quad . \qquad (10)\ 5.2.6$$

Upon substituting Equations (7) 5.2.6 and (8) 5.2.6, into Equation (10) 5.2.6 we find

$$\mathrm{coh}(\omega, z_1, z_2) = \exp\left(-0.693 \frac{\Delta f}{\Delta f_{0.5}}\right) \quad . \qquad (11)\ 5.2.6$$

It is clear from this relationship that $\Delta f_{0.5}$ is that value of Δf for which the coherence (coh) is equal to 0.5.

The quantity γ can be interpreted by forming the ratio between Equations (7) 5.2.6 and (8) 5.2.6 so that

$$\tan 2\pi 2\Delta f = \frac{Q(\omega, z_1, z_2)}{C(\omega, z_1, z_2)} \quad . \qquad (12)\ 5.2.6$$

It follows from this relation that the time lag τ_ω at each frequency between the longitudinal or lateral components of turbulence at height z_2 in relation to those at z_1 is given by

$$\tau_\omega = \gamma\left(\frac{z_2}{\bar{u}(z_2)} - \frac{z_1}{\bar{u}(z_1)}\right) \quad . \qquad (13)\ 5.2.6$$

where

$$\tan(2\pi\omega\tau_\omega) = \frac{Q(\omega, z_1, z_2)}{C(\omega. z_1, z_2)} \quad . \qquad (14)\ 5.2.6$$

The quantity τ_ω is the period of time the eddies with a frequency ω at height z, lag behind the eddies with frequency ω at height z_2. The quantity γ is the dimensionless counterpart of τ_ω and is a measure of the eddy slope. Based upon these comments and the data in Table 5.2.39, it may be concluded that the time delay for changes between levels in the longitudinal component of turbulence is about one-half of that for the lateral wind change, other things being equal. This same effect has been observed at three other meteorological tower sites, Brookhaven, New York; White Sands Missile Range, New Mexico; and South Dartmouth, Massachusetts.

5.2.6.4 Units.

The spectral model of turbulence presented in Sections 5.2.6.2 and 5.2.6.3 is a dimensionless model. Accordingly, the user is free to select the system of units he desires, except that ω must have the units of cycles per unit time. Table 5.2.40 gives the appropriate metric and U. S. Customary units for the various quantities in the model.

5.2.7 Ground Wind Gust Factors.

The solutions of problems dealing with surface winds for the design and launch of space vehicles include analyses of wind gustiness or gust factor. Previous Marshall Space Flight Center ground wind gust factor design criteria adopted a gust factor of 1.4 and treated the gust as acting over the entire length of the vehicle. Revised ground wind mean gust factor design criteria were derived from data obtained during 1967 and 1968 at NASA's 150-meter meteorological tower facility at Kennedy Space Center, Florida.

To more precisely determine gust factors to a height of 150 meters, analyses have been made relating gust factors to height, steady-state or mean wind speed, peak wind speed at reference height 18.3 meters, and length of time used to obtain the mean wind speed. A study was made of 181 hours of data recorded when the atmosphere was generally unstable (daytime).

The gust factor G is defined to be

$$G = u/\bar{u} \qquad (1)\ 5.2.7$$

TABLE 5.2.40 METRIC AND U. S. CUSTOMARY UNITS OF VARIOUS QUANTITIES IN THE TURBULENCE MODEL

Quantity	Metric Units	U. S. Customary Units
ω	cps	cps
$S(\omega)$, $Q(\omega)$, $C(\omega)$	$m^2\ s^{-2}$/cps	$ft^2\ s^{-2}$/cps
f, f_m, Δf, $\Delta f_{0.5}$	Dimensionless	Dimensionless
z, z_r, z_0	m	ft
u, u_*	ms^{-1}	$ft\ s^{-1}$
β	Dimensionless	Dimensionless
Coh	Dimensionless	Dimensionless
γ	Dimensionless	Dimensionless
Ψ	Dimensionless	Dimensionless

where

u is the maximum wind speed at height h within an averaging period of length τ in time

$\bar{u}$ is the mean wind speed associated with the averaging period τ and is given by

$$\bar{u} = \frac{1}{\tau} \int_{-\tau/2}^{\tau/2} v(t)\, dt \qquad (2)\ 5.2.7$$

where

$v(t)$ is the instantaneous wind speed at time t

t is reckoned from the beginning of the averaging period.

If $\tau = 0$, then $\bar{u} = u$ according to Equation (2) 5.2.7, and it follows from Equation (1) 5.2.7 that G = 1.0. As τ increases, $\bar{u}$ departs from u, and $\bar{u} \leq u$, and G > 1.0. Also, as τ increases, the probability of finding a maximum wind of a given magnitude increases. In other words, the maximum wind speed increases as τ increases. In the case of $\bar{u} = 0$ and $u \geq 0$ ($\bar{u} = 0$ might correspond to windless free convection), $G = \infty$. As $\bar{u}$ or u increases, G tends to decrease; for very high wind speeds (neutral stratification), G tends to approach a constant value for given values of z and τ. Finally, as z increases, G decreases. Thus, the gust factor is a function of the averaging time τ over which the mean wind speed is calculated, the height z, and the wind speed (mean or maximum).

5.2.7.1 Gust Factor as a Function of Peak Wind Speed at Reference Height ($u_{18.3}$).

Representation of the first factor (G) as a function of height h, averaging period τ, and the 18.3-meter peak wind speed $u_{18.3}$ is based upon the fact that Kennedy Space Center wind statistics are calculated in terms of peak winds. Thus G will be given as a function of $u_{18.3}$, z and τ.

Investigations of the mean gust factor data revealed that the variation of the gust factor in the first 150 meters of the atmosphere could be described with the following relationships:

$$G = 1 + \frac{1}{g_0} \left(\frac{18.3}{z} \right)^p \qquad (4)\ 5.2.7$$

where h is the height in meters above natural grade.

The parameter p, a function of the 18.3-meter peak wind speed in meters per second, is given by

$$p = 0.283 - 0.435\, e^{-0.2\, u_{18.3}} \quad . \qquad (5)\ 5.2.7$$

The parameter g_0, depends on the averaging time and the 18.3-meter peak wind speed and is given by

$$g_0 = 0.085 \left(\ln \frac{\tau}{10}\right)^2 - 0.329 \left(\ln \frac{\tau}{10}\right)$$

$$+ 1.98 - 1.887\, e^{-0.2 u_{18.3}} \qquad (6)\ 5.2.7$$

where τ is in minutes and, $u_{18.3}$ is in meters per second.

These relationships are valid for $u_{18.3} \geq 4\ ms^{-1}$ and $\tau \leq 10$ min. In the interval 10 min $\leq \tau \leq$ 60 min, G is a slowly increasing monotonic function of τ, and for all practical purposes the 10-minute gust factors (τ = 10 min) can be used as estimates of the gust factors associated with averaging times greater than 10 minutes and less than 60 minutes (10 min $\leq \tau \leq$ 60 min).

The dependence of the 18.3-meter height gust factor upon the averaging time and the peak wind speed is shown in Figure 5.2.30. Figure 5.2.31 illustrates the dependence of the 10-minute gust factors upon the peak wind speed and height.

The calculated mean gust factors for τ = 0.5, 1, 2, 5, and 10 minutes for values of $u_{18.3}$ in the interval $4.63\ ms^{-1} \leq u_{18.3} \leq \infty$ are presented in Tables 5.2.42 through 5.2.46 in both the U. S. customary and metric units for $u_{18.3}$ and h. For example, the gust factor profile for τ = 1.0 min and $u_{18.3}$ = 18 knots ($9.27\ ms^{-1}$) is given by Table 5.2.41. These values are valid only for the Cape Kennedy, Florida area.

Since the basic wind statistics are given in terms of hourly peak winds, use for this example the τ = 10 minute gust factors to convert the peak winds to mean winds by dividing by G. All gust factors in these sections are mean values for any particular set of values for u, τ, and h. The extremes will be published at a later date.

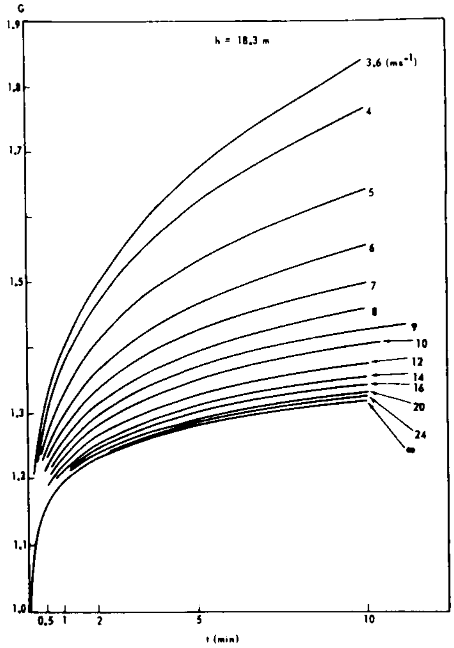

FIGURE 5.2.30 GUST FACTOR AS A FUNCTION OF TIME FOR VARIOUS VALUES OF $u_{18.3}$ IN THE INTERVAL $3.6 \leq u_{18.3} \leq \infty$

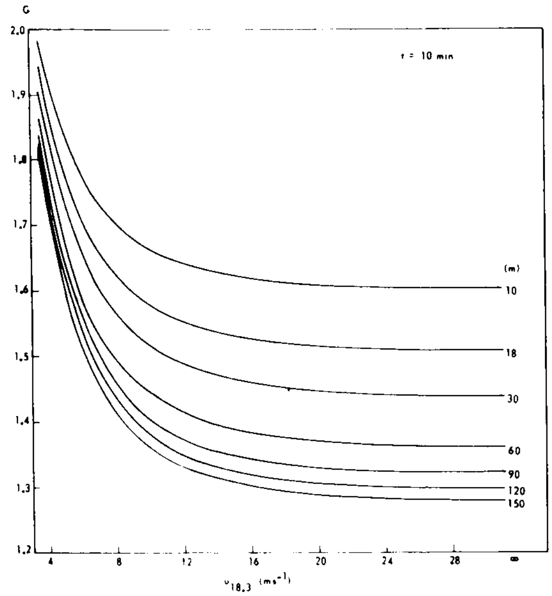

FIGURE 5.2.31 GUST FACTOR AS A FUNCTION OF PEAK WIND (u) FOR VARIOUS HEIGHTS

TABLE 5.2.41 GUST FACTOR PROFILE FOR $\tau = 1.0$ MIN AND $u_{18.3}$ = 18 knots (9.27 ms^{-1})

Height		Gust Factor
(ft)	(m)	(G)
33	10.0	1.394
60	18.3	1.346
100	30.5	1.310
200	61.0	1.267
300	91.4	1.245
400	121.9	1.230
500	152.4	1.219

TABLE 5.2.42 ONE-HALF-MINUTE GUST FACTORS FOR KENNEDY SPACE CENTER, FLORIDA

60-ft (18.3-m) peak wind kts (ms^{-1})	Height Above Natural Grade in Feet (meters)						
	33 (10.0)	60 (18.3)	100 (30.5)	200 (61.0)	300 (91.4)	400 (121.9)	500 (152.4)
9.0 (4.63)	1.359	1.335	1.317	1.294	1.281	1.272	1.265
10.0 (5.15)	1.354	1.327	1.307	1.281	1.267	1.257	1.250
11.0 (5.66)	1.349	1.320	1.298	1.270	1.255	1.244	1.237
12.0 (6.18)	1.346	1.314	1.290	1.260	1.244	1.234	1.226
13.0 (6.69)	1.342	1.309	1.284	1.252	1.236	1.225	1.216
14.0 (7.21)	1.340	1.305	1.278	1.245	1.228	1.217	1.208
15.0 (7.72)	1.337	1.301	1.273	1.239	1.221	1.210	1.201
16.0 (8.24)	1.335	1.297	1.268	1.234	1.216	1.204	1.195
17.0 (8.75)	1.333	1.294	1.264	1.229	1.211	1.198	1.189
18.0 (9.27)	1.332	1.291	1.261	1.225	1.206	1.194	1.185
19.0 (9.78)	1.330	1.289	1.258	1.221	1.202	1.190	1.181
20.0 (10.30)	1.329	1.287	1.255	1.218	1.199	1.186	1.177
25.0 (12.87)	1.324	1.279	1.245	1.206	1.187	1.174	1.164
30.0 (15.44)	1.322	1.274	1.240	1.200	1.180	1.167	1.157
$\infty(\infty)$	1.318	1.268	1.232	1.191	1.170	1.157	1.147

TABLE 5.2.43 ONE-MINUTE GUST FACTORS FOR KENNEDY SPACE CENTER, FLORIDA

60-ft (18.3-m) peak wind kts (ms^{-1})	Height Above Natural Grade in Feet (meters)						
	33 (10.0)	60 (18.3)	100 (30.5)	200 (61.0)	300 (91.4)	400 (121.9)	500 (152.4)
9.0 (4.63)	1.438	1.410	1.387	1.359	1.343	1.332	1.324
10.0 (5.15)	1.430	1.398	1.373	1.341	1.324	1.312	1.304
11.0 (5.66)	1.423	1.388	1.360	1.326	1.308	1.296	1.286
12.0 (6.18)	1.416	1.379	1.350	1.314	1.295	1.282	1.272
13.0 (6.69)	1.411	1.371	1.341	1.303	1.283	1.270	1.260
14.0 (7.21)	1.407	1.365	1.333	1.294	1.273	1.259	1.249
15.0 (7.72)	1.403	1.359	1.326	1.286	1.264	1.250	1.240
16.0 (8.24)	1.399	1.354	1.320	1.279	1.257	1.243	1.232
17.0 (8.75)	1.396	1.350	1.315	1.272	1.250	1.236	1.225
18.0 (9.27)	1.394	1.346	1.310	1.267	1.245	1.230	1.219
19.0 (9.78)	1.391	1.342	1.306	1.262	1.240	1.225	1.214
20.0 (10.30)	1.389	1.339	1.302	1.258	1.235	1.220	1.210
25.0 (12.87)	1.382	1.328	1.289	1.243	1.220	1.205	1.193
30.0 (15.44)	1.378	1.322	1.282	1.235	1.211	1.196	1.185
$\infty(\infty)$	1.372	1.314	1.271	1.223	1.199	1.183	1.172

TABLE 5.2.44 TWO-MINUTE GUST FACTORS FOR KENNEDY SPACE CENTER, FLORIDA

60-ft (18.3-m) peak wind kts (ms^{-1})	Height Above Natural Grade in Feet (meters)						
	33 (10.0)	60 (18.3)	100 (30.5)	200 (61.0)	300 (91.4)	400 (121.9)	500 (152.4)
9.0 (4.63)	1.539	1.505	1.477	1.442	1.422	1.409	1.399
10.0 (5.15)	1.526	1.487	1.456	1.417	1.396	1.382	1.371
11.0 (5.66)	1.514	1.471	1.438	1.397	1.375	1.360	1.348
12.0 (6.18)	1.504	1.459	1.423	1.380	1.357	1.341	1.329
13.0 (6.69)	1.496	1.448	1.411	1.365	1.341	1.325	1.313
14.0 (7.21)	1.488	1.438	1.400	1.353	1.328	1.311	1.299
15.0 (7.72)	1.482	1.430	1.390	1.342	1.317	1.300	1.287
16.0 (8.24)	1.477	1.423	1.382	1.333	1.307	1.290	1.277
17.0 (8.75)	1.472	1.416	1.375	1.324	1.298	1.281	1.268
18.0 (9.27)	1.468	1.411	1.368	1.317	1.291	1.274	1.261
19.0 (9.78)	1.464	1.406	1.363	1.311	1.284	1.267	1.254
20.0 (10.30)	1.461	1.402	1.358	1.306	1.279	1.261	1.248
25.0 (12.87)	1.450	1.387	1.340	1.286	1.259	1.241	1.228
30.0 (15.44)	1.443	1.378	1.331	1.276	1.248	1.230	1.217
$\infty(\infty)$	1.435	1.366	1.317	1.261	1.232	1.214	1.201

TABLE 5.2.45 FIVE-MINUTE GUST FACTORS FOR KENNEDY SPACE CENTER, FLORIDA

60-ft (18.3-m) peak wind kts (ms^{-1})	Height Above Natural Grade in Feet (meters)						
	33 (10.0)	60 (18.3)	100 (30.5)	200 (61.0)	300 (91.4)	400 (121.9)	500 (152.4)
9.0 (4.63)	1.712	1.666	1.630	1.583	1.558	1.540	1.527
10.0 (5.15)	1.686	1.635	1.595	1.545	1.518	1.499	1.485
11.0 (5.66)	1.665	1.610	1.567	1.514	1.485	1.465	1.451
12.0 (6.18)	1.647	1.588	1.543	1.487	1.458	1.437	1.422
13.0 (6.69)	1.632	1.570	1.523	1.466	1.435	1.414	1.399
14.0 (7.21)	1.619	1.555	1.506	1.447	1.416	1.395	1.379
15.0 (7.72)	1.608	1.542	1.492	1.431	1.399	1.378	1.362
16.0 (8.24)	1.598	1.531	1.479	1.418	1.385	1.364	1.348
17.0 (8.75)	1.590	1.521	1.468	1.406	1.373	1.351	1.336
18.0 (9.27)	1.583	1.512	1.459	1.396	1.363	1.341	1.325
19.0 (9.78)	1.577	1.505	1.451	1.387	1.354	1.332	1.316
20.0 (10.30)	1.572	1.498	1.444	1.379	1.346	1.324	1.308
25.0 (12.87)	1.553	1.475	1.418	1.352	1.318	1.296	1.280
30.0 (15.44)	1.542	1.462	1.404	1.337	1.303	1.281	1.265
$\infty(\infty)$	1.528	1.445	1.385	1.316	1.282	1.260	1.244

TABLE 5.2.46 TEN-MINUTE GUST FACTORS FOR KENNEDY SPACE CENTER, FLORIDA

60-ft (18.3-m) peak wind kts (ms^{-1})	Height Above Natural Grade in Feet (meters)						
	33 (10.0)	60 (18.3)	100 (30.5)	200 (61.0)	300 (91.4)	400 (121.9)	500 (152.4)
9.0 (4.63)	1.868	1.812	1.767	1.710	1.679	1.658	1.642
10.0 (5.15)	1.828	1.766	1.718	1.657	1.624	1.602	1.585
11.0 (5.66)	1.795	1.729	1.678	1.614	1.580	1.556	1.539
12.0 (6.18)	1.768	1.699	1.645	1.579	1.544	1.520	1.502
13.0 (6.69)	1.746	1.674	1.618	1.550	1.514	1.489	1.471
14.0 (7.21)	1.727	1.652	1.595	1.525	1.488	1.464	1.446
15.0 (7.72)	1.712	1.634	1.576	1.505	1.467	1.442	1.424
16.0 (8.24)	1.698	1.619	1.559	1.487	1.449	1.424	1.406
17.0 (8.75)	1.686	1.606	1.545	1.472	1.434	1.409	1.390
18.0 (9.27)	1.676	1.594	1.532	1.459	1.421	1.395	1.377
19.0 (9.78)	1.668	1.584	1.522	1.447	1.409	1.384	1.365
20.0 (10.30)	1.660	1.575	1.512	1.437	1.399	1.374	1.355
25.0 (12.87)	1.634	1.545	1.480	1.403	1.365	1.339	1.321
30.0 (15.44)	1.619	1.528	1.462	1.385	1.346	1.321	1.302
∞ (∞)	1.599	1.505	1.437	1.359	1.320	1.295	1.277

5.2.7.2 Gust Factors for Other Test Ranges.

For design purposes, the gust factor value of 1.4 will be used over all altitudes of the ground wind profile at other test ranges. This gust factor should correspond to approximately a 10-minute averaging period.

5.2.8 Ground Wind Shear.

Local or point values of wind shear can be obtained by differentiating Equation (1) 5.2.5 with respect to height, z. When the 18.3-meter level is used as a reference and the 99.97 percentile values of k are employed, the equation for local wind shear is given by.

$$\frac{du}{dz} = \frac{1.6\, u_{18.3}^{1/4}}{z} \left(\frac{z}{18.3}\right)^{1.6\, u_{18.3}^{-3/4}} \qquad (1)\ 5.2.8$$

Figure 5.2.32 presents the shears as computed with the above equation for six levels. Wind shear near the surface, for design purposes, is a shear that acts upon a space vehicle, free-standing on the pad, or at time of lift-off. For overturning moment calculations, the 10-minute mean wind at the height of the vehicle base and the peak wind profile value at the height of the vehicle top is employed in the calculations.

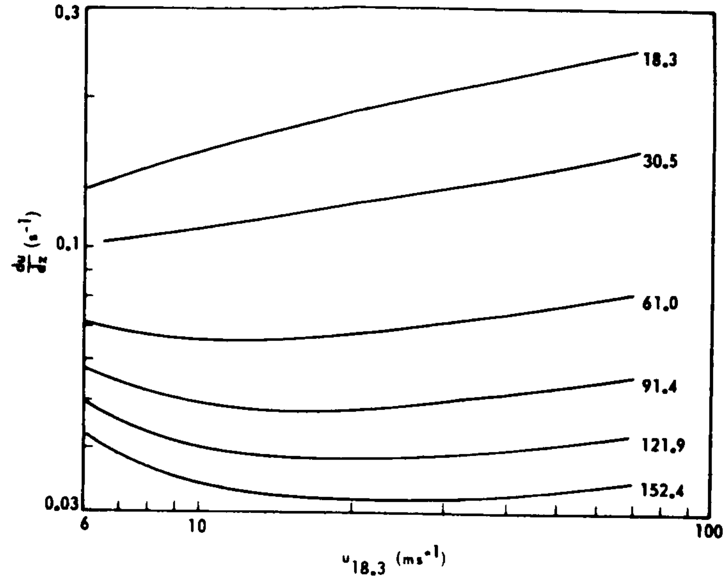

FIGURE 5.2.32 LOCAL WIND SHEARS FOR SIX LEVELS

5.2.9 Ground Wind Direction Characteristics.

Ground wind direction climatology is shown in Section 5.2.3, Figures 5.2.8 through 5.2.11. The circular and elliptical standard vector deviation wind roses were prepared from the January and July wind statistics given in Table 5.2.1. As indicated in 5.2.3, the percentage label on each circle or ellipse indicates the percentage of wind vectors that will originate in that circle or ellipse. These data show the influence of large-scale or synoptic influences upon the statistical variations in wind direction in the Cape Kennedy area. They do not provide information on variations in wind direction over specified periods of time. However, a detailed analysis of wind direction data is now possible with approximately 3 years of continuously acquired meteorological data from NASA's 150-meter meteorological tower on Merritt Island, Kennedy Space Center, Florida.

Figure 5.2.9 (Section 5.2.5) shows a time trace of wind direction (a section of a wind direction recording chart). This wind direction trace may be visualized as being composed of a mean wind direction plus fluctuations about the mean. An accurate measure of wind direction in the free atmosphere near the ground is difficult to obtain because of the interference of the structure that supports the instrumentation and other obstacles in the vicinity of the measurement location (Ref. 5.8). The measured wind directions represent conditions existing at a given place, and they are directly applicable in vehicle-response-to-ground-winds studies. General information such as that which follows is available and may be used to specify conditions for particular studies. For instance, the publication "Meteorology and Atomic Energy — 1968," (Ref. 5.24) discusses the variation of lateral wind-direction for various stability regimes. A graph is shown in this report (Ref. 5.24) that gives values of the standard deviation of the lateral wind direction σ^{θ} as a function of height for a sampling time of about 10 minutes. It states that σ^{θ} for sampling periods greater than 1 minute with some given stability condition will always be greater when the wind is light than when it is strong. In general, the more stable the air, the smaller the σ^{θ}, except for the case of meandering wind directions for very low wind speeds and very stable conditions.

A study by Lifsey (Ref. 5.14) of daily peak ground winds at Cape Kennedy showed that a large percentage of wind speeds equal to or exceeding 23 ms^{-1}, excluding hurricane influenced winds, occur with a westerly wind component. These wind directions were most likely associated with frontal passages or local thunderstorms. Another interesting conclusion from this study was that, from February through September, the most frequently occurring wind direction with the associated daily peak wind speed was either from the east, east-southeast, or southeast, while from September through February, the most often experienced wind direction was northerly.

5.2.10 Tornadoes, Hurricanes, and Thunderstorm Winds.

5.2.10.1 Introduction.

The causes of high winds are summarized as follows:

a. Tornadoes: Upper limit unknown; estimated ~ 500 knots.

b. Hurricanes: By definition, a tropical storm with winds > 64 knots, upper limit unknown; estimated ~ 160 knots.

c. Tropical Storms: By definition, a storm with winds < 64 knots and > 34 knots.

d. Thunderstorms: Upper limit not defined; typical values ~ 45 knots; severe thunderstorm by definition > 50 knots.

e. Frontal Passages: Without thunderstorms; typical to 35 knots, with squalls same as for thunderstorms.

f. Pressure Gradients: Long duration winds; winds to ~ 60 knots.

These winds are discussed briefly in the following sections. References are given for a more detailed discussion if required in mission analysis studies.

5.2.10.2 Tornadoes.

Tornadoes are recognized as the cause of the most destructive force winds, and because of differential pressures created by tornadoes, buildings have been known to literally explode. Fortunately, the aerial extent of tornadoes is small compared with hurricanes, and the occurrence of tornadoes at the seven stations of interest covered in this document is less frequent than in the Central Plain states of the United States. Tornadoes are observed at times in association with hurricanes in Florida and along the coastal states. Thom (Ref. 5.25) has made an analysis of number of tornado occurrences. Based on Thom's Analysis (Ref. 5.25), Table 5.2.47 has been prepared giving tornado statistics for stations of interest.

TABLE 5.2.47 TORNADO STATISTICS FOR STATIONS SPECIFIED

Station	Number of Tornadoes	Mean Number of Tornadoes Per Year	Area A_2 (sq. mi.)	Mean Number of Tornadoes Per Year at a Point	Mean Recurrence Interval for a Tornado Striking a Point (years)
Cape Kennedy	9	0.9	4220	0.00060	1667
Huntsville	12	1.2	3930	0.00086	1163
New Orleans	9	0.9	4140	0.00061	1639
Mississippi Test Facility	12	1.2	4110	0.00083	1205
Western Test Range	0	0	3710	0.00000	∞
Wallops Island	5	0.5	3760	0.00038	2632
White Sands	2	0.2	4030	0.00015	6667

The probability of one or more tornadoes in N years in area (A_1) is given by

$$P\{E_1, A_1; N\} = 1 - \exp\left(-\bar{x}\frac{A_1}{A_2} N\right) \qquad (1)\ 5.2.10^*$$

We choose for the area size for A_1 as 2.8 square miles because Thom (Ref. 5.25) reports 2.8209 square miles is the average ground area covered by tornadoes in Iowa, and the vital industrial complexes for most locations are of this general size. Thus, taking $A_1 = 2.8$ sq. mi. and $A_1 = 1$ sq. mi. and evaluating Equation (1) 5.2.10 for the values of $\bar{x}$ and A_2 for the stations given in Table 5.2.47, we have Table 5.2.48, which gives the probability of one or more tornado events in a 2.8 square miles area and a 1 square mile area in 1 year, 10 years, and 100 years for the indicated seven locations. It is noted that for $A_1 << A_2$ and $N < 100$, Equation (1) 5.2.10 can be approximated by

$$P\{E_1, A_1; N\} \doteq \bar{x}\frac{A_1}{A_2} N \quad . \qquad (2)\ 5.2.10$$

An interpretation of the statistics in Table 5.2.48 is given using Cape Kennedy as an example. There is a 5.8 percent chance that at least one tornado will "hit" within a 2.8 square miles area on Cape Kennedy in 100 years. For a 1 square mile area of Cape Kennedy, the chance of a tornado hit in 100 years is 2.1 percent. If several structures within a 2.8-square mile area on Cape Kennedy are vital to a space mission and these structures are not designed to withstand the wind and internal pressure forces of a tornado, then there is a 5.8 percent chance that one or more of these vital structures will be destroyed by a tornado in 100 years. If the desired lifetime of these structures (or 2.8 square miles industrial complex) is 100 years and the risk of destruction by tornadoes is accepted in the design, then the design risk or calculated risk of failure of at least one structure due to tornado occurrences is 5.8 percent. This example serves to point out that the probability of occurrence of an event which it rare in one year becomes rather large when taken over many years and that estimates for the desired lifetime versus design risk for structures discussed in Section 5.2.11 should be made with prudence.

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* Credit is due Prof. J. Goldman, Institute Storm Research, St. Thomas University, Houston, Texas for this form of the probability expression.

TABLE 5.2.48 PROBABILITY OF ONE OR MORE TORNADO EVENTS IN A 2.8-SQUARE-MILE AREA AND A 1-SQUARE-MILE AREA IN 1, 10, AND 100 YEARS

Station	Mean Number of Tornadoes Per Year in Area, A_2	$P\{E_1, A_1; N\}$ for A_1 = 2.80-square-mile			$P\{E_1, A_1; N\}$ for A_1 = 1.00-square-mile		
		N=1 year	N=10 years	N=100 years	N=1 year	N=10 years	N=100 years
Cape Kennedy	0.9	0.00060	0.00596	0.05797	0.00021	0.00213	0.02110
Huntsville	1.2	0.00085	0.00851	0.08195	0.00031	0.00305	0.03007
New Orleans	0.9	0.00061	0.00608	0.05906	0.00022	0.00217	0.02160
Mississippi Test Facility	1.2	0.00082	0.00815	0.07850	0.00029	0.00292	0.02878
Western Test Range	0.0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Wallops Island	0.5	0.00037	0.00371	0.03655	0.00013	0.00133	0.01321
White Sands	0.2	0.00012	0.00121	0.01203	0.00004	0.00043	0.00431

$$P\{E_1, A_1; N\} = 1 - e^{-\bar{x} \frac{A_1}{A_2} N}$$

5.2.10.3 Hurricanes.

The occurrence of hurricanes at Cape Kennedy and other locations for the Eastern Test Range is of concern to the space program because of high winds and because range support for space operations is closed during passage or near approach of a hurricane. Since the statistics for hurricanes and tropical storm frequencies have not been completed to date, this discussion will be restricted to the frequency of tropical storms, hurricanes, and tropical storms and hurricanes combined (tropical cyclones) for annual reference periods and certain monthly groupings, as a function of radial distances from Cape Kennedy only.

By definition, a hurricane is a tropical storm with winds greater than 64 knots, and a tropical storm is a cyclone whose origin is in the tropics with winds less than 64 knots. There is no known upper limit for wind speeds in hurricanes, but estimates are as high as 160 knots. Also, tornadoes have been observed in association with hurricanes.

To give a general indication of the frequency of tropical storms and hurricanes by months within 100- and 400-nautical-mile radii of Cape Kennedy, see Tables 5.2.49 and 5.2.50. From Table 5.2.49, it is noted that hurricanes within 100 and 400 nautical mile of Cape Kennedy have been observed as early as May and as late as December, with the highest frequency during September. In the 68-year period (1899 to 1966), there were 117 hurricanes whose path (eye) came within a 400-nautical-mile radius of Cape Kennedy; there were 19 hurricanes that came within a 100-nautical-mile radius of Cape Kennedy during this period. From all available wind records along the coast from Melbourne, Florida, to Titusville, Florida, the highest wind gust during the passage of 16 of the 19 hurricanes that came within a 100-nautical-mile radius of Cape Kennedy were obtained. For the three hurricanes

TABLE 5.2.49 NUMBER OF HURRICANES IN A 68-YEAR PERIOD (1899 to 1966) WITHIN A 100- AND A 400-NAUTICAL-MILE RADIUS OF CAPE KENNEDY, FLORIDA

Months	Number of Hurricanes Within:	
	100-n.-mi. radius	400-n.-mi. radius
Jan.	0	0
Feb.	0	0
Mar.	0	0
Apr.	0	0
May	1	1
June	2	3
July	2	12
Aug.	3	23
Sept.	5	42
Oct.	5	30
Nov.	0	5
Dec.	1	1
Total	19	117

TABLE 5.2.50 NUMBER OF TROPICAL STORMS IN A 96-YEAR PERIOD (1871 to 1966) WITHIN A 100- AND A 400-NAUTICAL-MILE RADIUS OF CAPE KENNEDY, FLORIDA

Months	Number of Tropical Storms Within:	
	100-n.-mi. radius	400-n.-mi. radius
Jan.	0	0
Feb.	1	1
Mar.	0	0
Apr.	0	0
May	2	4
June	6	26
July	6	27
Aug.	22	65
Sept.	22	101
Oct.	32	96
Nov.	1	17
Dec.	1	1
Total	93	338

for the years 1899, 1906, and 1925, the peak gusts were not available. Of the 16 hurricanes that came within a 100-nautical-mile radius of Cape Kennedy for which the wind records are available, five produced wind gusts greater than

65 knots,* ten produced wind gusts to 50 knots, and twelve had wind gusts less than 36 knots. Thus, from these records, even if a defined hurricane path comes within a 100-nautical-mile radius of Cape Kennedy, hurricane force winds (speeds > 64 knots) are not always observed at Cape Kennedy. Hurricanes at greater distances than 100 nautical miles could possibly produce hurricane force winds at Cape Kennedy. It is recognized that hurricanes approaching Cape Kennedy from the east (from the sea) will, in general, produce higher winds at Cape Kennedy than those approaching the Cape after crossing the peninsula of Florida (from land).

5.2.10.3.1 Distribution of Hurricane and Tropical Storm Frequencies.

Given the mean number of tropical storms or hurricanes (events) per year that come within a given radius of Cape Kennedy, and no other information, has little utility. If the distribution of the number of tropical storms or hurricanes is known to be a Poisson distribution, then the mean number of events per year (or any reference period) can be used to completely define the Poisson distribution function. In Table 5.2.51**, we present the annual observed (g_0) and the Poisson (g_c) frequencies for both tropical storms and hurricanes that come within 100-, 400-, and 600-nautical-mile radii of Cape Kennedy. For example, there were 33 years when there were no tropical cyclones (either tropical storms or hurricanes) within 100 nautical miles of Cape Kennedy; there were four years in which three tropical cyclones came within 100 nautical miles of Cape Kennedy. Tables 5.2.52 and 5.2.53** give the Poisson distribution for tropical storms and hurricanes in the Cape Kennedy, area.

The mean number of tropical cyclones per year within any radius of Cape Kennedy can be read from Figure 5.2.33. Similarily, the means versus radius for tropical storms and hurricanes for the annual reference period can be found from Figure 5.2.34, and for the monthly groupings July-August-September and July-August-September-October, can be obtained from Figures 5.2.35 and 5.2.36.

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* Highest recorded Cape Kennedy Hurricane associated wind speed was about 76 knots.

** Tables 5.2.51 through 5.2.53 are taken from an internal document prepared for the Aerospace Environment Division by the Environmental Science Services Administration Environmental Data Service, National Weather Records Center, Asheville, North Carolina, under cross-service order: by N. B. Guttman and F. T. Quinlan, NASA Report 67-6, July 1967.

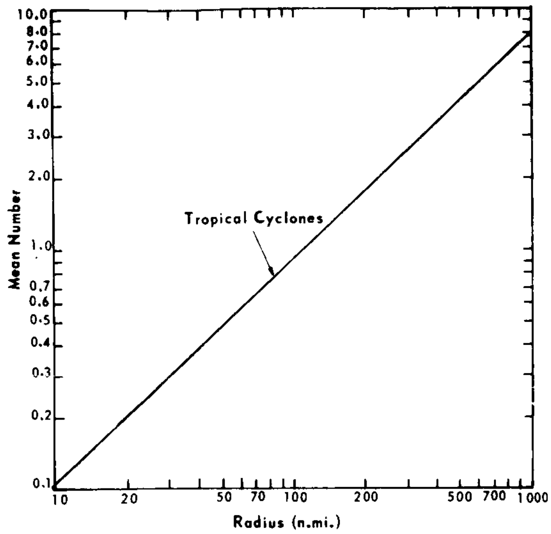


FIGURE 5.2.33 MEAN NUMBER OF TROPICAL CYCLONES PER YEAR WITHIN ANY RADIUS OF CAPE KENNEDY, FLORIDA

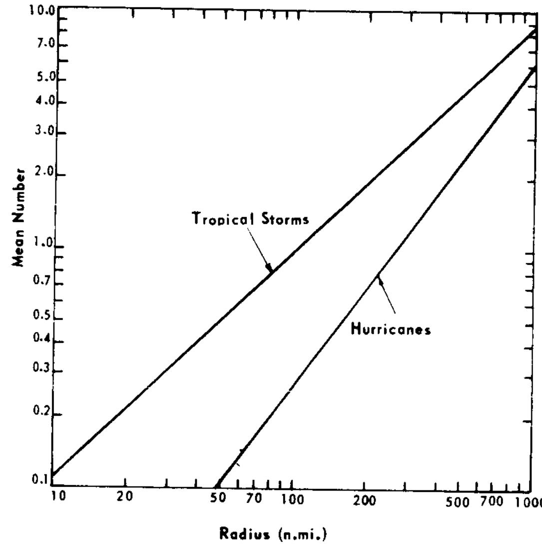


FIGURE 5.2.34 MEAN NUMBER OF TROPICAL STORMS AND HURRICANES PER YEAR WITHIN ANY RADIUS OF CAPE KENNEDY, FLORIDA

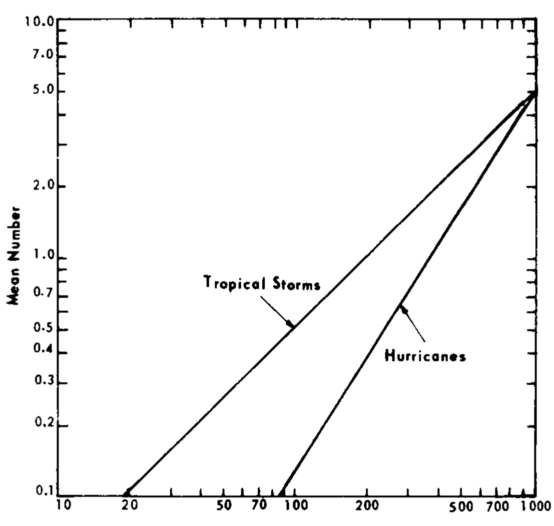


FIGURE 5.2.35 MEAN NUMBER OF TROPICAL AND STORMS AND HURRICANES FOR THE MONTHLY GROUPING, JULY-AUGUST-SEPTEMBER, WITHIN ANY RADIUS OF CAPE KENNEDY, FLORIDA

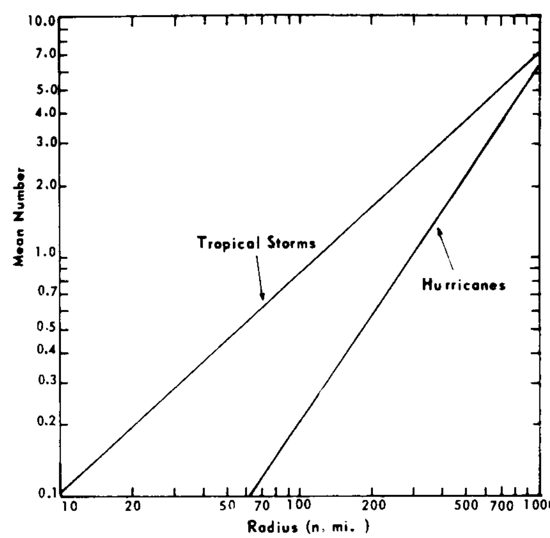


FIGURE 5.2.36 MEAN NUMBER OF TROPICAL STORMS AND HURRICANES FOR THE MONTHLY GROUPING, JULY-AUGUST-SEPTEMBER-OCTOBER, WITHIN ANY RADIUS OF CAPE KENNEDY, FLORIDA

TABLE 5.2.51 POISSON DISTRIBUTION FOR ANNUAL FREQUENCY OF HURRICANES AND TROPICAL STORMS COMBINED WITHIN A 100-, A 400-, AND A 600-NAUTICAL-MILE RADIUS OF CAPE KENNEDY, FLORIDA (1886 to 1967)

	100-n. -mi. Radius				400-n. -mi. Radius				600-n. -mi. Radius			
x	g_0	f(x)	g_c	1-F	g_0	f(x)	g_c	1-F	g_0	f(x)	g_c	1-F
0	33	0.4056	33.3	0.5944	2	0.0295	2.4	0.9705	2	0.0093	0.8	0.9907
1	28	0.3660	30.0	0.2284	11	0.1038	8.5	0.8667	5	0.0433	3.6	0.9474
2	17	0.1652	13.5	0.0633	15	0.1830	15.0	0.6836	6	0.1014	8.3	0.8460
3	4	0.0497	4.1	0.0136	16	0.2150	17.6	0.4686	12	0.1584	13.0	0.6876
4					14	0.1895	15.5	0.2792	13	0.1854	15.2	0.5022
5					14	0.1335	11.0	0.1456	18	0.1736	14.2	0.3286
6					4	0.0785	6.4	0.0672	14	0.1355	11.1	0.1931
7					2	0.0395	3.2	0.0277	3	0.0907	7.4	0.1024
8					2	0.0174	1.4	0.0103	3	0.0531	4.4	0.0493
9					0	0.0099	0.8	0.0091	3	0.0276	2.3	0.0217
10					2	0.0024	0.2	0.0079	2	0.0129	1.1	0.0088
11									0	0.0088	0.8	0.0086
12									0	0.0048	0.4	0.0083
13									1	0.0008	0.1	0.0080
$\bar{x}$	0.9024				3.5244				4.6829			
s_x^2	0.7954				4.1518				5.5092			
Goodness of fit cannot reject at level	5%				5%				5%			

Notes:

g_0 is observed frequency
f(x) is theoretical (Poisson) frequency
g_c is relative frequency

(1-F) is probability of having greater than χ events
1886 - 1967 = N = 82

TABLE 5.2.52 POISSON DISTRIBUTION FOR ANNUAL FREQUENCY OF TROPICAL STORMS WITHIN A 100- AND A 400-NAUTICAL-MILE RADIUS OF CAPE KENNEDY, FLORIDA

x	100-n.-mi. Radius				400-n.-mi. Radius			
	g_0	f(x)	g_c	1-F	g_0	f(x)	g_c	1-F
0	38	0.3795	36.43	1.0000	2	0.0296	2.84	1.000
1	29	0.3677	35.30	0.6205	9	0.1042	10.00	0.9704
2	23	0.1780	17.09	0.2528	24	0.1834	17.61	0.8662
3	6	0.0575	5.52	0.0748	13	0.2152	20.66	0.6828
4					17	0.1894	18.18	0.4676
					21	0.1334	12.81	0.2782
					5	0.0783	7.52	0.1448
					2	0.0394	3.78	0.0665
					2	0.0173	1.66	0.0271
					1	0.0068	0.65	0.0091
Adequacy of Poisson		$0.70 > P(\chi^2_{95} > 87.7) > 0.60$				$0.60 > P(\chi^2_{95} > 92.0) > 0.50$		
Goodness of fit		$0.20 > P(\chi^2_2 > 3.28) > 0.10$				$0.05 > P(\chi^2_2 > 11.8) > 0.025$		

5.2.10.3.2 Probability of One or More Storm Events Versus Any Radius of Cape Kennedy.

From the Poisson distributions, we can obtain the following equation:

$$-\ln[-\ln P\{E_0, r\}] = -[\ln a + b \ln r]. \quad (3)\ 5.2.10$$

TABLE 5.2.53 POISSON DISTRIBUTION FOR ANNUAL FREQUENCY OF HURRICANES WITHIN A 100- AND A 400-NAUTICAL-MILE RADIUS OF CAPE KENNEDY, FLORIDA

	100-n.-mi. Radius				400-n.-mi. Radius			
x	g_0	f(x)	g_c	1-F	g_0	f(x)	g_c	1-F
0	54	0.7674	52.00	1.0000	15	0.1790	12.17	1.0000
1	11	0.2031	15.82	0.2326	19	0.3081	20.95	0.8210
2	4	0.0269	2.00	0.0295	14	0.2650	18.02	0.5129
3			0.18	0.0026	14	0.1521	10.34	0.2479
4					2	0.0654	4.45	0.0958
5					4	0.0226	1.54	0.0304
6								
Adequacy of Poisson					$P(\chi^2 > 76.5) = 20$			
Goodness of fit					$0.40 > P(\chi^2 > 3.03) > 0.30$			

where $x = a r^b$ is an empirc al function for the mean number of storm events versus radius r. If either a tropical storm or a hurricane within a 600-nautical-mile radius of Cape Kennedy is of concern to the space mission planner, then he can expect to have this event one or more times in any year with a probability of 0.9907. Stated in another way: 99 percent of the years he can expect to have this concern more than once. This probability is taken from Table 5.2.51, the last column (1-F).

Using the tabulated values for a's and b's given in Table 5.2.54, Equation (3) 5.2.10 was evaluated, and the results are illustrated in Figure 5.2.37. From Figure 5.2.37, the probability of no event, $P\{E_0, r\}$, for the following can be read: (1) tropical cyclones, tropical storms, and hurricanes for annual reference periods; and (2) tropical storms, and hurricanes for July-August-September; and (3) tropical storms and hurricanes for July-August-September-October, versus radius in nautical miles from Cape Kennedy. To obtain the probability for one or more events, $P\{E_0, r\}$, for Figure 5.2.37, the reader is required to subtract the $P\{E_0, r\}$, read from the abscissa, from unity; that is, $[1 - P\{E_0, r\}] = P\{E_1, r\}$. For example, the probability that no hurricane path (eye) will come within 300 nautical miles of Cape Kennedy in a year is 0.31, ($P\{E_0, r = 300\} = 0.31$), and the probability that there will be one or more hurricanes within 300 nautical miles of Cape Kennedy in a year is 0.69, ($1 - 0.31 = 0.69$).

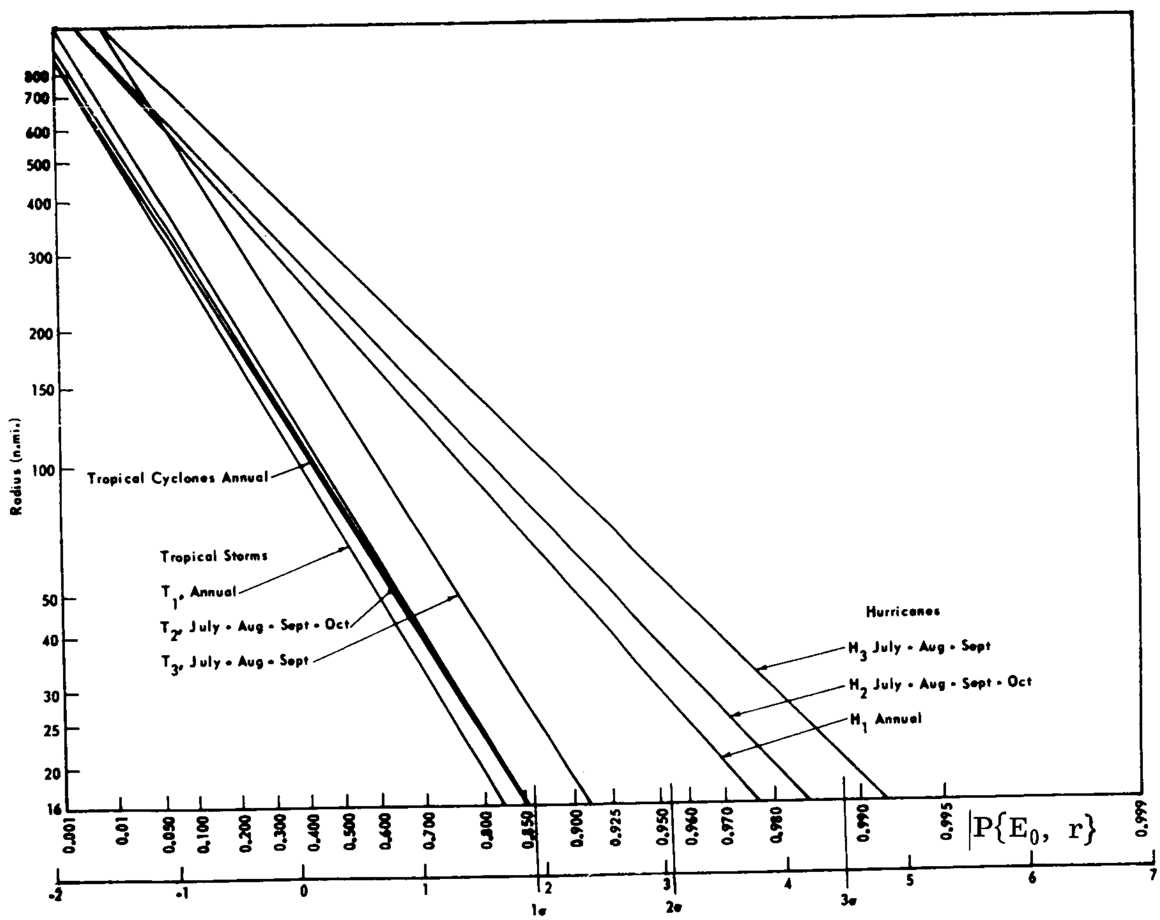


FIGURE 5.2.37 PROBABILITY OF NO TROPICAL CYCLONES, TROPICAL STORMS, OR HURRICANES FOR VARIOUS REFERENCE PERIODS VERSUS VARIOUS RADII FROM CAPE KENNEDY, FLORIDA

TABLE 5.2.54 STATISTICS OF HURRICANES AND TROPICAL STORMS WITHIN A 100- AND A 400-NAUTICAL-MILE RADIUS OF CAPE KENNEDY, FLORIDA

	$P\{E_0\}$	$P\{E_1\}$	$\bar{x}$	a	ln a	b
Hurricanes or Tropical Storms						
Annual						
Hurricanes:						
100 n. mi.	0.7674	0.2326	0.2647	5.2765×10^{-4}	-7.54713	1.35022
400 n. mi.	0.1790	0.8210	1.7206			
Tropical Storms:						
100 n. mi.	0.3795	0.6205	0.9688	1.332×10^{-2}	-4.31855	0.93087
400 n. mi.	0.0296	0.9704	3.5208			
July-Aug.-Sept.						
Hurricanes:						
100 n. mi.	0.8760	0.1240	0.13235	1.059×10^{-4}	-9.15312	1.54844
400 n. mi.	0.3223	0.6777	1.13235			
Tropical Storms:						
100 n. mi.	0.5940	0.4060	0.5208	5.862×10^{-3}	-5.13919	0.97431
400 n. mi.	0.1339	0.8661	2.0104			
July-Aug.-Sept.-Oct.						
Hurricanes:						
100 n. mi.	0.8139	0.1861	0.2059	2.3962×10^{-4}	-8.33646	1.46705
400 n. mi.	0.2073	0.7927	1.5735			
Tropical Storms:						
100 n. mi.	0.4256	0.5744	0.8542	1.3007×10^{-2}	-4.34225	0.90868
400 n. mi.	0.0493	0.9507	3.0104			
Tropical Cyclone (Hurricanes and Tropical Storms)						
Annual						
Hurricanes:						
100 n. mi.	0.4056	0.5944	0.9024	0.0115	-4.4697	0.9444
400 n. mi.	0.0295	0.9705	3.5243			
600 n. mi.	0.00925	0.99075	4.6830			

Notes:

a, ln a, b are coefficients for the expression

$\bar{x} = a\, r^b$, where r is the radius in nautical miles

$x \triangleq$ mean number of events in the specified reference period

$P\{E_0\} \triangleq$ probability of no events occurring in the specified reference periods.

$P\{E_1\} \triangleq$ probability of one or more events occurring in the specified reference periods.

5.2.10.4 Thunderstorms.

Thunderstorms are of primary concern in the design of space vehicles and related facilities, in the planning of space missions, and in launch operations, because of high winds, lightning hazards, and extreme turbulence associated with this atmospheric phenomena.

5.2.10.4.1 Frequency of Thunderstorm Days and Associated Peak Winds for Cape Kennedy, Florida.

Because of the high frequency of occurrence of thunderstorms at Cape Kennedy, particularly during the summer, thunderstorms are perhaps the most frequent cause for operational decisions concerning space operations relative to meteorological factors. Since the frequency of the thunderstorm events are well documented for Cape Kennedy by Falls (Ref. 5.26), and since the persistence of thunderstorms at Cape Kennedy, in terms of conditional probabilities have been documented as well (Ref. 5.27), the following discussions will be devoted primarily to distributions of daily wind speeds on thunderstorm days, nonthunderstorm days, and daily peak thunderstorm wind speeds.

In Figure 5.2.38, we present the empirical probability that a thunderstorm will occur in the Cape Kennedy area at each hour of the day versus month. The highest frequency of thunderstorms (24%) is at 1600 EST

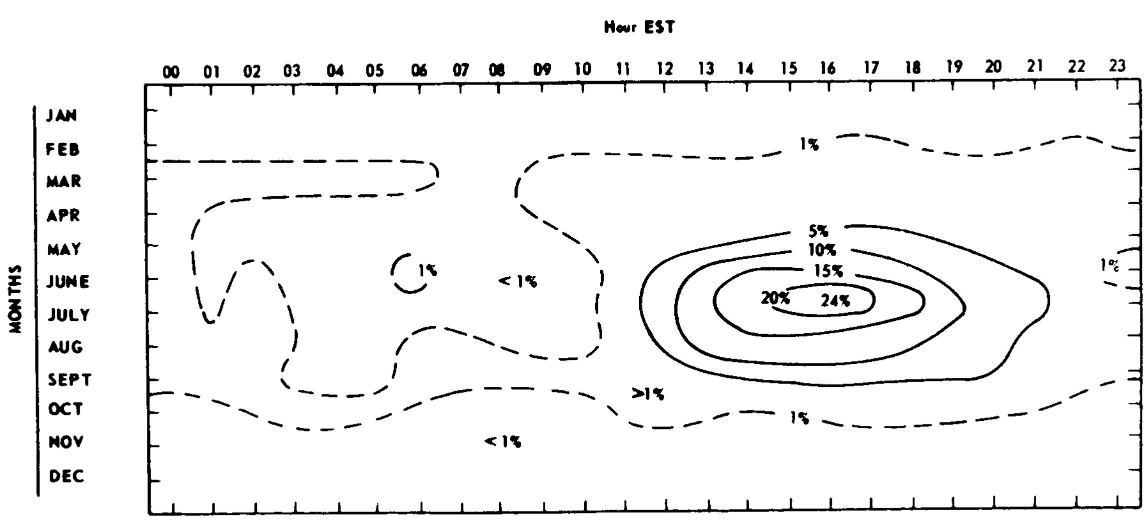


FIGURE 5.2.38 PROBABILITY (%) OF OCCURRENCE OF THUNDERSTORMS BY MONTHS VERSUS TIME OF DAY IN THE CAPE KENNEDY, FLORIDA AREA

in July. A thunderstorm is reported by standard observational practice if thunder is heard, which it can be over a radius of approximately 25 kilometers. Thus, the statistics presented in Figure 5.2.38 are not necessarily the probability that a thunderstorm will "hit," for example, a vehicle on the launch pad, or occur at a given location on Cape Kennedy. Information on probability of lightning stroke is given in Section 9.1.2.

From a statistical 10-year sample of thunderstorm events for Cape Kennedy, including the beginning and ending times of thunderstorms; the peak winds during each thunderstorm event; and a code indicating whether more than one thunderstorm was observed for each event; weather; and other related phenomena, we have computed the percentage of days that had one or more thunderstorm events (see column A, Table 5.2.55); the parameters, α and μ (The Gumbel distribution is discussed in Section 5.2.4.4.5.); and the 95th percentile for samples of (1) daily peak wind speeds for nonthunderstorm days, (2) daily peak winds for thunderstorm days, (3) daily peak winds on all days, and (4) daily peak thunderstorm wind speeds for the indicated reference periods. Also see Reference 5.62 for additonal information.

From the mode, μ, (the 36.788th percentile) and the 95th percentile values from Table 5.2.55, plots of the Gumbel distribution for these samples are shown in Figures 5.2.39 through 5.2.55.

Using April, (Fig. 5.2.42) as an example to show the utility of these distributions of daily peak winds, the following summary is made:

(a) The probability that the peak wind speed for any day in April exceeding 30 knots at the 10-meter level ($\sim$32 knots at the 60-ft reference level) is 0.070. (This probability is obtained from the distribution for "all days," Fig. 5.2.42 as 1 - 0.930 = 0.070.)

(b) For nonthunderstorm days, the probability that the daily peak wind speed will exceed 30 knots, 10-meter level, is 0.04 (1 - 0.96 = 0.04 from Fig. 5.2.42, nonthunderstorm days).

(c) For thunderstorm days (when thunder is heard one or more times), the probability that the daily peak wind speed will exceed 30 knots, 10-meter level, is 0.30 (1 - 0.70 = 0.30).

(d) From Column A, Table 5.2.55, the frequency of days with thunderstorms is 10 percent. Thus, the probability that a daily peak thunderstorm wind will exceed 30 knots (10-meter level) on any day in April

TABLE 5.2.55 PERCENTAGE OF DAYS WITH ONE OR MORE THUNDERSTORMS, THE GUMBEL DISTRIBUTION PARAMETERS α AND μ, THE 95th PERCENTILE DAILY WIND SPEEDS FOR NONTHUNDERSTORM DAYS, THUNDERSTORM DAYS, AND ALL DAYS, AND DAILY PEAK THUNDERSTORM WIND SPEEDS FOR CAPE KENNEDY, FLORIDA

A		B			C			D			E		
		Daily Peak Winds on Non TSTM Days			Daily Peak Winds on TSTM Days (knots)			Daily Peak Winds on All Days (knots)			Daily Peak TSTM Winds (knots)		
Reference Period	Days With TSTM (%)	$\hat{\alpha}$ (knots)$^{-1}$	$\hat{\mu}$ (knots)	95th Percentile (knots)	$\hat{\alpha}$ (knots)$^{-1}$	$\hat{\mu}$ (knots)	95th Percentile (knots)	$\hat{\alpha}$ (knots)$^{-1}$	$\hat{\mu}$ (knots)	95th Percentile (knots)	$\hat{\alpha}$ (knots)$^{-1}$	$\hat{\mu}$ (knots)	95th Percentile (knots)
Jan.	1.8	0.208	17.4	31.6	0.199	23.1	38.0						
Feb.	4.5	0.186	18.5	34.5	0.210	24.5	38.6	0.208	17.5	31.7	*	*	*
Mar.	9.7	0.208	18.8	33.0	0.142	22.6	42.3	0.186	18.8	34.8	*	*	*
Apr.	10.0	0.265	17.9	29.1	0.135	22.5	44.5	0.199	19.0	34.0	0.132	19.0	41.5
May	21.7	0.296	16.2	26.4	0.253	18.5	30.6	0.227	18.2	31.3	0.105	16.9	46.2
June	42.4	0.252	16.0	27.7	0.180	17.6	34.1	0.284	16.8	27.3	0.205	15.9	30.4
July	46.9	0.286	15.7	26.1	0.183	18.5	34.7	0.212	16.6	30.2	0.159	16.2	34.8
Aug.	46.1	0.212	13.3	27.4	0.201	15.9	30.7	0.212	16.8	30.8	0.168	17.4	35.1
Sept.	30.7	0.225	15.4	28.6	0.180	18.0	34.5	0.202	14.9	29.6	0.170	15.0	33.0
Oct.	9.4	0.235	16.7	29.3	0.183	16.7	42.9	0.205	16.1	30.7	0.170	15.9	33.4
Nov.	2.7	0.227	16.0	29.1	0.281	21.1	31.6	0.236	16.8	29.4	0.164	14.3	32.4
Dec.	2.0	0.216	16.3	20.0	0.140	16.9	37.4	0.227	16.1	29.2	*	*	*
Annual	19.1	0.225	16.6	29.8	0.189	18.3	34.0	0.216	16.4	30.1	*	*	*
Mar.-Apr.-May	13.8	0.244	17.6	29.8	0.175	20.0	37.0	0.214	16.9	30.8	0.189	16.7	32.4
June-July-Aug.	45.1	0.247	15.1	27.0	0.190	17.7	33.3	0.226	17.9	31.1	0.148	16.8	37.0
Sept.-Oct.	19.9	0.233	16.1	28.9	0.184	17.6	33.8	0.208	16.0	30.3	0.170	16.2	33.7
Nov.-Dec.-Jan.-Feb.	2.7	0.209	17.0	31.3	0.210	21.8	36.0	0.221	16.4	29.8	0.171	15.5	32.9
								0.209	18.1	31.4	0.195	18.2	33.5

* Not computed because of small sample sized

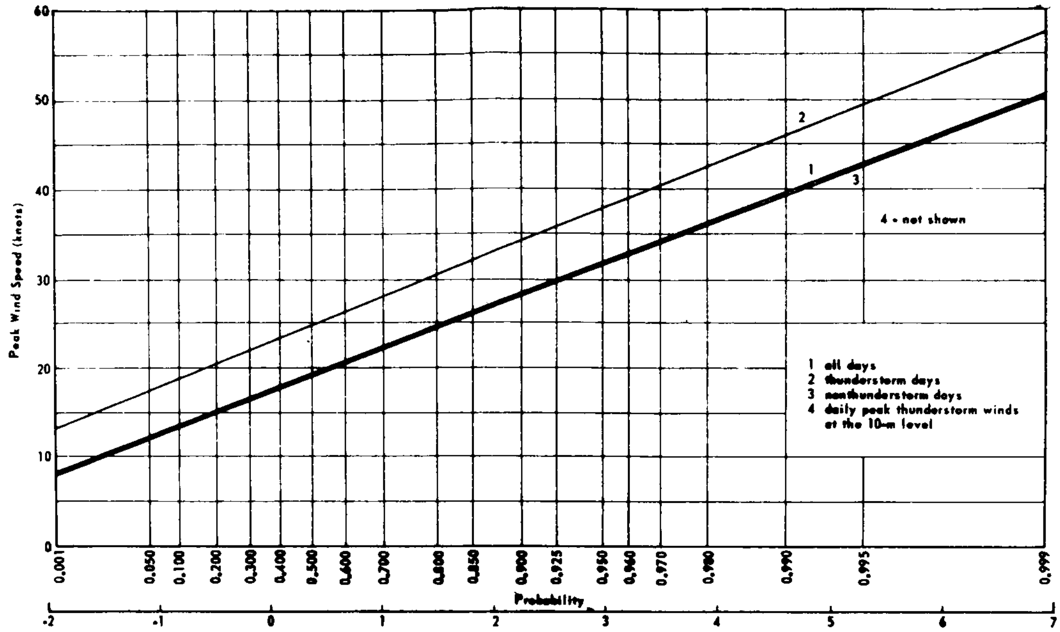


FIGURE 5.2.39 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — JANUARY

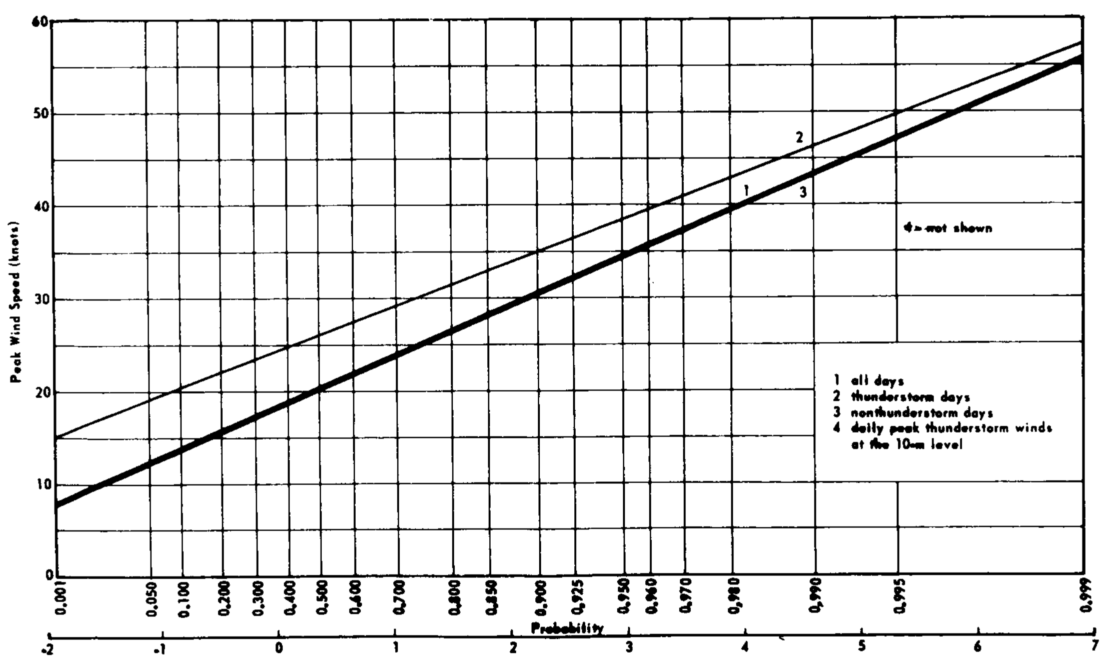


FIGURE 5.2.40 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — FEBRUARY

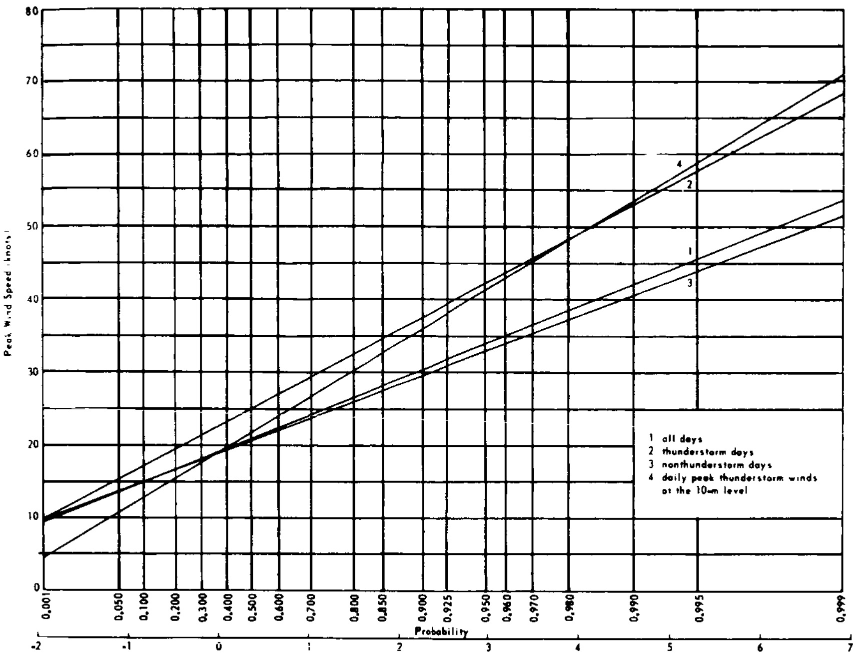


FIGURE 5.2.41 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — MARCH

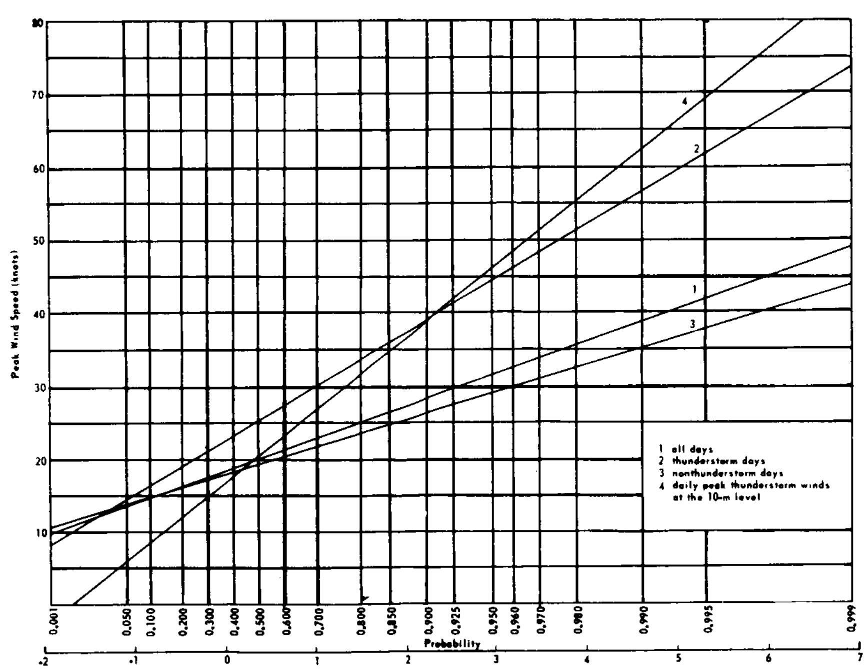


FIGURE 5.2.42 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — APRIL

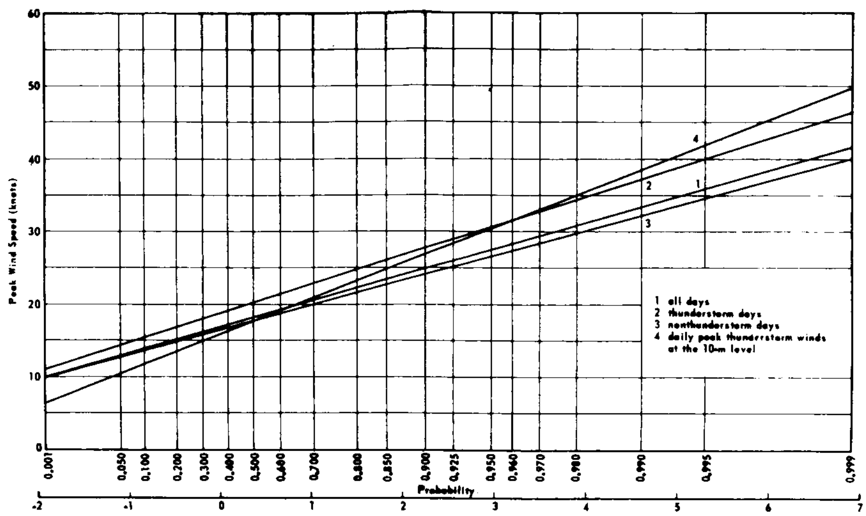


FIGURE 5.2.43 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — MAY

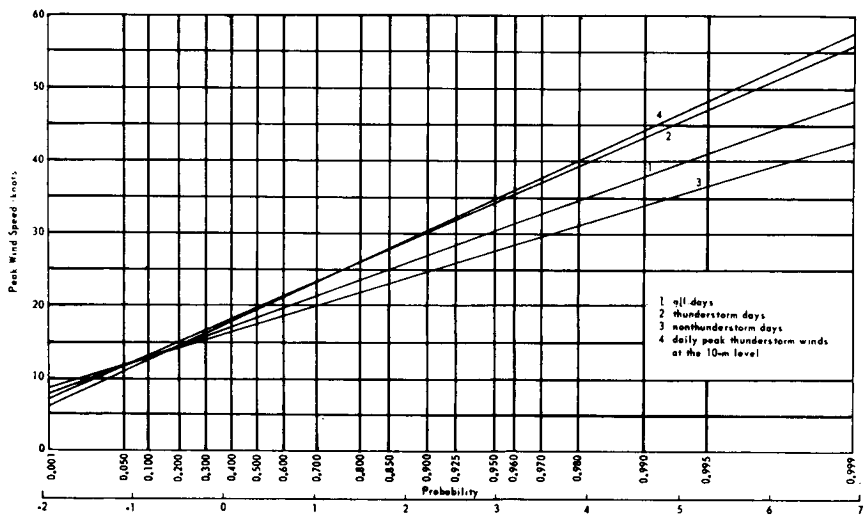


FIGURE 5.2.44 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — JUNE

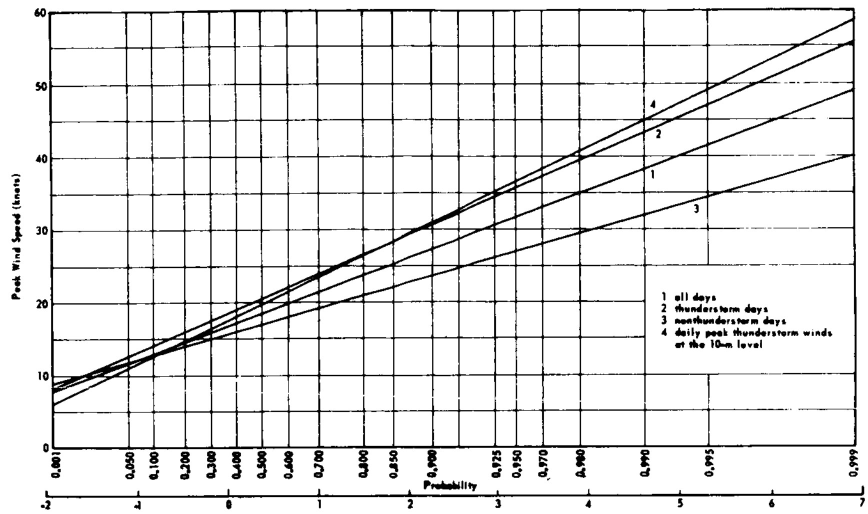


FIGURE 5.2.45 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA – JULY

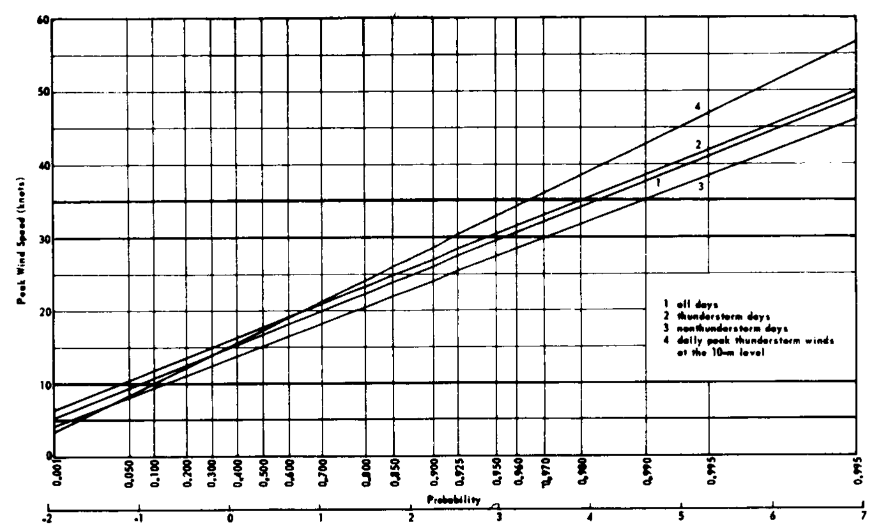


FIGURE 5.2.46 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA – AUGUST

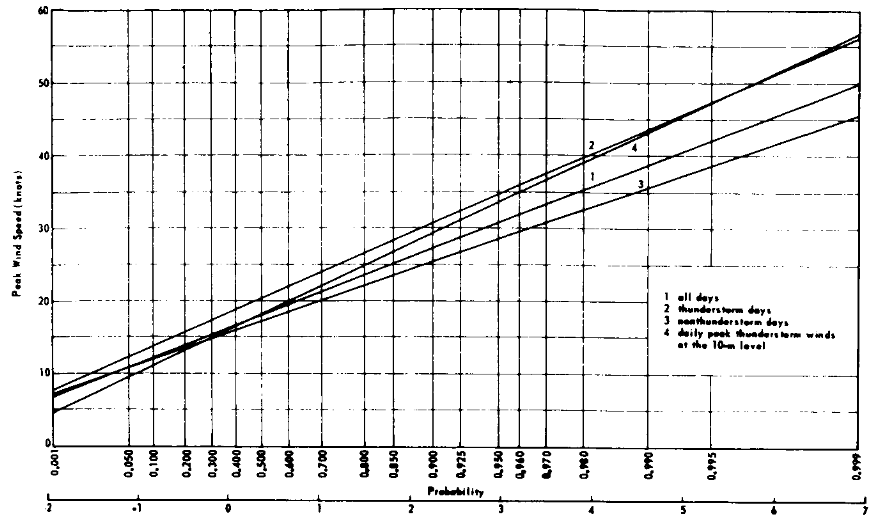


FIGURE 5.2.47 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — SEPTEMBER

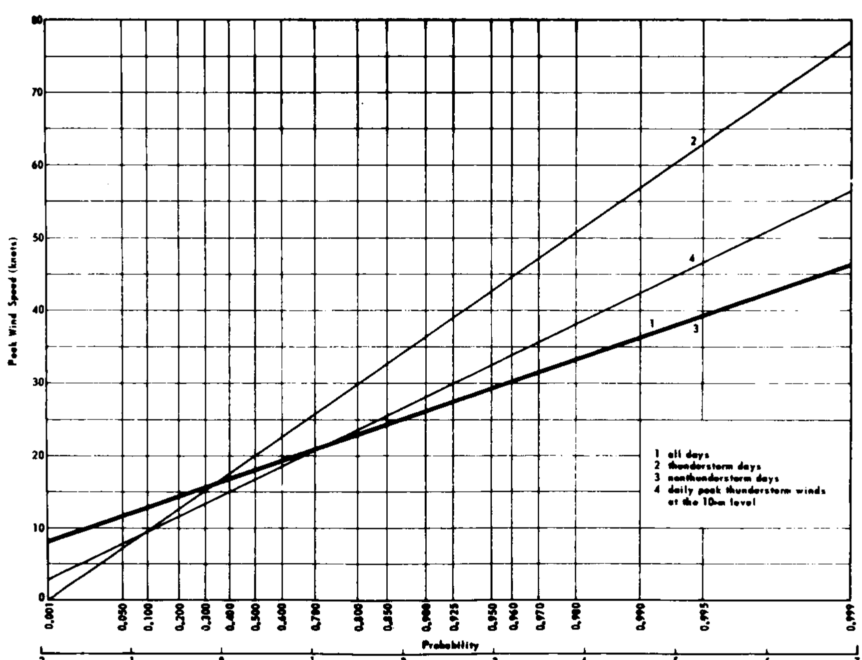


FIGURE 5.2.48 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — OCTOBER

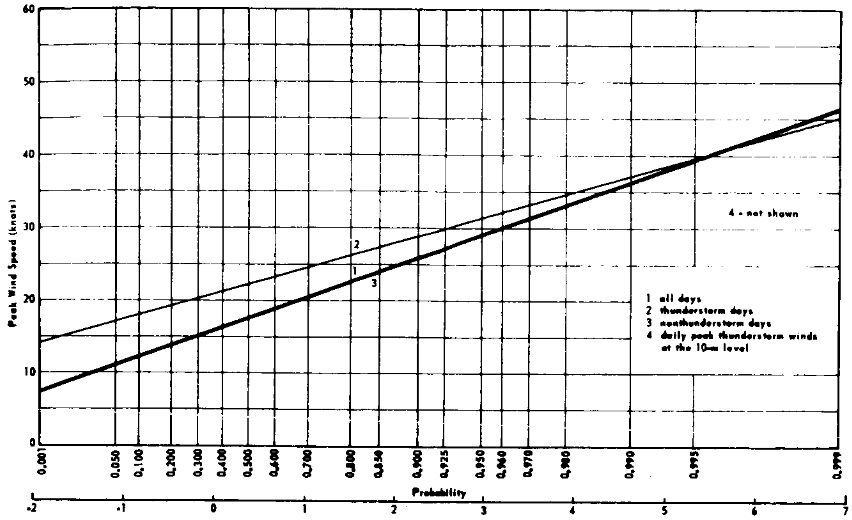


FIGURE 5.2.49 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — NOVEMBER

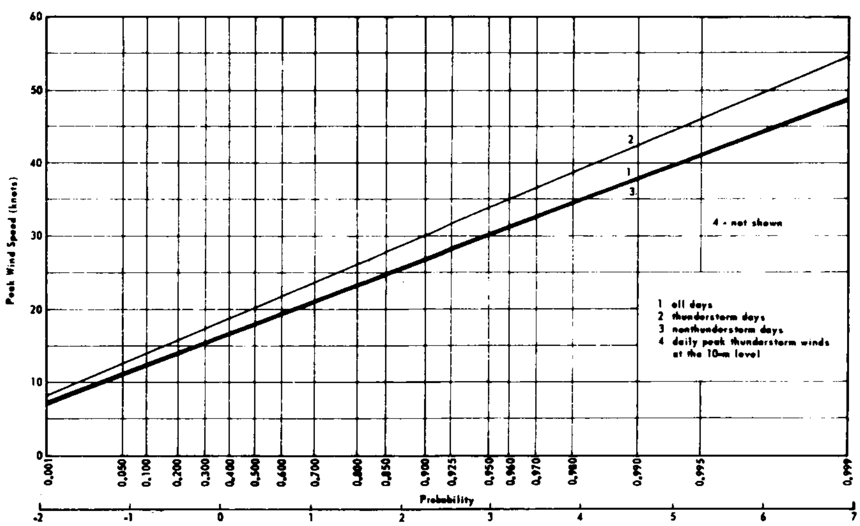


FIGURE 5.2.50 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — DECEMBER

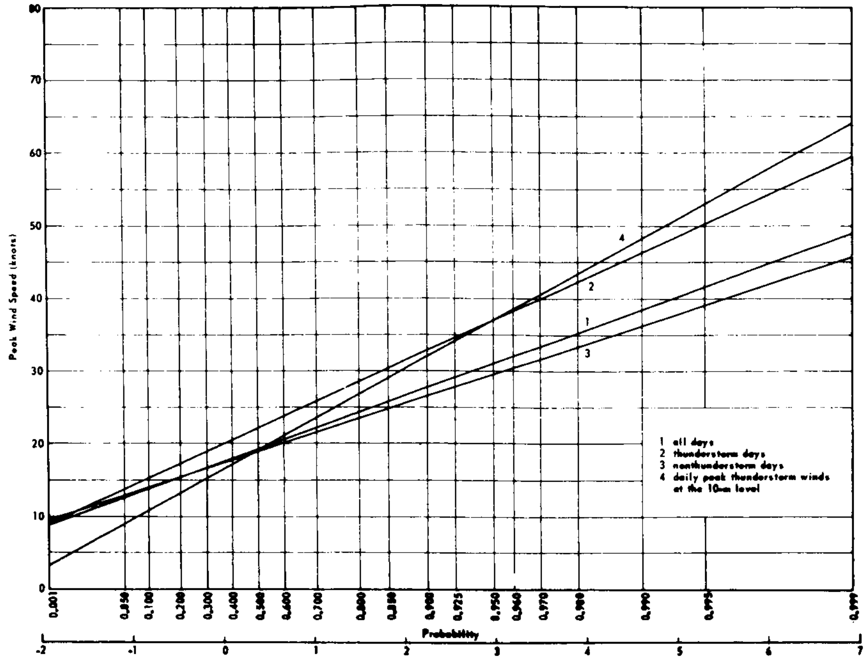


FIGURE 5.2.51 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — MARCH-APRIL-MAY

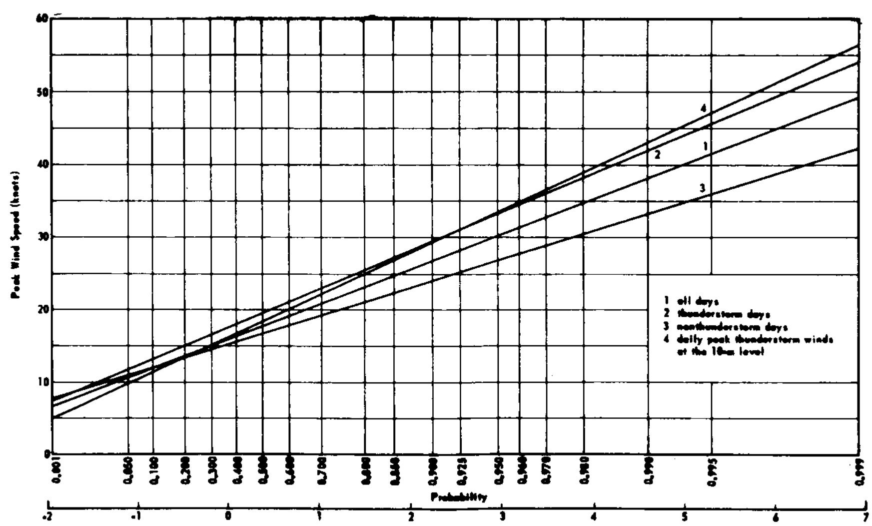


FIGURE 5.2.52 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — JUNE-JULY-AUGUST

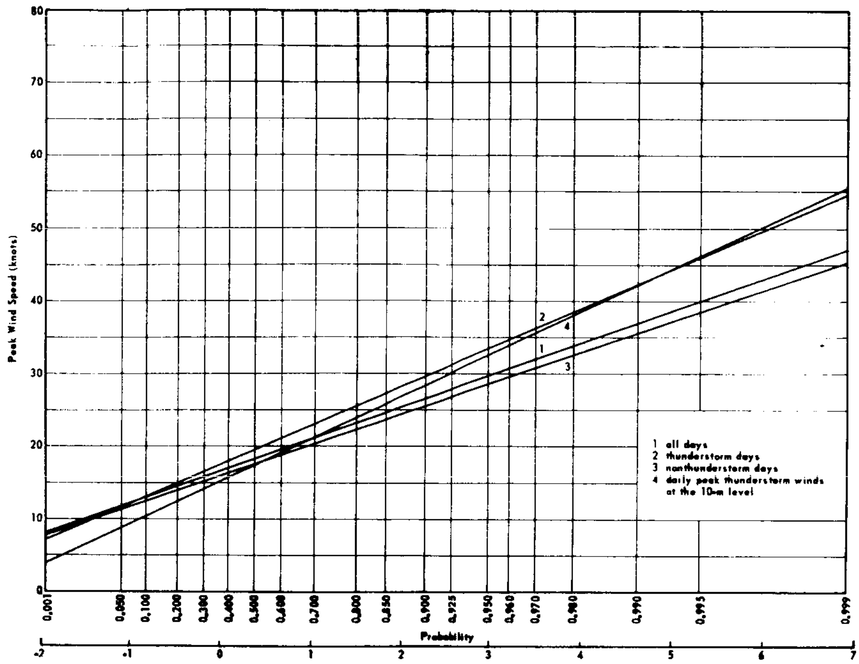


FIGURE 5.2.53 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — SEPTEMBER-OCTOBER

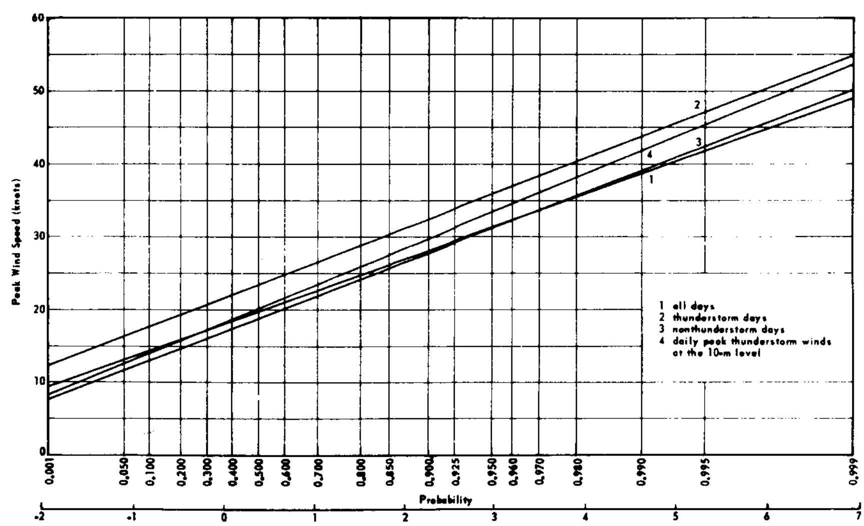


FIGURE 5.2.54 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — NOVEMBER-DECEMBER-JANUARY-FEBRUARY

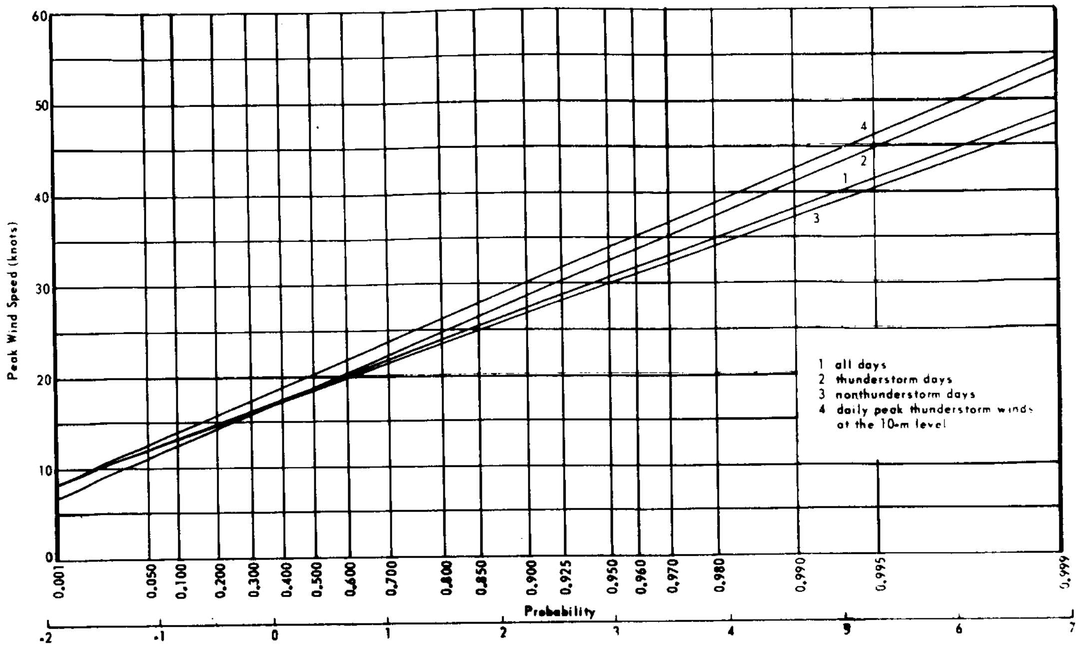


FIGURE 5.2.55 GUMBEL DISTRIBUTIONS OF DAILY PEAK WINDS, CAPE KENNEDY, FLORIDA — ANNUAL

is the probability that a 30-knots peak wind will be exceeded on a thunderstorm day (which is 0.30 obtained in (b) above) times the probability that a day in April will have a thunderstorm $(0.30 \times 0.10 = 0.03)$.

(e) The probability that the daily peak thunderstorm wind will exceed 30 knots is 0.23 (1 - 0.77).

(f) If the operations weather forecaster can predict with certainty that a day will or will not have thunderstorms at Cape Kennedy, then, with no other information, a very good probability prediction for the daily peak wind can be made using the distributions given in Figures 5.2.39 through 5.2.55.

From the empirical conditional probabilities for consecutive days with and without thunderstorms (Ref. 5.27), the forecaster has a further aid in predicting whether or not the next or any future day will have a thunderstorm.

From (Ref. 5.26), the frequency of the observed number of days that had x (x = 0, 1, 2, . . .) thunderstorm events at Cape Kennedy is an excellent fit to the negative binomial distribution. The probability of exactly x events (density function) for the negative binomial distribution is given by

$$P\{x\} = \binom{x + k - 1}{k - 1} p^k q^x \quad , \qquad (4)\ 5.2.10$$

or, in terms of the gamma function as

$$P\{x\} = \frac{\Gamma\ (x + k)}{x!\ \ \Gamma(k)}\ p^k q^x \quad . \qquad (5)\ 5.2.10$$

where $x = 0,\ 1,\ 2,\ \ldots;\ k > 0,\ 0 \leqq P \leqq 1$; and the distribution function is given by

$$F(x) = \sum_{x=0}^{N} \frac{\Gamma\ (x + k)}{x!\ \ \Gamma(k)}\ p^k q^x \quad , \qquad (6)\ 5.2.10$$

which gives the probability of obtaining a value of less than or equal to some particular value x, say x_0.

The sample moment estimators for the parameters k and p are

$$k^* = \frac{\bar{x}^2}{s_x^2 - \bar{x}} \quad , \quad p^* = \frac{k}{k + \bar{x}} \quad .$$

The sample estimators for $\bar{x}$, s_x^2, k^*, p^* and the sample size n for thunderstorm events are given in Table 5.2.56 for those months that had a sufficiently large number of days with thunderstorm events.

Using the values for the parameters given in Table 5.2.56, Equations (5) 5.2.10 and (6) 5.2.10 have been evaluated and reported in Ref. 5.26. Also given in Ref. 5.26 are the conditional probabilities to answer this question: Given that 1, 2, 3, . . . thunderstorm events have occurred on a day, what is the probability that 1, 2, 3, . . . additional thunderstorm events will occur on that day? Specific recommendations for vehicle design criteria are given in Section 5.2.11.1 and Section 5.2.5.5.

5.2.10.4.2 Frequency of Thunderstorm Days for Wallops Island, White Sands, and Vandenberg, A.F.B.

Unfortunately, the statistics for thunderstorms for other ranges are not as comprehensive as for Cape Kennedy. The mean number of days

TABLE 5.2.56 PARAMETERS FOR NEGATIVE BINOMIAL DISTRIBUTION FOR THUNDERSTORM EVENTS AT CAPE KENNEDY, FLORIDA

Reference Period	$\bar{x}$	s_x^2	k*	p*	n
Mar.	0.150	0.268	0.189	0.558	341
Apr.	0.142	0.237	0.214	0.600	330
May	0.352	0.621	0.460	0.567	341
June	0.752	1.169	1.354	0.643	330
July	0.874	1.277	1.893	0.684	341
Aug.	0.809	1.280	1.391	0.632	341
Sept.	0.509	0.777	0.967	0.655	330
Oct.	0.138	0.242	0.182	0.570	341
Mar.-Apr.-May	0.215	0.386	0.271	0.557	1012
June-July-Aug.	0.812	1.245	1.523	0.652	1012
Sept.-Oct.-Nov.	0.227	0.397	0.302	0.571	1001

TABLE 5.2.57 MEAN NUMBER OF DAYS WITH THUNDERSTORMS FOR WALLOPS ISLAND TEST RANGE, VIRGINIA; WHITE SANDS MISSILE RANGE, NEW MEXICO; AND VANDENBERG AIR FORCE BASE, CALIFORNIA

Reference Period	Wallops Island	White Sands	Vandenberg AFB
Jan.	0.2	0.3	0.1
Feb.	0.5	<0.05	0.3
Mar.	2.1	0.7	0.3
Apr.	3.4	1.8	0.1
May	5.1	2.9	<0.05
June	7.0	5.8	<0.05
July	8.8	11.6	0.2
Aug.	8.3	9.1	0.2
Sept.	3.2	3.3	0.5
Oct.	1.3	2.0	<0.05
Nov.	0.4	0.2	0.1
Dec.	0.3	0.4	0.1
Annual	40.6	38.1	1.9

with thunderstorms at Norfolk, Virginia, taken from 12 years of record used in lieu of Wallops, and for Holloman, taken from 13 years of records used in lieu of White Sands, and for Vandenberg, taken from 9 years record, are given in Table 5.2.57.

5.2.11 Ground Wind Criteria.

5.2.11.1 Vehicle Design Wind Criteria.

Data on basic wind speed profiles given in section 5.2.5.5 are to be used for vehicle design. With respect to design practices, the application of peak winds and the associated turbulence spectra and discrete gusts should be considered. The maximum response obtained for the selected risk levels for each physically realistic combination of conditions should be employed in the design, but not the sum of all individual response calculations, for example, to the peak wind, discrete gust, turbulence spectra, and steady state wind. Also consideration should be given to the appropriate exposure period for free standing risk wind value selection. See Appendix 5A also.

5.2.11.2 Design Winds for Facilities and Ground Supply Equipment.

5.2.11.2.1 Introduction.

In this section, the important relationships between desired lifetime (N), calculated risk (U), design return period (T_D), and design wind (W_D) relative to the 10-meter reference level for ground winds will be described for use in facilities design for several locations.

a. The desired lifetime (N) is expressed in years, and preliminary estimates must be made as to how many years the proposed facility is to be used.

b. The calculated risk (U) is a probability expressed either as a percentage or as a decimal fraction. Calculated risk, sometimes referred to as design risk, is a probability measure of the risk the designer is willing to accept that the facility will be destroyed by wind loading in less time than the desired lifetime.

c. The design return period (T_D) is expressed in years and is a function of desired lifetime and calculated risk.

d. The design wind (W_D) is a function of the desired lifetime, and calculated risk, which can be derived either through the design return period and a probability distribution function of yearly peak winds or from an analytical expression.

5.2.11.2.2 Development of Relationships.

From the theory of repeated trial probability we can derive the following expression:

$$N = \frac{\ln(1 - U)}{\ln\left(1 - \frac{1}{T_D}\right)} \quad . \qquad (1)\ 5.2.11$$

Equation (1) 5.2.11 gives the important relationships for the three variables, calculated risk (U), design return period (T_D), and desired lifetime (N). Having estimates for any two variables, the third can be determined.

From the derivation of equation (1) 5.2.11, solutions for the design return period versus desired lifetime for various design risks are illustrated in Figure 5.2.56. In Table 5.2.58, the exact and adopted values for design return period versus desired lifetime for various design risk are presented. The adopted values for T_D are in some cases greatly oversized to facilitate a convenient use of the tabulated probabilities for the distributions of yearly peak winds.

5.2.11.2.3 Design Winds 10-Meter Level for Facilities at Cape Kennedy.

To obtain the design wind, it is required to determine the wind speed corresponding to the design return period. Since the design return period can be expressed in terms of probability, either of two procedures can be used to determine the design wind: one being through a graphical or numerical interpolation procedure; and the second, from an analytical function that will be derived. A knowledge of the distribution of yearly peak winds is required for both procedures. For the greatest statistical efficiency in arriving at a knowledge of the probability that peak winds will be less than or equal to some specified value of yearly peak winds (that is, $P\{W \le W^*\}$ or for exceedance probabilities, $P\{W > W^*\} = [1 - P\{W \le W^*\}]$), the choice of an appropriate probability distribution function is made, and the parameters for the function are estimated from the sample of yearly peak winds. For the investigation leading to the distribution of hourly, daily, monthly, and yearly

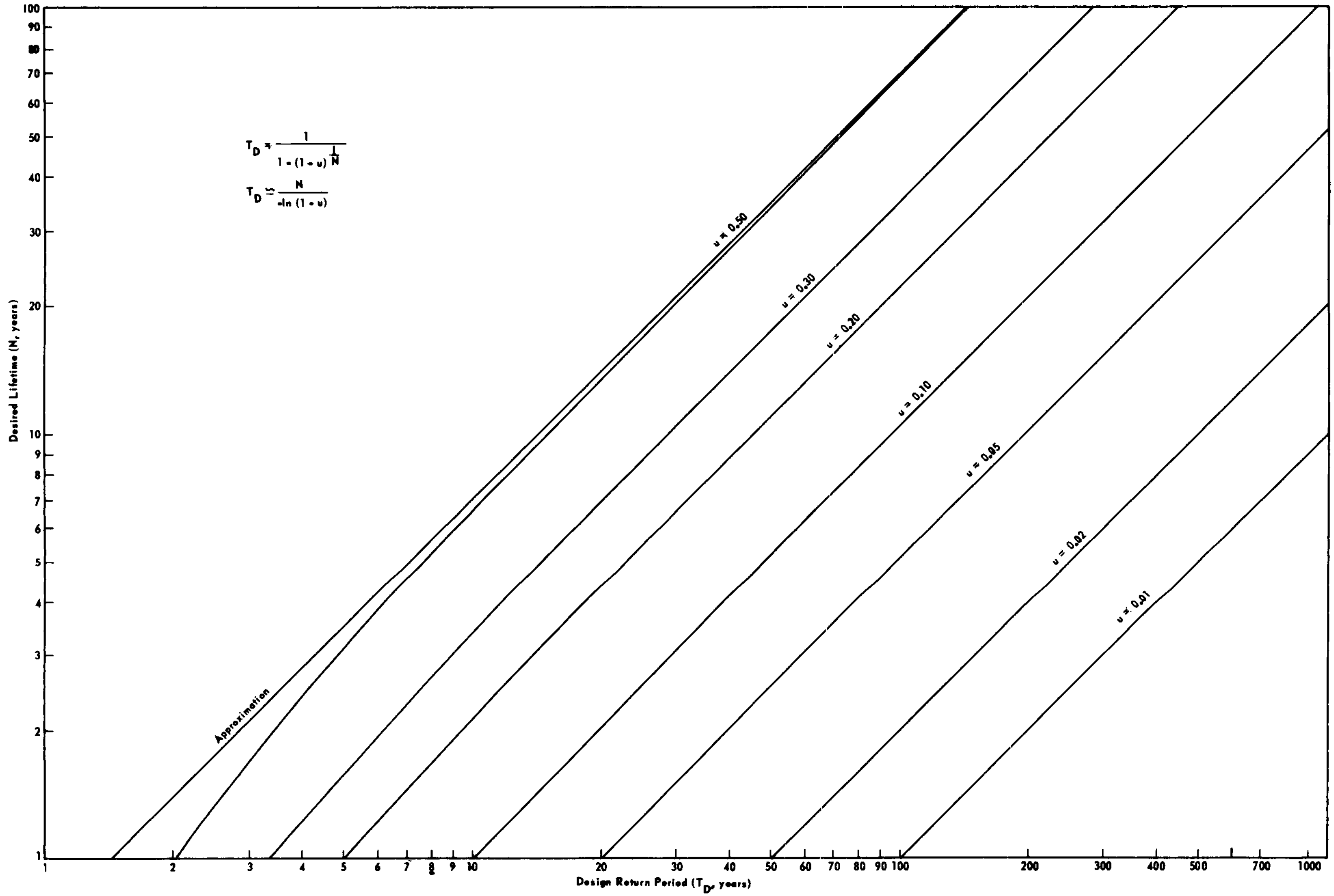


FIGURE 5.2.56 DESIGN RETURN PERIOD (T_0, years) VERSUS DESIRED LIFETIME (N, years) FOR VARIOUS DESIGN RISKS (U)

TABLE 5.2.58 EXACT AND ADOPTED VALUES FOR DESIGN RETURN PERIOD (T_D, years) VERSUS DESIRED LIFETIME (N, years) FOR VARIOUS DESIGN RISKS (U)

N (years)	Design Return Period (years)									
	U = 0.50%		U = 0.20%		U = 10%		U = 5%		U = 1%	
	Exact	Adopted	Exact	Adopted	Exact	Adopted	Exact	Adopted	Exact	Adopted
1	2	2	15	5	10	10	20	20	100	100
10	15	15	45	50	95	100	196	200	996	1000
20	29	30	90	100	190	200	390	400	1991	2000
25	37	40	113	125	238	250	488	500		
30	44	50	135	150	285	300	585	600		
50	73	100	225	250	475	500	975	1000		
100	145	150	449	500	950	1000	1950	2000		

peaks, discussed in Section 5.2.4.4, it was learned that the Gumbel distribution was an excellent fit for the 17 years of yearly peak ground winds at the 10-meter level for Cape Kennedy. (The Frèchet, a special case of Fisher-Tippett Type II, distribution mentioned in Section 5.2.4.45 was also an adequate fit to this sample.) The distribution of yearly peak wind (10-meter level), as obtained by the Gumbel distribution, is tabulated for various percentiles along with the corresponding return periods in Table 5.2.59. The values for the parameters, α and μ, for this distribution are also given in Table 5.2.59. Figure 5.2.57 gives a plot of the Gumbel distribution for yearly peak wind (10-meter level) for Cape Kennedy. The design wind can now be determined by making a choice for desired lifetime and design risk and by taking the design return period from Table 5.2.58 and looking up the wind speed corresponding to the return period given in Table 5.2.59. For combinations not tabulated in Tables 5.2.58 and 5.2.59, the design return period can be interpolated from Figure 5.2.56, and the design wind can be interpolated from figure 5.2.57.

5.2.11.2.4 Analytical Procedure to Determine Design Winds for Facilities Relative to 10-Meter Level Ground Winds.

It is desired to show an analytical form for the design wind (W_D) as a function of desired lifetime (N) and calculated risk (U), given a Gumbel

TABLE 5.2.59 GUMBEL DISTRIBUTION FOR YEARLY PEAK WIND SPEED, 10-METER LEVEL, INCLUDING HURRICANE WINDS, CAPE KENNEDY, FLORIDA

Return Period (years)	Probability	y	Knots
2	0.50	0.36651	49.47
5	0.80	1.49994	61.79
10	0.90	2.25037	69.95
15	0.933	2.66859	74.50
20	0.95	2.97020	77.77
30	0.967	3.39452	82.39
45	0.978	3.80561	86.86
50	0.98	3.90191	87.90
90	0.9889	4.49523	94.35
100	0.99	4.60015	95.49
150	0.9933	5.00229	99.86
200	0.995	5.29581	103.05
250	0.996	5.51946	105.48
300	0.9967	5.71218	107.58
400	0.9975	5.99021	110.60
500	0.9980	6.21361	113.02
600	0.9983	6.37628	114.20
1000	0.9990	6.90726	120.56
10000	0.9999	9.21029	145.60

$\alpha = 0.0920\ (\text{knots})^{-1} \qquad \frac{1}{\alpha} = 10.8675\ (\text{knots}) \qquad \mu = 45.49\ (\text{knots})$

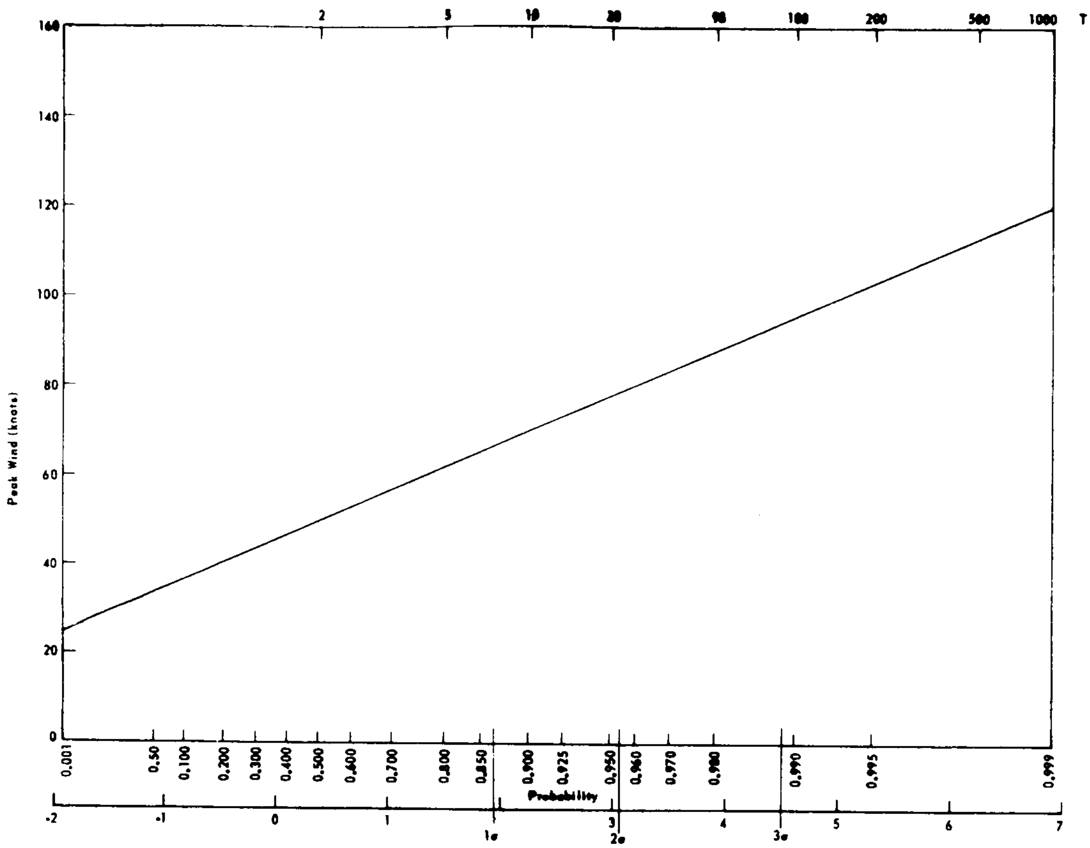


FIGURE 5.2.57 GUMBEL DISTRIBUTIONS FOR YEARLY EXTREME PEAK WIND SPEED, 10-METER LEVEL, HURRICANE WINDS INCLUDED, CAPE KENNEDY, FLORIDA

This expression for the design wind (W_D) as a function of N and U for the Gumbel distribution of peak winds at the 10-meter reference level can be derived as:

$$W_D = \frac{1}{\alpha} \{- \ln [-\ln (1 - U)] + \ln N\} + \mu \qquad (2)\ 5.2.11$$

where α and μ are estimated from the sample of yearly peak winds discussed in Section 5.4.4.5.

Taking the values for $\frac{1}{\alpha}$ = 10.8695 (knots) and for μ = 45.49 (knots) from Table 5.2.59 and evaluating Equation (2) 5.2.11 for selected values of N and U, gives Table 5.2.60 the design wind (W_D) in terms of the peak wind at the 10-meter level as a function of desired lifetime for various calculated risk for facilities design at Cape Kennedy.

An inspection of Equation (13) 5.2.11 reveals that the design wind ($W_{D_{10}}$) is a linear function of the logarithm of the desired lifetime for given values of α and μ. Thus, a convenient plot for design wind versus desired lifetime can be illustrated as in Figure 5.2.58. The slope of all curves in Figure 5.2.58 is the same; therefore $\frac{\partial W_D}{\partial N}$ is a constant equal to $\frac{1}{\alpha}$ for all risk levels, in contrast to Figures 5.2.14 and 5.2.15, Section 5.2.4, where the slopes increased with decreasing risk because $\frac{1}{\alpha}$ increased with increasing exposure time.

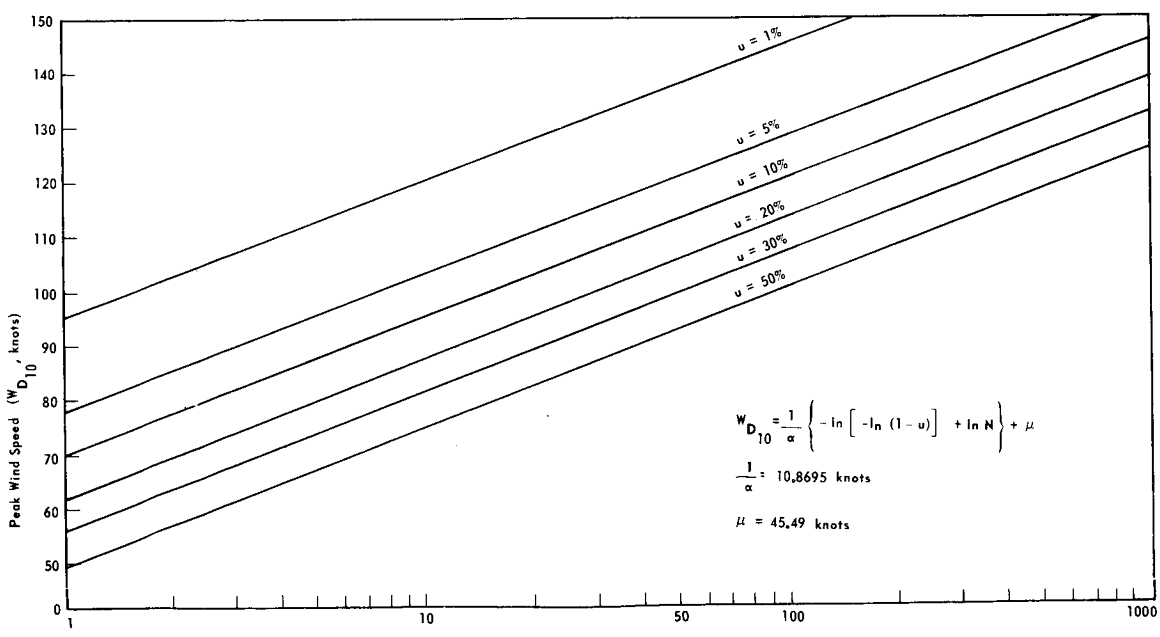
5.2.11.2.5 Requirements for Wind Load Calculations.

The design wind for a facility cannot be determined solely by wind statistics at a particular height. Estimates of wind loads are required, for which a wind profile is needed. The design engineer is most interested in designing a facility which satisfies the users' requirements for utility, which will have a minimum risk of failure within the desired lifetime of the facility and which can carry the maximum wind load and be constructed at a minimum cost. The total wind loading on a structure is composed of two interrelated components, drag wind loads and dynamic wind loads. The time required for a structure to respond to the drag wind loads dictates the averaging time for the wind profile. In general, the structure response time depends upon the shape and size of the structure. The natural frequency of the structure, the size and shape of the structure, and of its components, are important in estimating the dynamic wind load. It is conceivable that a structure could be designed to withstand very high wind speeds without structural failure and still oscillate in moderate wind speeds. If such a structure, for example, has as its use to support a precision tracking radar, then there may be little danger of overloading the structure by high winds; but the structure might be useless for its intended purpose if it oscillated in a moderate wind. Also, a building may have panels or small members that could respond to dynamic loading in such a way that long term vibrations could cause failure, and yet there would be no structural failure of the main supporting members. Since dynamic wind loading requires an intricate knowledge of the particular facility and its components, no attempt is made here to state generalized design criteria for dynamic wind loading. The emphasis in this section is upon winds for estimating drag wind loads in establishing design wind criteria for facilities. Reference is made to Section 5.2.5 for some information appropriate to dynamic wind loads.

TABLE 5.2.60 DESIGN WIND ($W_{D_{10}}$) WITH RESPECT TO THE 10-METER LEVEL PEAK WIND SPEED FOR VARIOUS LIFETIMES (N), CAPE KENNEDY, FLORIDA

U	1-U	ln [ln (1-U)]	Design Wind ($W_{D_{10}}$, knots) for Various Lifetimes (N)[a]			
			N=1	N=10	N=30	N=100
0.63212	0.36788	0	45.49	70.52	82.46	95.55
0.50	0.50	0.36651	49.47	74.50	86.44	99.53
0.4296	0.5704	0.57722	51.76	76.79	88.73	101.82
0.40	0.60	0.67173	52.79	77.82	89.76	102.85
0.30	0.70	1.03093	56.70	81.72	93.67	106.75
0.20	0.80	1.49994	61.79	86.82	98.76	111.85
0.10	0.90	2.25037	69.95	94.98	106.92	120.01
0.05	0.95	2.97020	77.77	102.80	114.74	127.83
0.01	0.99	4.60016	95.49	120.52	132.46	145.55

a Values of N are given in years



N Years

FIGURE 5.2.58 DESIGN WIND ($W_{D_{10}}$) WITH RESPECT TO THE 10-METER LEVEL PEAK WIND SPEED FOR VARIOUS LIFETIMES (N), CAPE KENNEDY, FLORIDA

5.2.11.2.6 Wind Profile Construction.

Given the peak wind at 10-meter level, the peak wind profile can be constructed using the peak wind profile law from Section 5.2.5, Equation

(1) 5.2.5, can be obtained by using the appropriate gust factors which are discussed in Section 5.2.7.

To illustrate the procedures and operations in deriving the wind profile and the application of the gust factors, three examples are worked out for Cape Kennedy. The peak wind speed at the 10-meter level of 70, 95, and 120 knots have been selected for these examples. These three wind speeds were selected because they correspond to a return period of 10 years, 100 years, and 1000 years for a peak wind at the 10-meter level at Cape Kennedy (see Fig. 5.2.57). Now, let us consider 70-, 95-, and 120-knot peak wind at the 10-meter level to be the design wind relative to the peak wind at the 10-meter level ($W_{D_{10}}$), and the corresponding return periods to be the design return periods. Then the calculated risks versus the desired lifetimes are given in Table 5.2.61.

From an evaluation of Equation (1) 5.2.5 for z = 10, 18.3 30.5, 61.0, 91.4, 121.9, and 152.4 m, the peak wind profiles corresponding to the peak winds of 70, 95, and 120 knots at the 10-meter level, shown in Table 5.2.62, were obtained by a table look-up. Table 5.2.62 gives the peak design wind profiles corresponding to the desired lifetimes and calculated risks presented in Table 5.2.61.

5.2.11.2.7 Use of Gust Factors Versus Height.

In estimating the drag load on a particular structure, it may be determined that wind force of a given magnitude must act on the structure for some period (for example, 1 min.) to produce a critical drag load. To obtain the wind profile corresponding to a time averaged wind, the peak wind profile values are divided by the required gust factors. The gust factors for winds > 30 knots versus height given in Table 5.2.63 are taken from Tables 5.2.42 through 5.2.46, Section 5.2.7. This operation may seem strange to those engineers who are accustomed to multiplying the given wind by a gust factor in establishing the design wind. This is because most literature on this subject gives the reference wind as averaged over some time increment (for example, 1 min, 2 min, or 5 min) or in terms of the "fastest mile" of wind that has a variable averaging time depending upon the wind speed. The design wind profiles for the three examples, that is, in terms of the peak winds of 70, 95, and 120 knots at the 10-meter level, for various averaging times (τ) are illustrated in Tables 5.2.64, 5.2.65, and 5.2.66. Following the procedures presented by this example, the design engineer can objectively derive several important design parameters that can be used in meeting the objective of designing a facility that will meet the requirements for utility and desired lifetime, that will withstand the maximum wind loading with a known calculated risk of failure, caused by wind loads, and proceed with trade-off studies between the design parameters and estimate the cost of building a structure to best meet these design objectives.

TABLE 5.2.61 CALCULATED RISK (U) VERSUS DESIRED LIFETIME (N, years) FOR ASSIGNED DESIGN WINDS ($W_{D_{10}}$ = 70, 95, and 120 knots) RELATED TO PEAK WINDS AT THE 10-METER LEVEL, CAPE KENNEDY, FLORIDA

N (years)	$W_{D_{10}}$ = 70 knots T_D = 10 years u%	$W_{D_{10}}$ = 95 knots T_D = 100 years u%	$W_{D_{10}}$ = 120 knots T_D = 1000 years u%
1	10	1.0	0.1
10	65	10	1
20	88	18	2
25	93	22	2.5
30	95.8	26	3
50	99.5	39.5	5
100	99.997	63.397	10

T_D = Design return period

5.2.11.2.8 Recommended Design Risk Versus Desired Lifetime.

Unfortunately, there is not a clear-cut precedent from building codes to follow in recommending design risk for a given desired lifetime of a structure. This could be because the consequences of total loss of a structure because of wind forces differ according to the purpose of the structure. Conceivably, a value analysis in terms of original investment cost, replacement cost, safety of property and human life, loss of national prestige, and many other factors could be made to give a measure of the consequences for the loss of a particular structure in arriving at a decision as to what risk the management is willing to accept for the loss within the desired lifetime of the structure. If the structure is an isolated tool shed, then obviously its loss is not as great as a structure that would house many people or a structure that is critical to the mission of a large organization; nor is it as potentially unsafe as the loss of a nuclear power plant

TABLE 5.2.62 DESIGN* PEAK WIND PROFILES FOR DESIGN WIND RELATIVE TO THE 10-METER LEVEL ($W_{D_{10}}$ = 70, 95, and 120 knots) FOR FACILITIES AT CAPE KENNEDY, FLORIDA

Height		$W_{D_{10}}$ = 70 knots		$W_{D_{10}}$ = 95 knots		$W_{D_{10}}$ = 120 knots	
(ft)	(m)	(knots)	(ms^{-1})	(knots)	(ms^{-1})	(knots)	(ms^{-1})
33	10	70.0	36.0	95.0	48.9	120.0	61.8
60	18.3	74.5	38.4	99.9	51.4	125.2	64.5
100	30.5	78.6	40.4	104.2	53.7	129.8	66.8
200	61.0	84.4	43.4	110.4	56.8	136.2	70.1
300	91.4	88.0	45.3	114.2	58.8	140.2	72.2
400	121.9	90.7	46.7	117.0	60.2	143.0	73.62
500	152.4	92.8	47.8	119.1	61.3	145.3	74.8

TABLE 5.2.63 GUST FACTORS FOR VARIOUS AVERAGING TIMES (τ) FOR PEAK WINDS >30 KNOTS AT THE 10-METER LEVEL VERSUS HEIGHT FOR CAPE KENNEDY, FLORIDA

Height		Various Averaging Times (τ, min.)				
(ft)	(m)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	1.318	1.372	1.435	1.528	1.599
60	18.3	1.268	1.314	1.366	1.445	1.505
100	30.5	1.232	1.271	1.317	1.385	1.437
200	61.0	1.191	1.223	1.261	1.316	1.359
300	91.4	1.170	1.199	1.232	1.282	1.320
400	121.9	1.157	1.183	1.214	1.260	1.295
500	152.4	1.147	1.172	1.201	1.244	1.277

* See Table 5.2.61 for calculated risk values versus desired lifetime for these design winds.

or storage facility for explosives or highly radioactive materials. To give a starting point for design studies aimed at meeting the design objectives, it is recommended that a design risk of ten percent for the desired lifetime be used in determining the wind loading on structures that have a high replacement cost. Should the loss of the structure be extremely hazardous to life or property, or critical to the mission of a large organization, then a design risk of five percent or less for the desired lifetime is recommended. These are subjective recommendations involving arbitrary assumptions about the design objectives. Note that the larger the desired lifetime, the greater the design risk is for a given wind speed (or wind loading). Therefore, realistic appraisals should be made for desired lifetimes.

TABLE 5.2.64 DESIGN* WIND PROFILES FOR VARIOUS AVERAGING TIMES (τ) FOR PEAK DESIGN WIND OF 70 KNOTS RELATIVE TO THE 10-METER LEVEL, CAPE KENNEDY, FLORIDA

Height		Design Wind Profiles (knots) for Various Averaging Times (τ)[a]					
(ft)	(m)	τ=0	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	70.0	53.1	51.0	48.8	45.8	43.8
60	18.3	74.5	58.8	56.7	54.5	51.6	49.5
100	30.5	78.6	63.8	61.8	59.7	56.8	54.7
200	61.0	84.4	70.9	69.0	66.9	64.1	62.1
300	91.4	88.0	75.2	73.4	71.4	68.6	66.7
400	121.9	90.7	78.4	76.7	74.7	72.0	70.0
500	152.4	92.8	80.9	79.2	77.3	74.6	72.7

a Values of τ are given in minutes.

* See Table 5.2.61 for calculated risk values versus desired lifetime for these design winds.

TABLE 5.2.65 DESIGN* WIND PROFILES FOR VARIOUS AVERAGING TIMES (τ) FOR PEAK DESIGN WIND OF 95 KNOTS RELATIVE TO THE 10-METER LEVEL, CAPE KENNEDY, FLORIDA

Height		Design Wind Profiles (knots) for Various Averaging Times (τ)[a]					
(ft)	(m)	τ=0	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	95.0	72.1	69.2	66.2	62.2	59.4
60	18.3	99.9	78.8	76.0	73.1	69.1	66.4
100	30.5	104.2	84.6	82.0	79.1	75.2	72.5
200	61.0	110.4	92.7	90.3	87.5	83.9	81.2
300	91.4	114.2	97.6	95.2	92.7	89.1	86.5
400	121.9	117.0	101.1	98.9	96.4	92.9	90.3
500	152.4	119.1	103.8	101.6	99.2	95.7	93.3

a Values of τ are given in minutes.

TABLE 5.2.66 DESIGN WIND* PROFILES FOR VARIOUS AVERAGING TIMES (τ) FOR PEAK DESIGN WIND OF 120 KNOTS RELATIVE TO THE 10-METER LEVEL, CAPE KENNEDY, FLORIDA

Height		Design Wind Profiles (knots) for Various Averaging Times (τ)[a]					
(ft)	(m)	τ=0	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	120.0	91.0	87.5	83.6	78.5	75.0
60	18.3	125.2	98.7	95.3	91.7	86.6	83.2
100	30.5	129.8	105.4	102.1	98.6	93.7	90.3
200	61.0	136.2	114.4	111.4	108.0	103.5	100.2
300	91.4	140.2	119.8	116.9	113.8	109.4	106.2
400	121.9	143.0	123.6	120.9	117.8	113.5	110.4
500	152.4	145.3	126.7	124.0	121.0	116.8	113.8

a Values of τ are given in minutes.

* See Table 5.2.61 for calculated risk values versus desired lifetime for these design winds.

5.2.11.2.9 Design Winds for Facilities at Huntsville, New Orleans, the Western Test Range, Wallops Island, and White Sands.

5.2.11.2.9.1 The Wind Statistics.

The basic wind statistics for these five locations are taken from Thom (Ref. 5.16), which presents isotachs, in the form of maps, for the 50th, 98th, and 99th percentile values for the yearly maximum "fastest mile" of wind in the units miles per hour for the 30-feet (~10-m) reference height above natural grade. By definition, the "fastest mile" is the fastest wind speed in miles per hour of any mile of wind during a specified period (usually taken as the 24-hour observational day), and the largest of these in a year for the period of record constitutes the statistical sample of yearly "fastest mile." From this definition, it is noted that the fastest mile as a measure of wind speed has a variable averaging time; for example, if the wind speed is 60 miles per hour, the averaging time for the fastest mile of wind is 1 minute. For a wind speed of 120 miles per hour, the averaging time for the fastest mile of wind is 1/2 minute. Thom reports that the Fréchet probability distribution function fits his samples of fastest mile very well. The Fréchet distribution function is given as

$$F(x) = e^{-\left(\frac{x}{\beta}\right)^{-\gamma}} , \qquad (3)\ 5.2.11$$

where the two parameters β and γ are estimated from the sample by the maximum likelihood method. From Thom's maps of the 50th, 98th, and 99th percentiles of fastest mile of wind for yearly extremals, we have estimated (interpolated) for these percentiles for the five locations and calculated the values for the parameters, β and γ, for the Fréchet distribution function and computed several additional percentiles, as shown in Table 5.2.67. To have units consistent with the other sections of this document, the percentiles and the parameters, β and γ, have been converted from miles per hour to knots. Thus, Table 5.2.67 gives the Fréchet distribution for the fastest mile of winds at the 30-feet (~10-m) level for the five locations with the units in knots. These distributions are also illustrated in Figure 5.2.59.

The discussion in Section 5.2.11.2.4, devoted to desired lifetime, calculated risk, and design winds with respect to the wind statistics at a particular height (10-m level) is applicable here, except that the reference statistics are with respect to the fastest mile converted to knots.

TABLE 5.2.67 FRÉCHET DISTRIBUTION OF FASTEST MILE WIND (converted to knots) AT THE 10-METER HEIGHT OF YEARLY EXTREMES FOR THE INDICATED STATIONS

P Proba-bility	T Return Period (years)	Fastest Mile Wind (knots)			
		Huntsville	New Orleans	Western Test Range and White Sands	Wallops Island
0.50	2	39.0	42.9	34.9	47.9
0.80	5	46.4	51.8	42.0	57.6
0.90	10	52.0	58.6	47.4	65.0
0.95	20	58.0	65.9	53.3	73.0
0.98	50	67.0	76.9	61.9	84.9
0.99	100	74.4	86.4	69.4	95.0
0.9933	150	79.2	92.2	73.9	101.4
0.995	200	82.2	96.7	77.6	106.3
0.996	250	85.7	100.4	80.4	110.2
0.99667	300	88.2	103.5	82.9	113.6
0.9975	400	92.1	108.4	86.7	118.9
0.998	500	95.3	112.5	89.9	123.2
0.99833	600	97.6	115.5	92.3	126.6
0.99875	800	102.4	121.6	97.7	133.0
0.999	1000	106.0	126.1	100.6	137.8
γ	Unitless	6.54686	6.08074	6.19591	6.19949
$1/\gamma$	Unitless	0.15274	0.16445	0.16140	0.16130
$\ln \beta$	Unitless	3.60758	3.70093	3.49620	3.81208
β	(knots)	36.892	40.488	32.983	45.241

5.2.11.2.9.2 The Design Wind in Terms of Fastest Mile at the 10-Meter Level.

An analytical expression for design wind relative to the wind at the 10-meter level, as a function of desired lifetime (N) and calculated risk (U), distribution is:

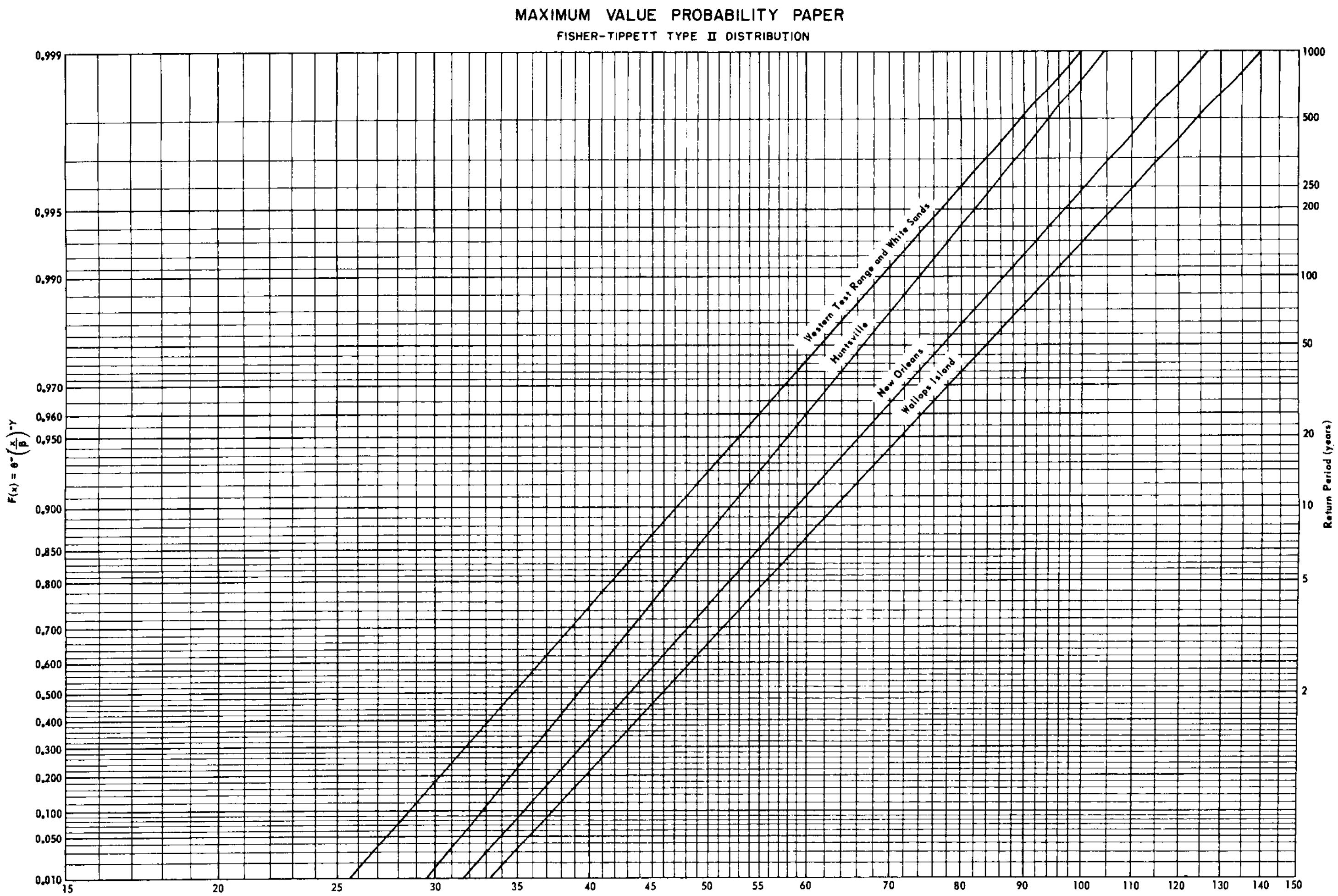


FIGURE 5.2.59 FRÉCHET DISTRIBUTION OF FASTEST MILE WIND AT THE 10-METER HEIGHT OF YEARLY EXTREMES

$$\ln W_{D_{10}} = \frac{1}{\gamma}\ [-\ln\ [-\ (1-U)\ +\ \ln N]\ +\ \ln\ \beta \qquad (4)\ 5.2.11$$

and

$$W_{D_{10}} = e^{\ln W_{D_{10}}} \quad .$$

Substituting the values for the parameters, $\frac{1}{\gamma}$ and $\ln\ \beta$ from Table 5.2.67 into Equation (4) 5.2.11 and evaluating for fixed risk (U) and varying the desired lifetime, N, we derived Tables 5.2.68 through 5.2.71. A convenient plot of the desired lifetime for fixed risk (U) for the design wind relative to the fastest mile (converted to knots) for the five stations are shown in Figure 5.2.60, 5.2.61, 5.2.62, and 5.2.63.

5.2.11.2.9.3 Conversion of Fastest Mile to Peak Winds.

It was mentioned in Section 5.2.4.4.5 that the Fréchet distribution for the 17-year sample of yearly peak winds for Cape Kennedy was an acceptable fit to this sample. The Fréchet distributions for the fastest mile (converted to knots) were obtained from Thom's data (maps) for Cape Kennedy. From these two distributions (the Fréchet for the peak winds as well as for the fastest mile), the ratio of the percentiles of the fastest mile (converted to knots) to the peak winds were taken. This ratio varied from 1.12 to 1.09, over range of percentiles from the 30th to the 99th. Thus, we adopted 1.10 as a factor to multiply the statistics of the fastest mile of wind to get the value in knots necessary to obtain peak (instantaneous) wind statistics. This procedure is based upon the evidence of only one station. A gust factor of 1.10 is often applied to the fastest mile statistics in facility design work to account for gust loads.

5.2.11.2.9.4 The Peak Wind Profile.

The peak wind profile law adopted for the five locations for peak winds at the 10-meter level greater than 44 knots is

$$u_Z = u_{10}\left(\frac{z}{10}\right)^{1/7} \qquad (5)\ 5.2.11$$

where u_{10} is the peak wind at the 10-meter height and u_z is the peak wind at height z in meters.

5.2.11.2.9.5 The Mean Wind Profile.

To obtain the mean wind profile for various averaging times, the gust factors given in Tables 5.2.42 through 5.2.46, Section 5.2.7, are applied to the peak wind profile as determined by Equation (17) 5.2.11.

TABLE 5.2.68 FACILITIES DESIGN WIND AS A FUNCTION OF DESIRED LIFETIME (N) AND CALCULATED RISK (U) WITH RESPECT TO THE 10-METER REFERENCE HEIGHT---"FASTEST MILE" FROM THOM (Ref. 5.16) CONVERTED TO KNOTS---HUNTSVILLE, ALABAMA

			Facilities Design Wind (W_D, knots) as a Function of Desired Lifetime (N)[a]			
U	(1-U)	y	N=1	N=10	N=30	N=100
0.63212	0.36788	0	36.88	52.40	61.99	74.51
0.50	0.50	0.36651	38.98	55.42	65.56	78.80
0.42960	0.57040	0.57722	40.28	57.23	67.69	81.37
0.40	0.60	0.67173	40.85	58.09	68.70	82.52
0.30	0.70	1.03093	43.16	61.37	72.53	87.19
0.20	0.80	1.49994	46.38	65.89	77.94	93.69
0.10	0.90	2.25037	51.99	73.92	87.44	105.10
0.05	0.95	2.97020	58.03	82.51	97.61	117.22
0.01	0.99	4.60016	74.44	105.84	125.20	150.44

a Values of N are given in years.

a. From Equation (4) 5.2.11, the design wind in terms of the fastest mile (converted to knots) relative to the 10-meter level is derived as a function of desired lifetime, and calculated risk is determined.

b. The fastest mile (in knots) obtained from step a is converted to peak wind at the 10-meter level by multiplying by a factor 1.10.

TABLE 5.2.69 FACILITIES DESIGN WIND AS A FUNCTION OF DESIRED LIFETIME (N) AND A CALCULATED RISK (U) WITH RESPECT TO THE 10-METER REFERENCE HEIGHT---"FASTEST MILE" FROM THOM (Ref. 5.16) CONVERTED TO KNOTS---NEW ORLEANS, LOUISIANA

U	(1-U)	y	Facilities Design Wind (W_D, knots) as a Function of Desired Lifetime (N)[a]			
			N=1	N=10	N=30	N=100
0.63212	0.36788	0	40.49	59.14	70.81	86.31
0.50	0.50	0.36651	42.99	62.80	75.19	91.70
0.42960	0.57040	0.57722	44.52	65.03	77.87	94.92
0.40	0.60	0.67173	45.20	66.02	79.12	96.45
0.30	0.70	1.03093	47.95	70.04	83.93	102.31
0.20	0.80	1.49994	51.83	75.64	90.65	110.50
0.10	0.90	2.25037	58.62	85.62	102.51	124.96
0.05	0.95	2.97020	65.96	96.35	115.46	140.75
0.01	0.99	4.60016	86.23	125.96	150.92	184.00

a Values of N are given in years.

c. The peak wind profile is obtained by Equation (5) 5.2.11.

d. The mean wind profiles for the desired averaging times are obtained by dividing the peak wind profile by the gust factors given in Tables 5.2.42 through 5.2.46, Section 5.2.7.

5.2.11.2.9.6 Examples of Design Wind Profiles for the Five Station Locations.

For each of the five stations, the values for the fastest mile (in knots) at the 10-meter level which correspond to the 10-, 100-, and 1000-year return periods from Table 5.2.67 (or from Figure 5.2.59) are considered as the design return period T_D. These values are tabulated in Table 5.2.72 and are now referred to as design winds with respect to the fastest mile (in knots) for the 10-meter reference height. The design risk versus desired lifetime for the design return periods of 10, 100, and 1000 years are presented in Table 5.2.58.

TABLE 5.2.70 FACILITIES DESIGN WIND AS A FUNCTION OF DESIRED LIFETIME (N) AND CALCULATED RISK (U) WITH RESPECT TO THE 10-METER REFERENCE HEIGHT---"FASTEST MILE" FROM THOM (Ref. 5.16) CONVERTED TO KNOTS---WESTERN TEST RANGE AND WHITE SANDS MISSILE RANGE

U	(1-U)	y	Facilities Design Wind (W_D, knots) as a Function of Desired Lifetime (N) [a]			
			N=1	N=10	N=30	N=100
0.63212	0.36788	0	32.98	47.84	57.11	69.34
0.50	0.50	0.36651	34.99	50.75	60.58	73.62
0.42960	0.57040	0.57722	36.20	52.51	62.68	76.17
0.40	0.60	0.67173	36.78	53.30	63.68	77.32
0.30	0.70	1.03093	38.97	56.49	67.49	81.94
0.20	0.80	1.49994	42.01	60.95	72.75	88.41
0.10	0.90	2.25037	47.42	68.79	82.11	99.78
0.05	0.95	2.97020	53.30	77.25	92.29	112.05
0.01	0.99	4.60016	69.33	100.49	120.06	145.77

a Values of N are given in years.

The fastest mile statistics (in knots) in Table 5.2.67 are converted to peak wind speeds by multiplying by a factor of 1.10 as discussed in Section 5.2.11.2.8.3. The resulting peak winds in knots at the 10-meter level corresponding to the design return periods of 10, 100, and 1000 years are given in Table 5.2.73.

The design peak wind profiles for the peak winds in Table 5.2.73 are obtained from the adopted peak wind power law given by Equation (5) 5.2.11, and the mean wind profile for various averaging times are obtained by dividing by the gust factors for the various averaging times. (The gust factors versus height and averaging times are presented in Table 5.2.63.) The resulting selected design wind profiles for design return periods of 10, 100, and 1000 years for the five stations are given in Tables 5.2.74 through 5.2.85.

TABLE 5.2.71 FACILITIES DESIGN WIND AS A FUNCTION OF DESIRED LIFETIME (N) AND CALCULATED RISK (U) WITH RESPECT TO THE 10-METER REFERENCE HEIGHT---"FASTEST MILE" FROM THOM (Ref. 5.16) CONVERTED TO KNOTS---WALLOPS TEST RANGE

U	(1-U)	y	Facilities Design Wind (W_D, knots) as a Function of Desired Lifetime (N)[a]			
			N=1	N=10	N=30	N=100
0.63212	0.36788	0	45.24	65.56	78.33	95.10
0.50	0.50	0.36651	47.99	69.61	83.09	100.89
0.42960	0.57040	0.57722	49.65	72.02	85.97	104.38
0.40	0.60	0.67173	50.40	73.11	87.27	105.95
0.30	0.70	1.03093	53.41	77.48	92.48	112.28
0.20	0.80	1.49994	57.63	83.52	99.78	121.14
0.10	0.90	2.25037	65.04	94.26	112.61	136.72
0.05	0.95	2.97020	73.04	105.95	126.47	153.15
0.01	0.99	4.60016	95.01	137.70	164.47	199.72

a Values of N are given in years.

TABLE 5.2.72 FASTEST MILE VALUES (in knots) FOR THE 10-METER LEVEL FOR 10-, 100-, AND 1000-YEAR RETURN PERIODS

T_D (years)	Fastest Mile Values (knots)			
	Huntsville	New Orleans	Western Test Range and White Sands	Wallops Island
10	52.0	58.6	47.4	65.0
100	74.4	86.4	69.4	95.0
1000	106.0	126.1	100.6	137.8

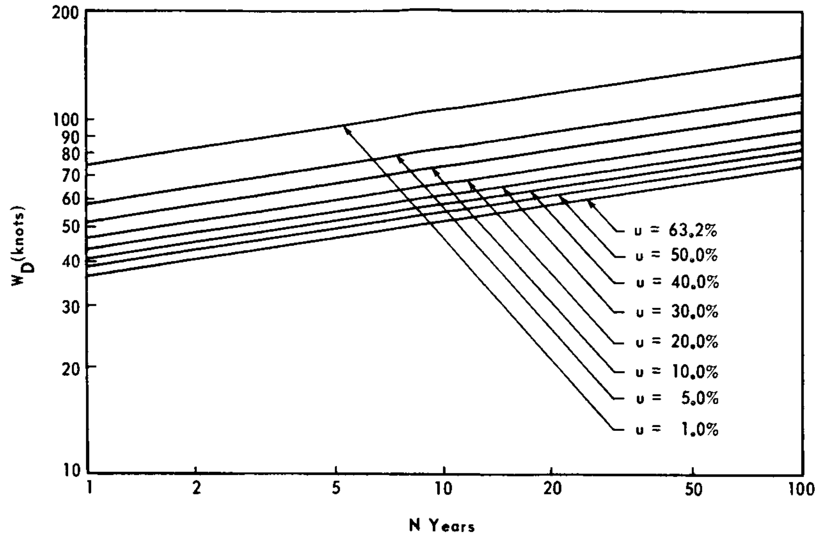


FIGURE 5.2.60 FACILITIES DESIGN WIND AS A FUNCTION OF DESIRED LIFETIME (N) AND CALCULATED RISK (U) WITH RESPECT TO THE 10-METER REFERENCE HEIGHT — "FASTEST MILE" FROM THOM (Ref. 5.16) CONVERTED TO KNOTS — HUNTSVILLE, ALABAMA

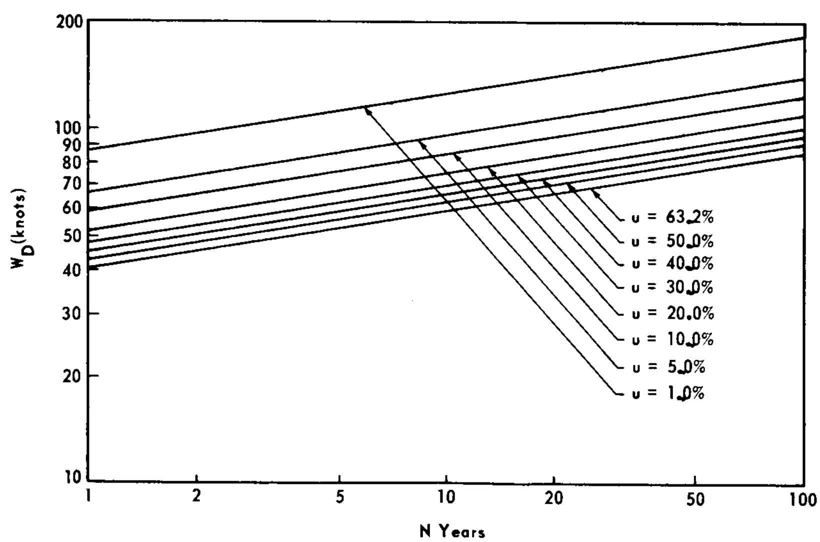


FIGURE 5.2.61 FACILITIES DESIGN WIND AS A FUNCTION OF DESIRED LIFETIME (N) AND CALCULATED RISK (U) WITH RESPECT TO THE 10-METER REFERENCE HEIGHT — "FASTEST MILE" FROM THOM (Ref. 5.16) CONVERTED TO KNOTS — NEW ORLEANS, LOUISIANA

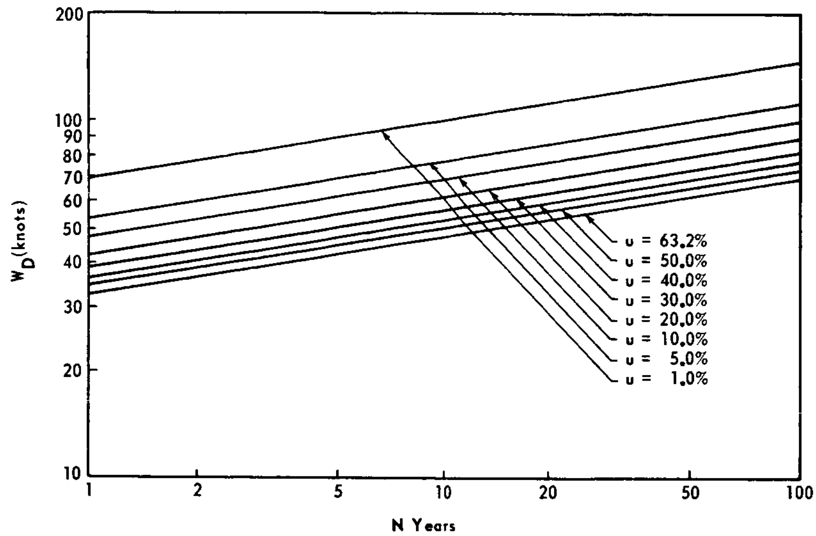


FIGURE 5.2.62 FACILITIES DESIGN WIND AS A FUNCTION OF DESIRED LIFETIME (N) AND CALCULATED RISK (U) WITH RESPECT TO THE 10-METER REFERENCE HEIGHT — "FASTEST MILE" FROM THOM (Ref. 5.16) CONVERTED TO KNOTS — WESTERN TEST RANGE AND WHITE SANDS MISSILE RANGE

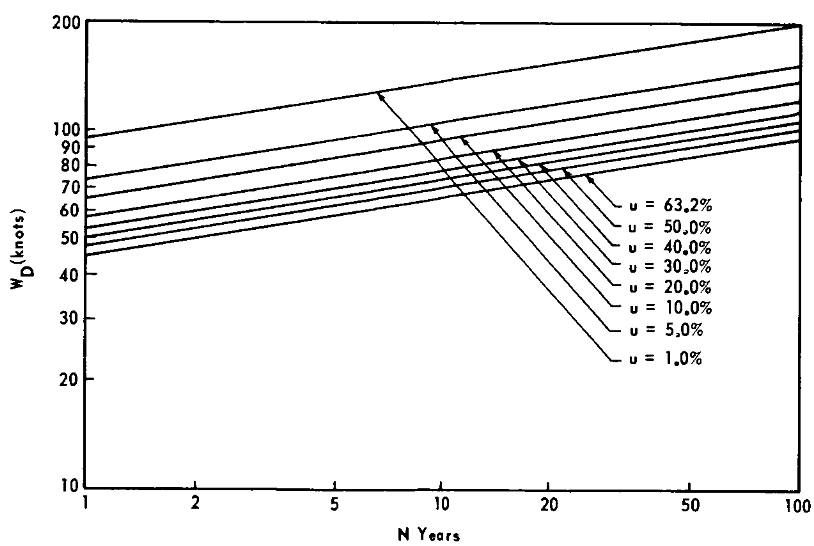


FIGURE 5.2.63 FACILITIES DESIGN WIND AS A FUNCTION OF DESIRED LIFETIME (N) AND CALCULATED RISK (U) WITH RESPECT TO THE 10-METER REFERENCE HEIGHT — "FASTEST MILE" FROM THOM (Ref. 5.16) CONVERTED TO KNOTS — WALLOPS ISLAND TEST RANGE

TABLE 5.2.73 PEAK WINDS (fastest mile values times 1.10) FOR THE 10-METER LEVEL FOR 10-, 100-, AND 1000-YEAR RETURN PERIODS

T_D (years)	Peak Winds (knots)			
	Huntsville	New Orleans	Western Test Range and White Sand	Wallops Island
10	57.2	64.5	52.1	71.5
100	81.8	95.0	76.3	104.5
1000	106.0	138.7	110.7	151.6

TABLE 5.2.74 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 57.2 KNOTS (10-year return period) FOR HUNTSVILLE, ALABAMA

Height (ft)	Height (m)	Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
		τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	57.2	43.4	41.7	39.9	37.4	35.8
60	18.3	62.4	49.2	47.5	45.7	43.2	41.5
100	30.5	67.1	54.5	52.8	50.9	48.4	46.7
200	61.0	74.1	62.2	60.6	58.8	56.3	54.5
300	91.4	78.5	67.1	65.5	63.7	61.2	59.5
400	121.9	81.8	70.7	60.7	67.4	64.9	63.2
500	152.4	83.6	72.9	71.3	69.6	67.2	65.5

a Values of τ are given in minutes.

TABLE 5.2.75 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 81.8 KNOTS (100-year return period) FOR HUNTSVILLE, ALABAMA

Height		Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
(ft)	(m)	τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	81.8	62.1	59.6	57.0	53.5	51.2
60	18.3	89.2	70.3	67.9	65.3	61.7	59.3
100	30.5	95.9	77.8	75.5	72.8	69.2	66.7
200	61.0	105.9	88.9	86.6	84.0	80.5	77.9
300	91.4	112.2	95.9	93.6	91.1	87.5	85.0
400	121.9	116.5	100.7	98.5	96.0	92.5	90.0
500	152.4	119.5	104.2	102.0	99.5	96.1	93.6

a Values of τ are given in minutes.

TABLE 5.2.76 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 116.6 KNOTS (1000-year return period) FOR HUNTSVILLE, ALABAMA

Height		Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
(ft)	(m)	τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	116.6	88.5	85.0	81.3	76.3	72.9
60	18.3	127.0	100.2	96.7	93.0	87.9	84.4
100	30.5	136.6	110.9	107.5	103.7	98.6	95.1
200	61.0	150.8	126.6	123.3	119.6	114.6	111.0
300	91.4	159.8	136.6	133.3	129.7	124.6	121.1
400	121.9	166.5	143.9	140.7	137.1	132.1	128.6
500	152.4	171.9	149.9	146.7	143.1	138.2	134.6

a Values of τ are given in minutes.

TABLE 5.2.77 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 64.5 KNOTS (10-year return period) FOR NEW ORLEANS, LOUISIANA

Height		Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
(ft)	(m)	τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	64.5	48.9	47.0	44.9	42.2	40.3
60	18.3	70.3	55.4	53.5	51.5	48.7	46.7
100	30.5	75.6	61.4	59.5	57.4	54.6	52.6
200	61.0	83.5	70.1	68.3	66.2	63.4	61.4
300	91.4	88.5	75.6	73.8	71.8	69.0	67.0
400	121.9	92.2	79.7	77.9	75.9	73.2	71.2
500	152.4	94.3	82.2	80.5	78.5	75.8	73.8

a Values of τ are given in minutes.

TABLE 5.2.78 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 95.0 KNOTS (100-year return period) FOR NEW ORLEANS, LOUISIANA

Height		Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
(ft)	(m)	τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	95.0	72.1	69.2	66.2	62.2	59.4
60	18.3	103.6	81.7	78.8	75.8	71.7	68.8
100	30.5	111.4	90.4	87.6	84.6	80.4	79.3
200	61.0	123.0	103.3	100.6	97.5	93.5	90.5
300	91.4	130.3	111.4	108.7	105.8	101.6	98.7
400	121.9	135.8	117.4	114.8	111.9	107.8	104.9
500	152.4	138.8	121.0	118.4	115.6	111.6	108.7

a Values of τ are given in minutes.

TABLE 5.2.79 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 138.7 KNOTS (1000-year return period) FOR NEW ORLEANS, LOUISIANA

Height (ft)	Height (m)	Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a] τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	138.7	105.2	101.1	96.7	90.8	86.7
60	18.3	151.2	119.2	115.1	110.7	104.6	100.5
100	30.5	162.7	132.1	128.0	123.5	117.5	113.2
200	61.0	179.6	150.8	146.9	142.4	136.5	132.2
300	91.4	190.3	162.6	158.7	154.5	148.4	144.2
400	121.9	198.2	171.3	167.5	163.3	157.3	153.1
500	152.4	202.7	176.7	173.0	168.8	162.9	158.7

a Values of τ are given in minutes.

TABLE 5.2.80 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 52.1 KNOTS (10-year return period) FOR THE WESTERN TEST RANGE AND WHITE SANDS MISSILE RANGE, NEW MEXICO

Height (ft)	Height (m)	Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a] τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	52.1	39.5	38.0	36.3	34.1	32.6
60	18.3	56.8	44.8	43.2	41.6	39.3	37.7
100	30.5	61.1	49.6	48.1	46.4	44.1	42.5
200	61.0	67.5	56.7	55.2	53.5	51.3	49.7
300	91.4	71.5	61.1	59.6	58.0	55.8	54.2
400	121.9	74.5	64.4	63.0	61.4	59.1	57.5
500	152.4	76.1	66.3	64.9	63.3	61.2	59.6

a Values of τ are given in minutes.

TABLE 5.2.81 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 76.3 KNOTS (100-year return period) FOR THE WESTERN TEST RANGE AND WHITE SANDS MISSILE RANGE, NEW MEXICO

Height		Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
(ft)	(m)	τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	76.3	57.9	55.6	53.2	49.9	47.7
60	18.3	83.2	65.6	63.3	60.9	57.6	55.3
100	30.5	89.5	72.6	70.4	68.0	64.6	62.3
200	61.0	98.8	83.0	80.8	78.4	75.1	72.7
300	91.4	104.7	89.5	87.3	85.0	81.7	79.3
400	121.9	109.1	94.3	92.2	89.9	86.6	84.2
500	152.4	111.5	97.2	95.1	92.8	89.6	87.3

TABLE 5.2.82 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 110.7 KNOTS (1000-year return period) FOR THE WESTERN TEST RANGE AND WHITE SANDS MISSILE RANGE, NEW MEXICO

Height		Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
(ft)	(m)	τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	110.7	84.0	80.7	77.1	72.4	69.2
60	18.3	120.7	95.2	91.9	88.4	83.5	80.2
100	30.5	129.8	105.4	102.1	98.6	93.7	90.3
200	61.0	143.3	120.3	117.2	113.6	108.9	105.4
300	91.4	151.9	129.8	126.7	123.3	118.5	115.1
400	121.9	158.2	136.7	133.7	130.3	125.6	122.2
500	152.4	161.8	141.1	138.1	134.7	130.1	126.7

a Values of τ are given in minutes.

TABLE 5.2.83 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 71.5 KNOTS (10-year return period) FOR WALLOPS TEST RANGE, VIRGINIA

Height		Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
(ft)	(m)	τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	71.5	54.2	52.1	49.8	46.8	44.7
60	18.3	77.9	61.4	59.3	57.0	53.9	51.8
100	30.5	83.8	68.0	65.9	63.6	60.5	58.3
200	61.0	92.6	77.7	75.7	73.4	70.4	68.1
300	91.4	98.1	83.8	81.8	79.6	76.5	74.3
400	121.9	102.2	88.3	86.4	84.2	81.1	78.9
500	152.4	104.5	91.1	89.2	87.0	84.0	81.8

a Values of τ are given in minutes.

TABLE 5.2.84 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 104.5 KNOTS (100-year return period) FOR WALLOPS TEST RANGE, VIRGINIA

Height		Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
(ft)	(m)	τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	104.5	79.3	76.2	72.8	68.4	65.4
60	18.3	113.9	89.8	86.7	83.4	78.8	75.7
100	30.5	122.5	99.4	96.4	93.0	88.4	85.2
200	61.0	135.3	113.6	110.6	107.3	102.8	99.6
300	91.4	143.4	122.6	119.6	116.4	111.9	108.6
400	121.9	149.4	129.1	126.3	123.1	118.6	115.4
500	152.4	152.7	133.1	130.3	127.1	122.7	119.6

a Values of τ are given in minutes.

TABLE 5.2.85 FACILITIES DESIGN WIND AS A FUNCTION OF AVERAGING TIME (τ) FOR A PEAK WIND OF 151.6 KNOTS (1000-year return period) FOR WALLOPS TEST RANGE, VIRGINIA

Height		Facilities Design Wind (knots) as a Function of Averaging Time (τ)[a]					
(ft)	(m)	τ=0 (peak)	τ=0.5	τ=1	τ=2	τ=5	τ=10
33	10	151.6	115.0	110.5	105.6	99.2	94.8
60	18.3	165.3	130.4	125.8	121.0	114.4	109.8
100	30.5	177.8	144.3	139.9	135.0	128.4	123.7
200	61.0	196.3	164.8	160.5	155.7	149.2	144.4
300	91.4	208.0	177.8	173.5	168.9	162.2	157.6
400	121.9	216.7	187.3	183.2	178.5	172.0	167.3
500	152.4	221.5	193.1	189.0	184.4	178.1	173.5

a Values of τ are given in minutes.

5.3 Inflight Winds

5.3.1 Introduction.

Inflight wind speed profiles are used in vehicle design studies primarily to establish structural and control system capabilities. The inflight wind speeds selected for vehicle design may not represent the same percentile value as the design surface wind speed. The selected wind speeds (inflight and surface) are determined by the desired vehicle launch capability and can differ in the percentile level since the inflight and surface wind speeds are statistically independent.

Wind information for inflight design studies is presented in three basic forms: discrete or synthetic profiles, statistical distributions, and measured profile samples. A detailed discussion of these three types of presentations and their uses may be found in Reference 5.55. There are certain limitations to each of these wind input forms, and their utility in design studies depends upon a number of considerations such as, (1) accuracy of basic measurements, (2) complexity of input to vehicle design, (3) economy and practicality for design use, (4) ability to represent significant features of the wind profile, (5) statistical assumption versus physical representation of the wind profile, (6) ability of input to ensure control system and structural integrity of the vehicle, and (7) flexibility of use in design trade-off studies.

Accurate and adequate numbers representative of measured wind profiles are necessary for developing a valid statistical description of the wind profile. Fortunately, current records of data from Cape Kennedy fulfill these requirements, although a continual program of data acquistion is vital to further enhance the confidence of the statistical information generated. The various methods and sensors for obtaining inflight profiles, which include the rawinsonde, the FPS-16/Jimsphere, and the rocketsonde, are described in Section 5.3.2. The statistical analyses performed on the inflight wind profiles provide detailed descriptions of the upper winds and an understanding of the profile characteristics such as temporal and height variations, as well as indications of the frequency and the persistence of transient meteorological systems. A statistical examination of winds aloft climatology is given in Section 5.3.3; Section 5.3.4 points out the peculiarities and unique properties of the wind profile over Kennedy Space Center.

The synthetic type of wind profile is the oldest method used to present inflight design wind data. The synthetic wind profile data are presented in this document since this method of presentation provides a reasonable approach for most design studies when properly used, especially during the early design periods. Also, the concept of synthetic wind profiles is generally understood and employed in most aerospace organizations for design computations. It should be understood that the synthetic wind profile incorporates the wind speed (Section 5.3.6), wind speed change (Section 5.3.7), maximum wind layer thickness (Section 5.3.3.3), and gusts (Section 5.3.8) that are required to establish vehicle design values. Section 5.3.9 describes the method of constructing synthetic wind profiles.

5.3.2 Measurement of Inflight Winds.

Wind velocity profiles are measured systematically in this country by three methods, the FPS-16 radar/Jimsphere, the rocketsonde, and the rawinsonde (GMD). The rawinsonde is employed extensively throughout the United States by the Department of Defense and the Weather Bureau, while the FPS-16/Jimsphere and rocketsonde are employed primarily at space vehicle and missile test ranges such as Kennedy Space Center, Florida; Wallops Island, Virginia; White Sands Missile Range, New Mexico; and Vandenberg AFB, California.

5.3.2.1 Rawinsonde (GMD).

This system provides measurements of horizontal wind speed and direction as a function of altitude averaged over approximately 600 meters. Wind data from this system can be obtained up to an altitude of approximately 35 kilometers. Approximate rms errors in wind speed (Ref. 5.28), based upon standard data reduction procedures, vary between 2 and 6 ms^{-1} for a speed range less than 15 ms^{-1}, 3 and 21 ms^{-1} for a range of 15 to 30 ms^{-1}, and 7 and 23 ms^{-1} for a range of 30 to 45 ms^{-1} as a function of altitude. For wind direction, the rms errors are estimated to be less than 10 degrees, and they probably average about 5 degrees.

Large quantities of data measured by this system at the Eastern Test Range, and at many locations throughout the United States are available. The Eastern Test Range rawinsonde data have been used extensively in investigating wind conditions in that area and for specifying average wind conditions for use in numerous space vehicle design studies. Because of smoothing inherent in the rawinsonde tracking system, it cannot provide small scale wind motion measurements that may be important in some space vehicle problems. Serial complete, edited and checked master rawinsonde wind data records have been prepared and cover a 10-year period for Cape Kennedy, Florida, and a 9-year period for Santa Monica, California. Similar serial complete records are now available for Wallops Island, Virginia area. These records constitute the source of statistical steady-state upper air wind statistics used in this document, unless otherwise noted.

5.3.2.2 FPS-16 Radar/Jimsphere.

This system provides considerably more accurate wind velocity profile data than does the rawinsonde, for its altitude range, which is up to approximately 18 kilometers. The measurements are averaged over approximately 50 meters in the vertical. In general, an rms error in wind speed of approximately 0.5 ms^{-1} and 1 degree in wind direction is obtained, but it depends upon radar elevation angle (Ref. 5.29 and 5.30). Thus, the FPS-16/Jimsphere wind profile data contain information on small scale motions as well as gross motions such as those provided by the rawinsonde. Several years of profile data measured twice daily, and in support of space vehicle launchings and special studies, are available. Some of these data have been published (Ref. 5.31), and a master magnetic tape has been prepared for ready access. In addition, a number of studies have been conducted using these improved wind data (Ref. 5.51).

5.3.2.3 Rocketsonde.

The rocketsonde system provides wind data to a higher altitude (approximately 80 km) than does either the FPS-16 radar/Jimsphere or the rawinsonde. The wind measurements are averaged over approximately a 300-meter or larger layer. The rms errors for wind speed (Ref. 5.28) are approximately 4 ms^{-1}, and for wind direction, about 5 degrees or greater, depending upon sensor and tracking systems. Wind data from the rocketsonde have been collected for approximately 10 years. These data are collected and published monthly by World Data Center A, Asheville, North Carolina.

5.3.3 Winds Aloft Climatology.

In the development of design wind speed profiles and associated shears and gusts, it is necessary to begin with the measured wind speed and wind direction data collected at the area of interest for some reasonably long period of time.

Analysis of the data may be accomplished in several ways by using high speed computers. Statistical data of various types are readily computed for a given application. The subject of wind climatology for any area, if treated in detail, would make up a voluminous document. The intent here is to give a brief treatment of selected topics that are frequently considered in space vehicle development and operations problems and references to more extensive information.

Generally, space vehicles for use in comprehensive space research are designed by use of synthetic wind profiles based upon scalar wind speeds without regard to specific wind directions. However, in special situations, when a vehicle is restricted to a given launch site, rather narrow flight azimuths (within approximately 20 deg), and a specific configuration and mission, winds based upon components (head, tail, left cross or right cross) may be used. For a given percentile, the magnitudes of component winds are equal to or less than those of the scalar winds. Component or directional dependent winds should not be employed in design studies unless specifically authorized by the cognizant design organization. Directional wind component frequency envelopes are presented in Section 5.3.3.1 for the Eastern Test Range.

5.3.3.1 Wind Component Statistics.

Wind component statistics are used in mission planning to provide information on the probability of exceeding a given wind speed in the pitch or yaw planes and to bias the tilt program (Section 5.3.5) at a selected launch time.

Computation of the wind component statistics are made for various launch azimuths (15-deg intervals were selected at Marshall Space Flight Center) for each month for the pitch plane (range) and yaw plane (cross range) at the Eastern Test Range and the Western Test Range. Figures 5.3.1A through 5.3.1C give pitch wind component, and Figures 5.3.2A through 5.3.2C give yaw wind component statistics for Cape Kennedy, Florida (Eastern Test Range), for a 90-degree launch azimuth as an illustration of these statistics. These profiles are based upon additional data available since the publication of the previous edition of this document (Ref. 5.18). The new data extends the profiles to 55 kilometers. Ten years of twice daily serial complete radiosonde data (approximately 600 for each monthly period) were used for the data up to 27 kilometers. Five years of rocketsonde wind data (about 70 observations for each monthly period) were used for the data between 28 and 55 kilometers. Only one launch azimuth (90 deg) was selected to be included in this revision. Tables for launch azimuths at every 15-degree interval are available upon request.

Tail winds in Figures 5.3.1A through 5.3.1C are positive pitch plane winds, that is, blowing in the direction of the flight azimuth; head winds are negative pitch plane winds. Right cross winds in Figures 5.3.2A through 5.3.2C are positive yaw plane winds, that is, blowing perpendicularly to the flight path from right to left; left cross winds are negative yaw plane winds.

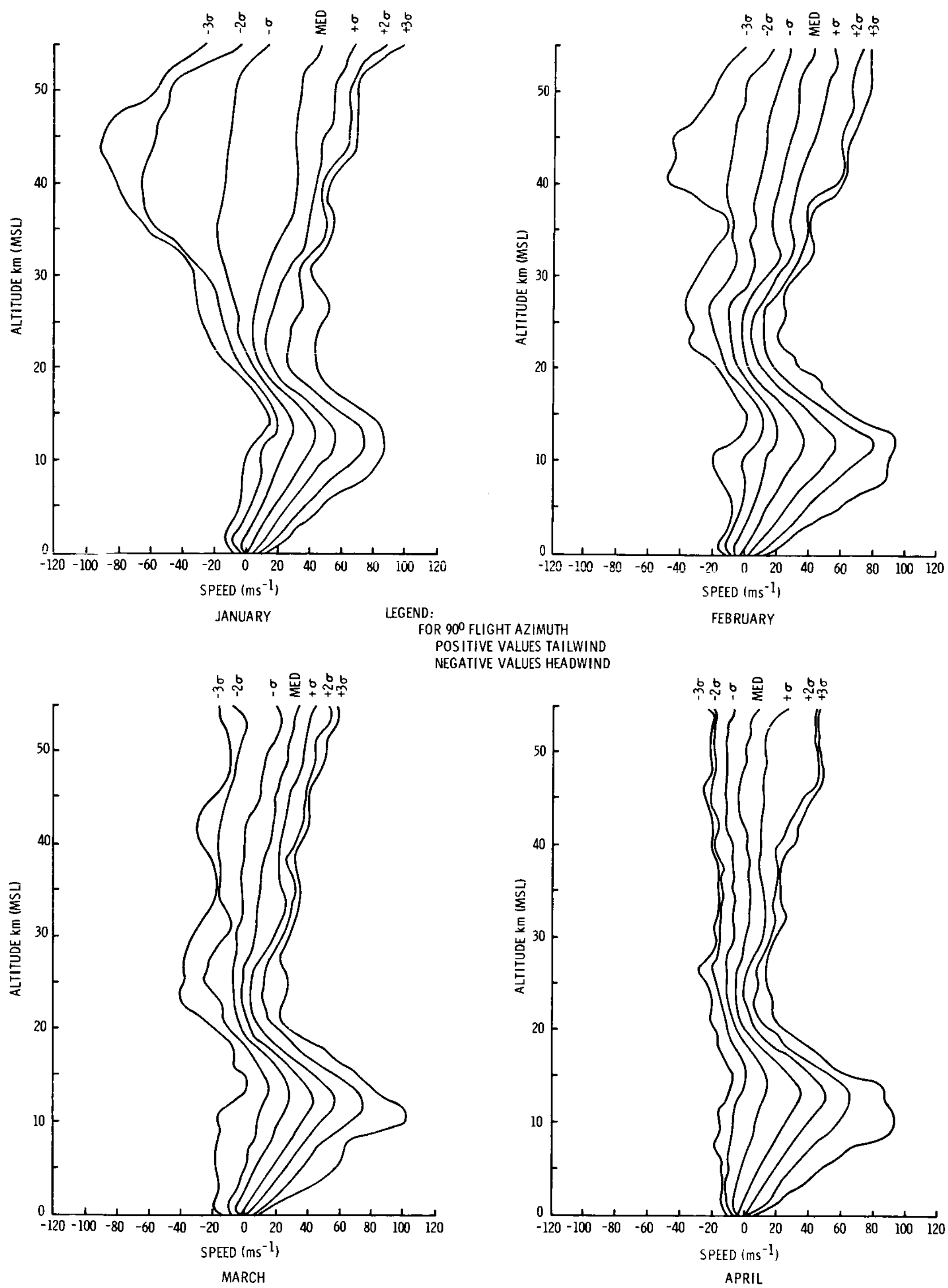


FIGURE 5.3.1A EMPIRICAL RANGE (pitch plane) WIND PROFILE ENVELOPES FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 90-DEGREE FLIGHT AZIMUTH — JANUARY THROUGH APRIL

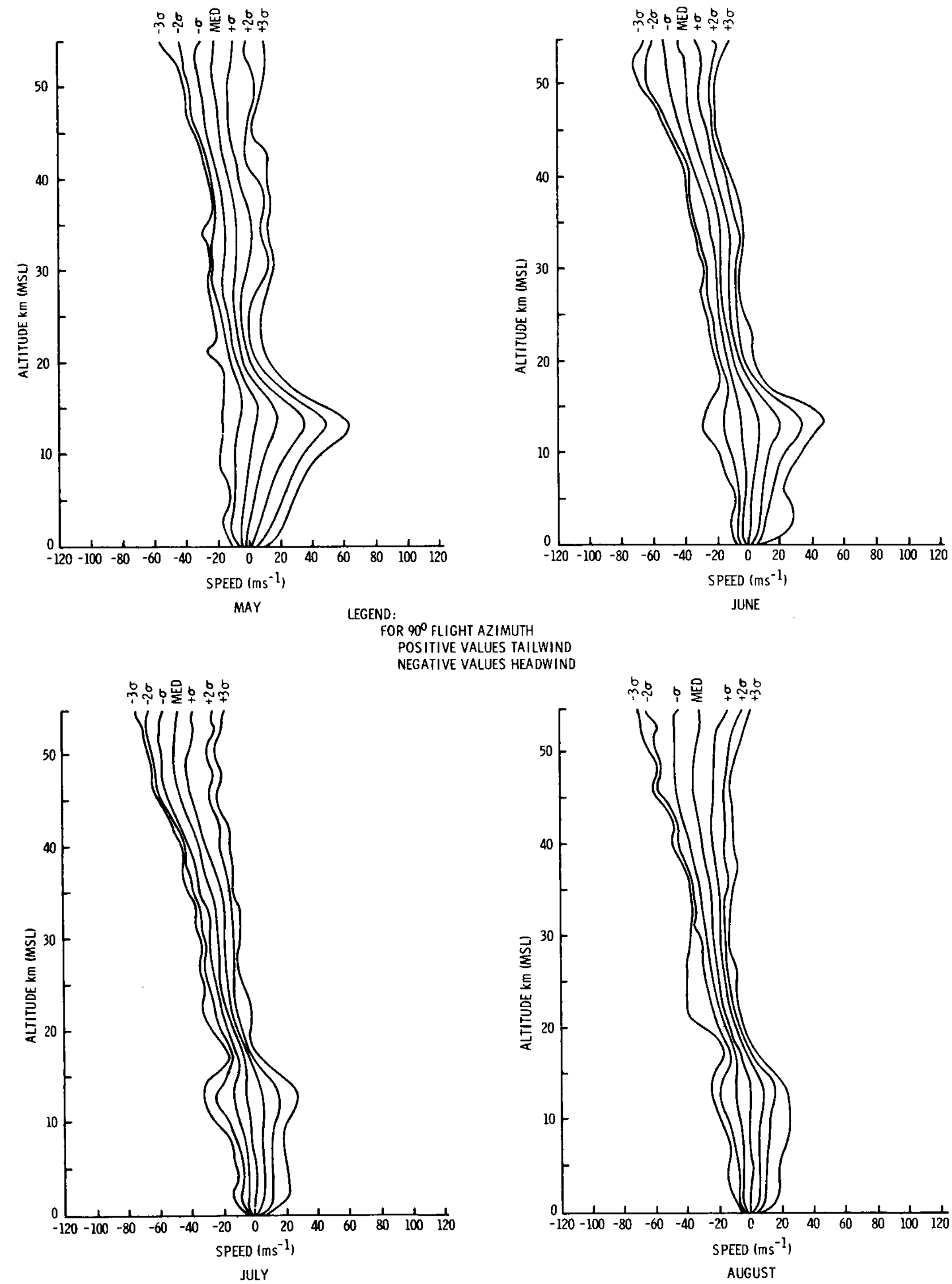


FIGURE 5.3.1B EMPIRICAL RANGE (pitch plane) WIND PROFILE ENVELOPES FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 90-DEGREE FLIGHT AZIMUTH — MAY THROUGH AUGUST

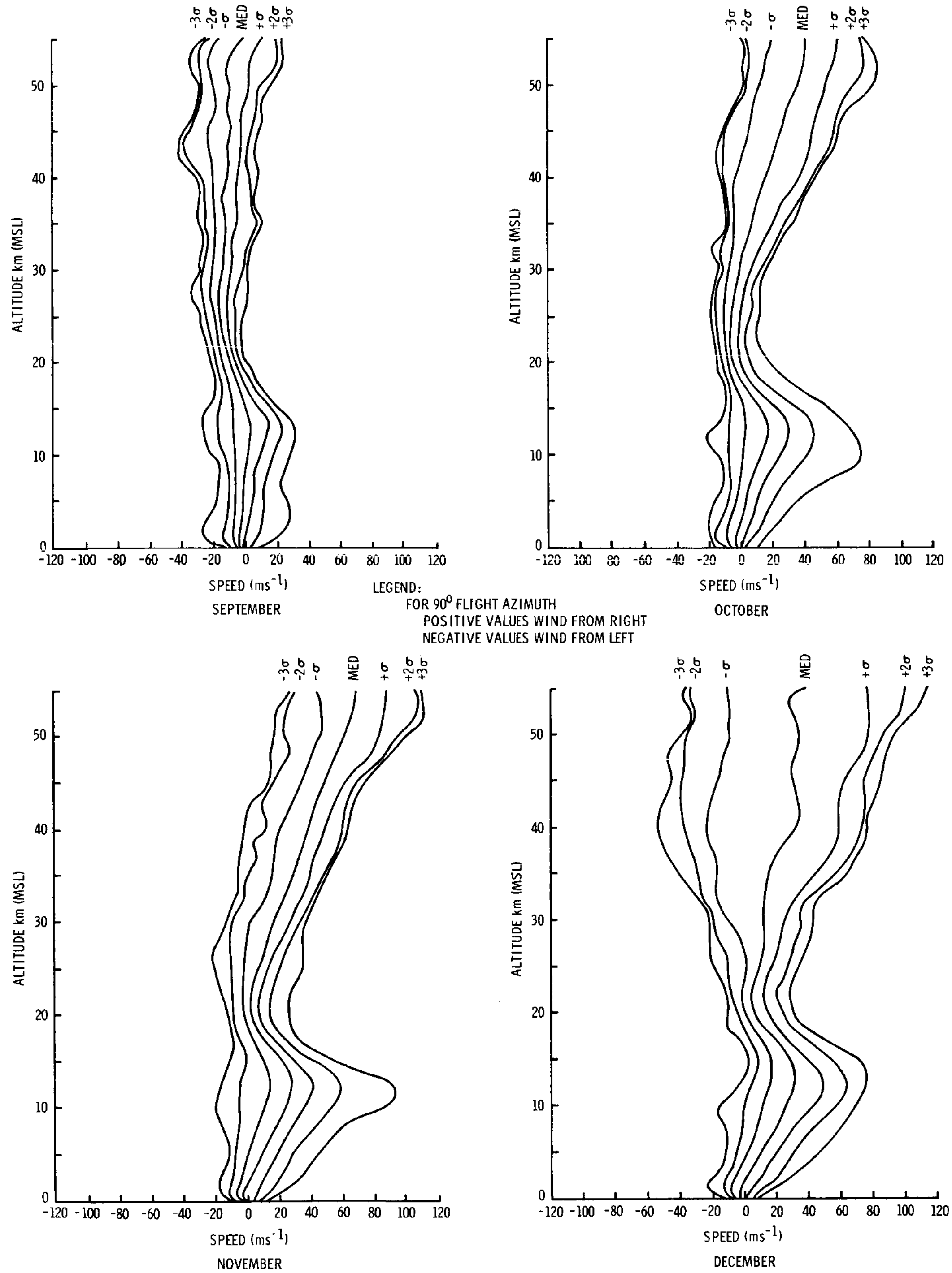


FIGURE 5.3.1C EMPIRICAL RANGE (pitch plane) WIND PROFILE ENVELOPES FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 90-DEGREE FLIGHT AZIMUTH — SEPTEMBER THROUGH DECEMBER

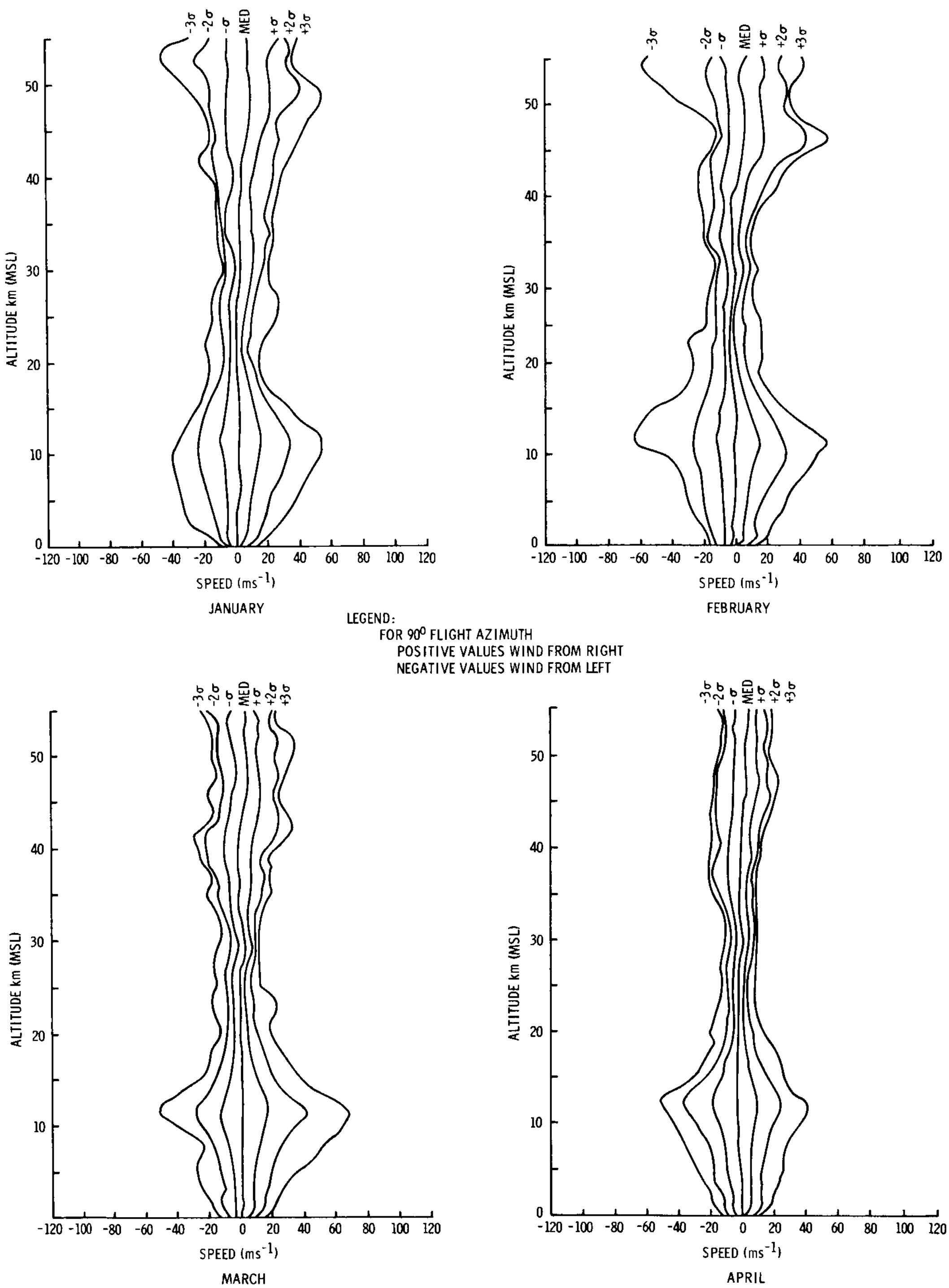


FIGURE 5.3.2A EMPIRICAL CROSS RANGE (yaw plane) WIND PROFILE ENVELOPES FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 90-DEGREE FLIGHT AZIMUTH – JANUARY THROUGH APRIL

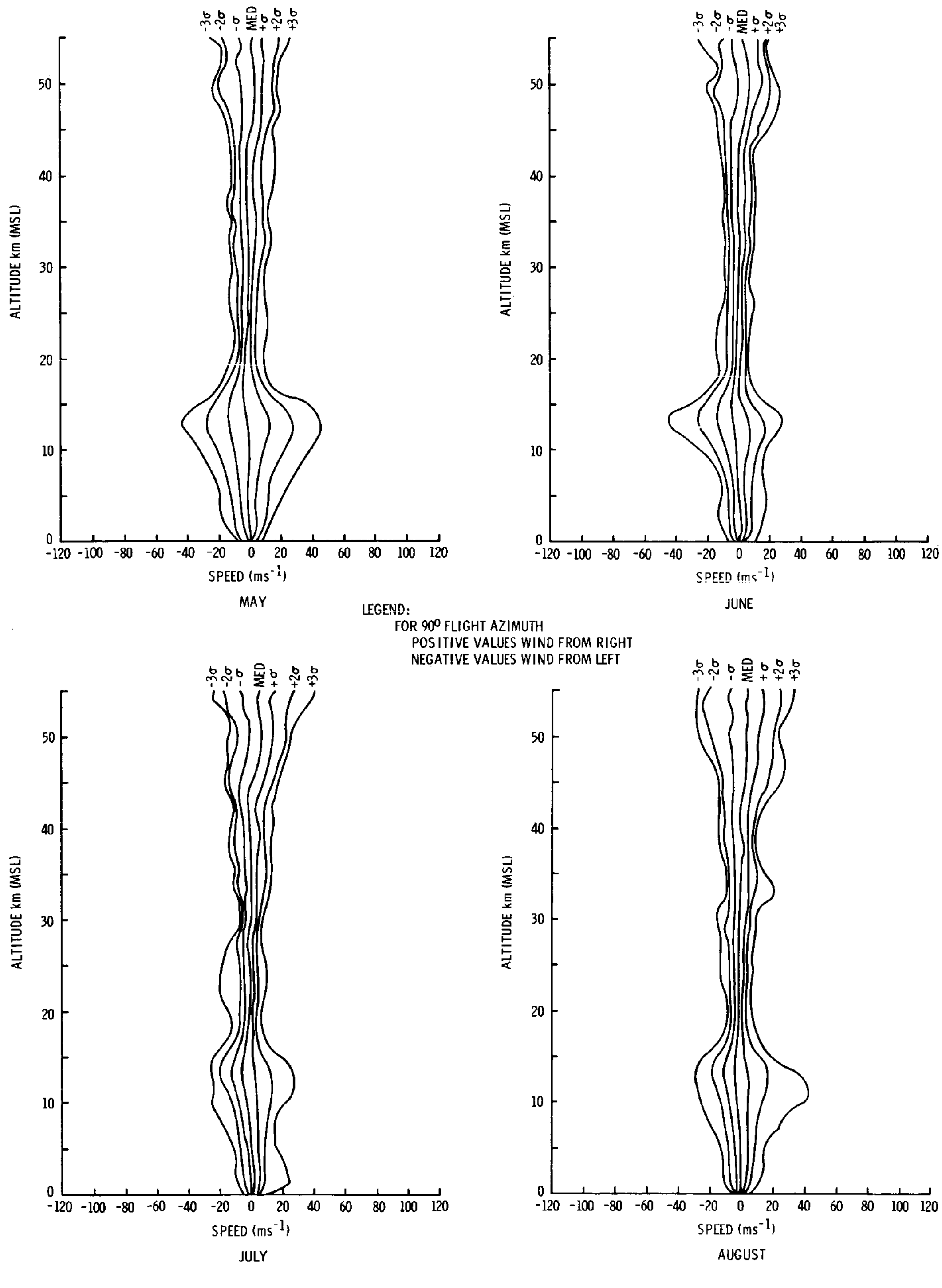


FIGURE 5.3.2B EMPIRICAL CROSS RANGE (yaw plane) WIND PROFILE ENVELOPES FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 90-DEGREE FLIGHT AZIMUTH — MAY THROUGH AUGUST

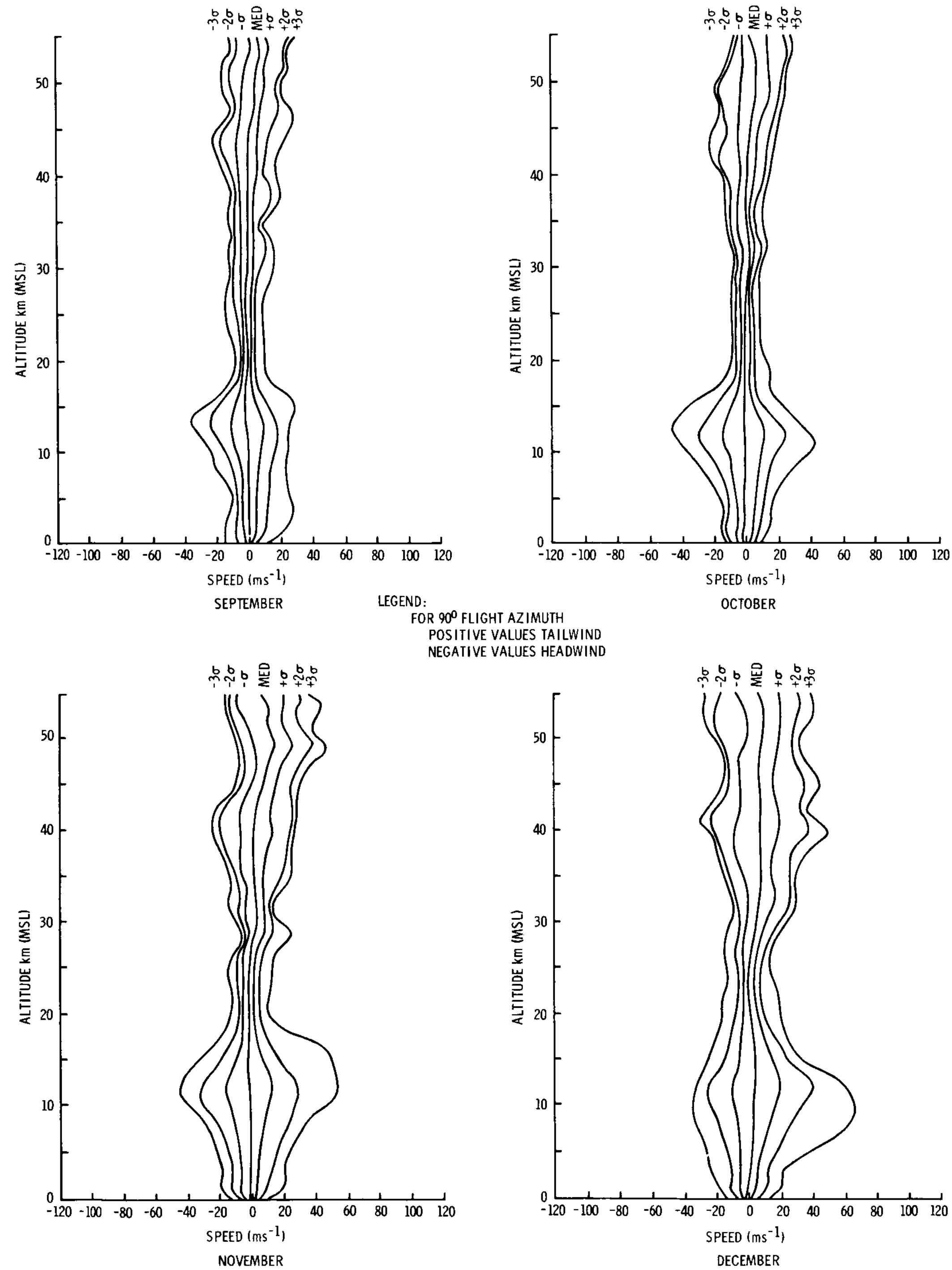


FIGURE 5.3.2C EMPIRICAL CROSS RANGE (yaw plane) WIND PROFILE ENVELOPES FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 90-DEGREE FLIGHT AZIMUTH — SEPTEMBER THROUGH DECEMBER

References 5.33, 5.34, 5.35 and 5.37 contain information on the statistical distributions of wind speeds and component wind speeds for Cape Kennedy, Florida (ETR); El Paso, Texas (WSMR); Santa Monica, California (WTR); and Wallops Island, Virginia (Wallops Test Range). The Range Reference Atmosphere Documents (Ref. 5.37) provide similar information for other test ranges.

5.3.3.1.1 Empirical Range and Cross Range Wind Component Envelopes.

An example of monthly empirical range and cross range component envelopes are shown in Figures 5.3.3A through 5.3.3C, which show the distribution of wind speeds for several percentile values as a function of wind direction at a 12-kilometer altitude for each month of the year.

Although wind velocity is reported as a speed and a direction, the data in the figures in this section (Figs. 5.3.3A through 5.3.3C and Fig. 5.3.4) show the wind as a vector toward its direction of motion; that is, a wind at 90 degrees would be a wind blowing toward the east.

Plots similar to Figures 5.3.3A through 5.3.3C have been prepared for altitudes from 1 to 27 kilometers, but, because of the great number of graphs, they could not be included in this document.

5.3.3.1.2 Idealized Annual Wind Component Envelopes — Windiest Monthly Reference Period Concept.

To provide information on the wind distribution for an entire year, envelopes like those shown for the Western Test Range in Figure 5.3.4 which is from Reference 5.38, are most useful because the data is based upon monthly frequency distributions. Thus, the data in Figure 5.3.4 can be used to determine the worst condition expected for a selected launch azimuth during any month of the entire year. Similar data are available for the Eastern Test Range in Reference 5.39.

5.3.3.2 Upper Wind Correlations.

Coefficients of correlations of wind components between altitude levels with means and standard deviations at altitude levels may be used in a statistical model to derive representative wind profiles. Reference 5.40 describes a method of preparing synthetic wind profiles by use of correlation coefficients between wind components. In addition, these correlation data are applicable to certain statistical studies of vehicle responses (Ref. 5.36).

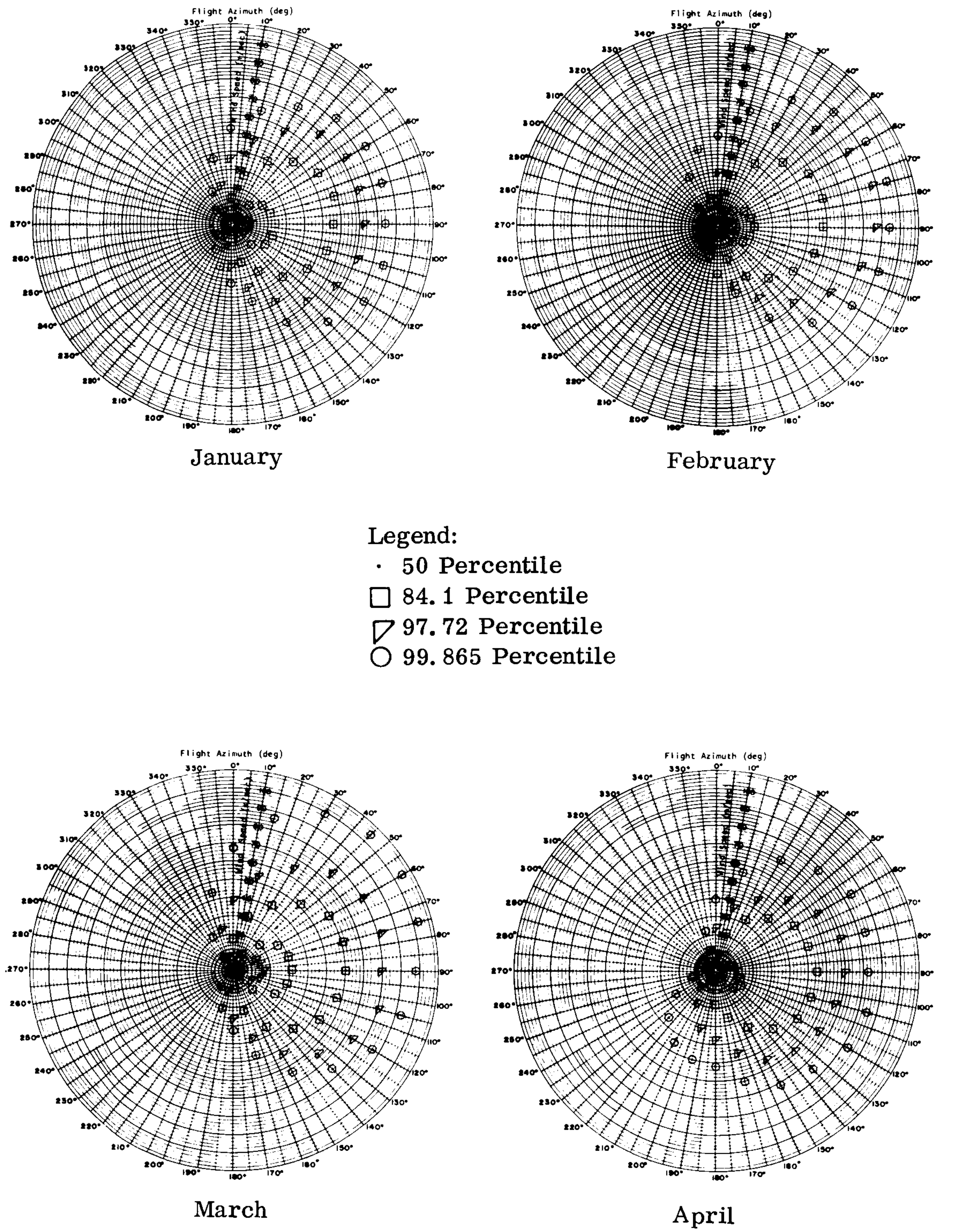
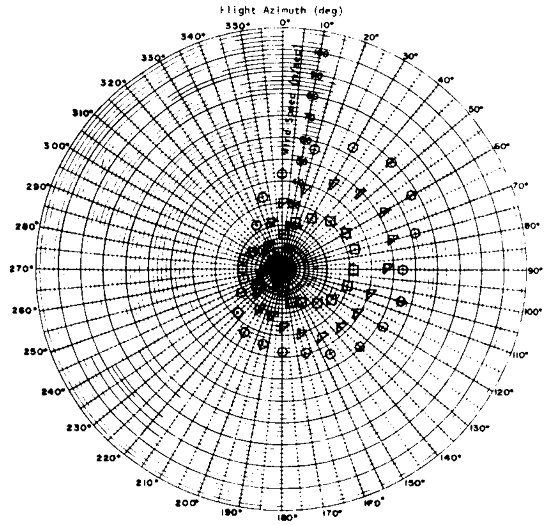
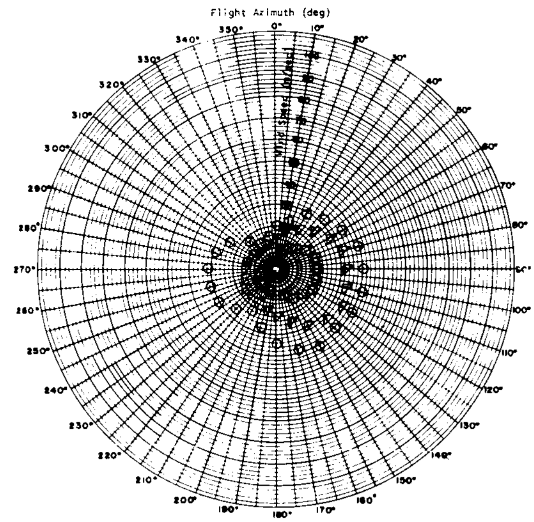


FIGURE 5.3.3A EMPIRICAL WIND COMPONENT ENVELOPES AS A FUNCTION OF FLIGHT AZIMUTH, EASTERN TEST RANGE (Cape Kennedy, Florida), 12-KILOMETER ALTITUDE — JANUARY THROUGH APRIL



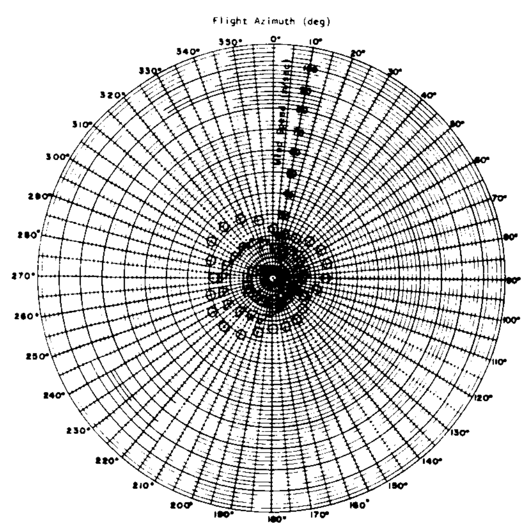
May



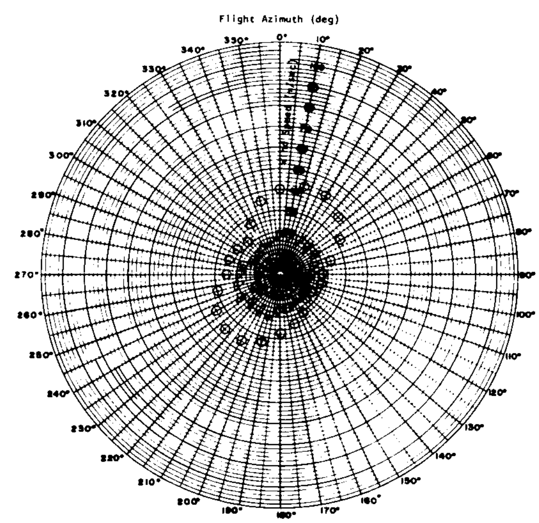
June

Legend:

- · 50 Percentile
- □ 84.1 Percentile
- ◸ 97.72 Percentile
- ○ 99.865 Percentile

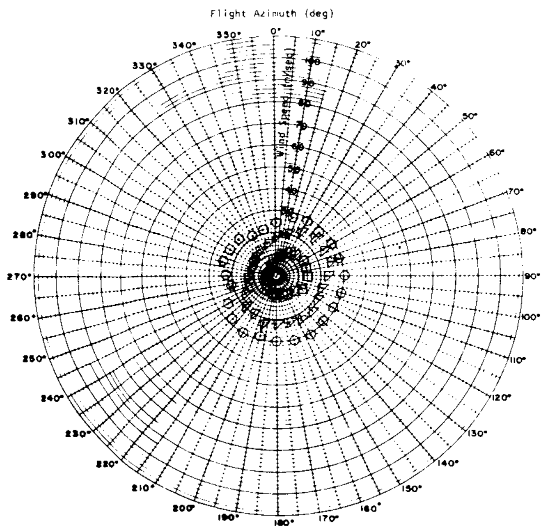


July

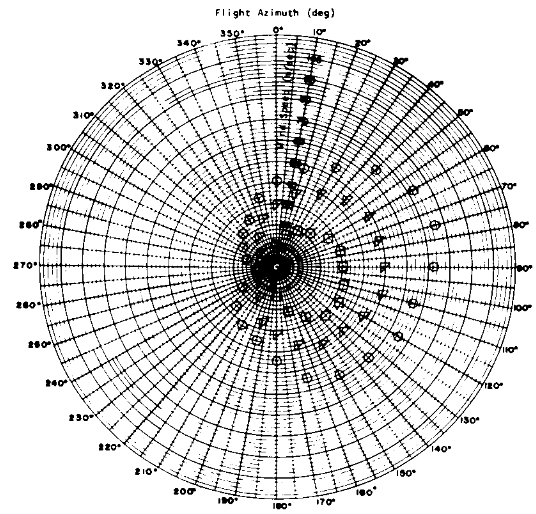


August

FIGURE 5.3.3B EMPIRICAL WIND COMPONENT ENVELOPES AS A FUNCTION OF FLIGHT AZIMUTH, EASTERN TEST RANGE (Cape Kennedy, Florida), 12-KILOMETER ALTITUDE – MAY THROUGH AUGUST

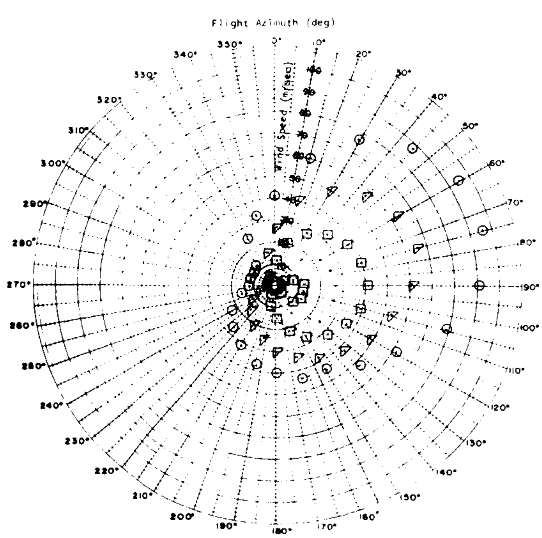


September

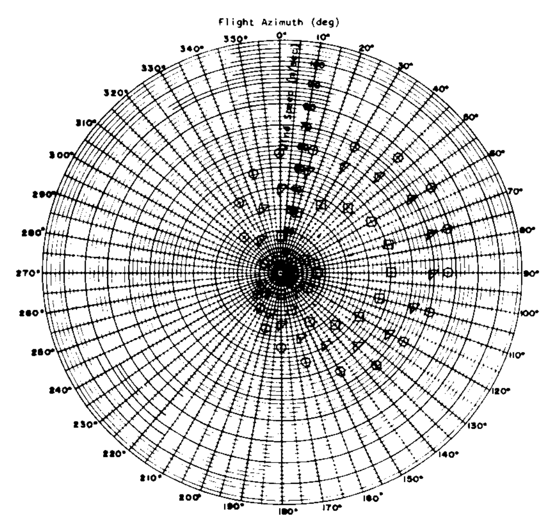


October

Legend:
· 50 Percentile
□ 84.1 Percentile
▽ 97.72 Percentile
○ 99.865 Percentile



November



December

FIGURE 5.3.3C EMPIRICAL WIND COMPONENT ENVELOPES AS A FUNCTION OF FLIGHT AZIMUTH, EASTERN TEST RANGE (Cape Kennedy, Florida), 12-KILOMETER ALTITUDE – SEPTEMBER THROUGH DECEMBER

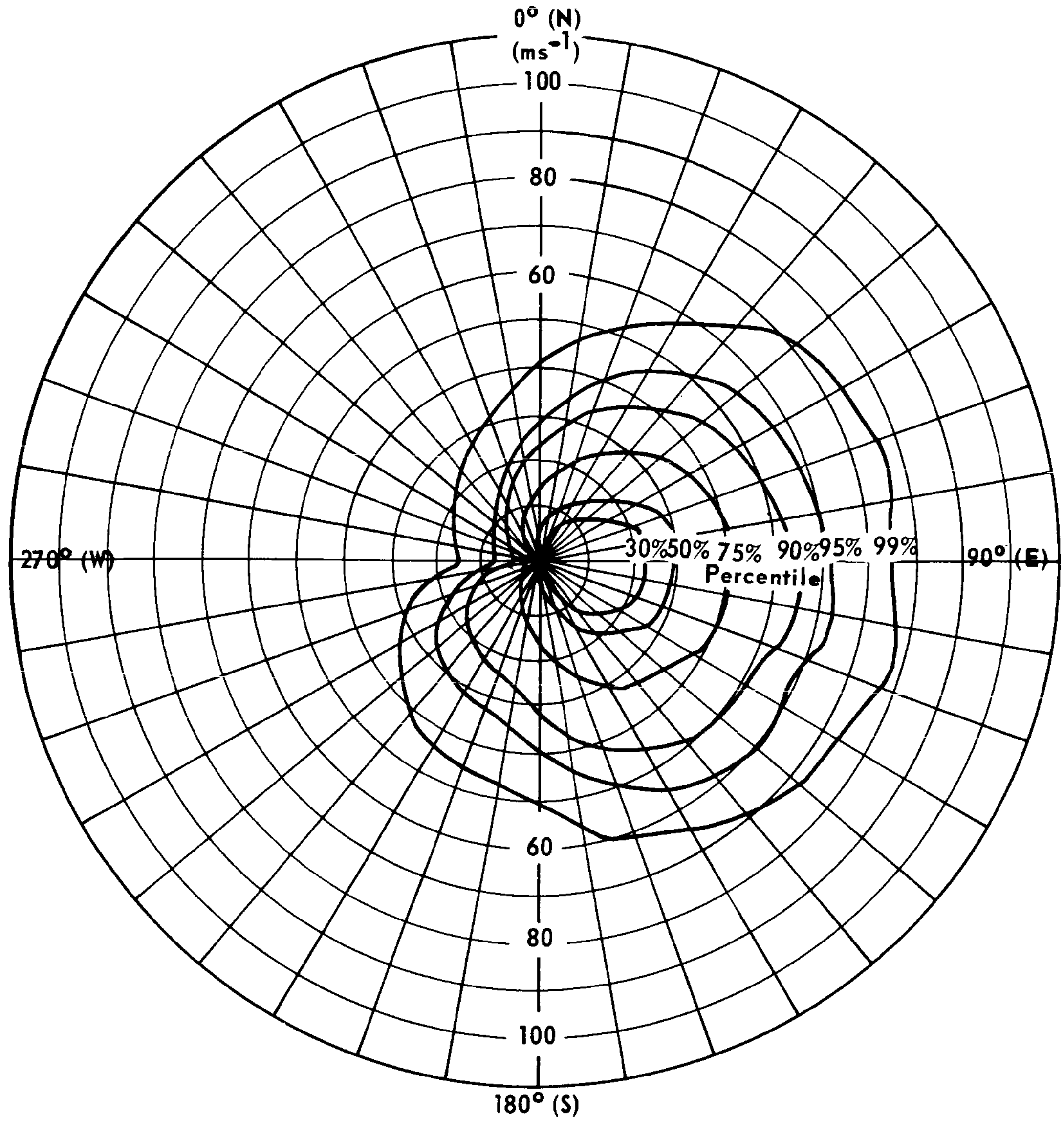


FIGURE 5.3.4 ENVELOPES OF IDEALIZED MONTHLY WIND COMPONENT (head, tail, right cross, and left cross) FREQUENCY DISTRIBUTIONS FOR 10- TO 13-KILOMETER ALTITUDE AS A FUNCTION OF FLIGHT AZIMUTH, SANTA MONICA (WTR), CALIFORNIA

Data on correlations of wind between altitude levels for various geographical locations are presented in NASA TN D-561 (Ref. 5.41), NASA TN D-3815 (Ref. 5.42), and NASA TN D-4570 (Ref. 5.43).

An example for the use of these upper wind correlations given in Tables 5.3.1 and 5.3.2 follows and was taken from Reference 5.42.

TABLE 5. 3. 1 ANNUAL INTERLEVEL AND INTRALEVEL COEFFICIENTS OF LINEAR CORRELATIONS BETWEEN WIND COMPONENTS, CAPE KENNEDY, FLORIDA

~~TABLE~~ I. 17 INTERLEVEL AND INTRALEVEL COEFFICIENTS OF LINEAR CORRELATIONS BETWEEN WIND COMPONENTS

STATION	ELEVATION MSL (meters)	LOCATION LATITUDE	LOCATION LONGITUDE	PERIOD OF DATA
PATRICK AFB, FLORIDA	7	28° 14' N	80° 36' W	JAN. 1, 1956 to NOV. 17, 1956
CAPE KENNEDY, FLORIDA	5	28°29' N	80° 33' W	NOV. 18, 1956 to DEC. 31, 1963

NOTES: ZONAL MEAN VALUES - POSITIVE FOR WIND COMPONENTS FROM WEST, UNIT $m s^{-1}$
MERIDIONAL MEAN VALUES - POSITIVE FOR WIND COMPONENTS FROM SOUTH, UNIT $m s^{-1}$
SD - STANDARD DEVIATION, UNIT $m s^{-1}$

INTRALEVEL CORRELATION COEFFICIENTS BETWEEN ZONAL AND MERIDIONAL WIND COMPONENTS ARE THE VALUES BETWEEN THE DIAGONAL LINES.

INTERLEVEL CORRELATION COEFFICIENTS FOR MERIDIONAL WIND COMPONENTS USE VALUES ABOVE AND TO THE RIGHT OF THE DIAGONAL LINES. FOR ZONAL WIND COMPONENTS USE VALUES BELOW AND TO THE LEFT OF THE DIAGONAL LINES.

ANNUAL

ZONAL AND MERIDIONAL WIND COMPONENT CORRELATIONS

CAPE KENNEDY, FLORIDA

PREPARED FROM EIGHT YEARS, TWICE DAILY, SERIALLY COMPLETE RECORDS BY:
TERRESTRIAL ENVIRONMENT BRANCH, AEROSPACE ENVIRONMENT DIVISION
AERO-ASTRODYNAMICS LABORATORY
GEORGE C. MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

NUMBER OF OBSERVATIONS FOR EACH ALTITUDE LEVEL: 5844

ALTITUDE (MSL) km	ZONAL MEAN	SD	SFC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
		MERIDIONAL MEAN	-0.12	0.93	0.70	0.65	0.70	0.73	0.75	0.82	0.81	0.82	0.74	0.42	0.13	-0.34	-0.80	-0.74	-0.58	-0.32	-0.26	-0.18	-0.18	-0.19	-0.22	-0.10	-0.05	-0.19	-0.25	-0.22
		SD	3.24	5.33	5.21	5.56	6.04	6.60	7.29	8.08	8.92	10.11	11.45	12.85	13.40	12.60	10.87	8.95	7.41	6.18	4.98	4.11	3.57	3.46	3.47	3.49	3.44	3.54	3.69	4.02
SFC	-0.44	3.25	-.140	.673	.483	.397	.231	.264	.204	.145	.058	.053	.005	-.025	-.050	-.079	-.077	-.082	-.071	-.062	-.056	-.035	-.045	-.050	-.062	-.048	-.045	-.035	-.019	-.018
1	0.79	6.37	.660	.088	.798	.652	.556	.479	.398	.315	.254	.199	.135	.088	.057	.031	.036	.048	.064	.059	.044	.040	.006	.009	-.029	-.006	-.012	-.000	.013	.003
2	3.11	7.02	.583	.851	.130	.845	.725	.645	.573	.495	.438	.381	.307	.251	.215	.185	.190	.210	.223	.220	.192	.157	.098	.061	.000	.025	.027	.037	.036	.037
3	5.12	7.99	.558	.737	.903	.121	.876	.777	.705	.633	.571	.514	.440	.382	.338	.303	.309	.329	.340	.335	.294	.237	.161	.083	.021	.048	.047	.055	.049	.064
4	7.01	9.14	.524	.658	.826	.933	.126	.885	.801	.729	.668	.608	.535	.478	.433	.397	.402	.420	.428	.408	.361	.299	.204	.107	.038	.066	.071	.070	.066	.082
5	8.85	10.57	.494	.600	.773	.881	.953	.160	.900	.819	.752	.687	.616	.551	.507	.473	.471	.487	.490	.467	.417	.340	.234	.134	.060	.076	.086	.092	.076	.092
6	10.78	12.04	.454	.538	.723	.837	.911	.960	.206	.915	.844	.779	.707	.640	.593	.558	.553	.564	.556	.517	.459	.376	.269	.155	.085	.085	.091	.092	.081	.101
7	12.72	13.67	.428	.490	.684	.802	.878	.928	.967	.236	.920	.849	.782	.717	.666	.628	.614	.617	.559	.553	.490	.397	.282	.171	.094	.096	.059	.096	.083	.102
8	14.72	15.42	.398	.445	.644	.772	.849	.859	.939	.971	.253	.927	.855	.792	.737	.697	.674	.662	.635	.578	.509	.408	.293	.175	.102	.105	.105	.096	.088	.118
9	16.81	17.41	.372	.407	.609	.741	.816	.866	.908	.941	.973	.262	.931	.866	.806	.757	.718	.689	.648	.586	.511	.413	.290	.169	.101	.105	.100	.087	.078	.109
10	18.91	19.34	.347	.371	.573	.709	.786	.837	.879	.913	.946	.975	.270	.936	.874	.811	.758	.713	.663	.601	.519	.425	.289	.174	.110	.107	.101	.088	.080	.118
11	21.06	20.99	.321	.339	.545	.682	.759	.811	.855	.890	.923	.953	.975	.255	.935	.858	.791	.727	.669	.596	.514	.420	.294	.175	.116	.107	.096	.077	.071	.105
12	22.76	22.02	.293	.316	.523	.660	.736	.790	.836	.869	.902	.928	.950	.972	.271	.918	.832	.756	.691	.609	.531	.425	.302	.172	.108	.105	.091	.069	.066	.106
13	23.17	21.75	.270	.291	.501	.638	.719	.772	.820	.853	.883	.903	.921	.940	.965	.307	.900	.803	.732	.638	.549	.435	.311	.179	.104	.109	.111	.089	.086	.114
14	21.54	20.30	.255	.281	.486	.623	.707	.761	.810	.843	.869	.884	.895	.913	.934	.958	.338	.878	.779	.685	.558	.483	.345	.158	.115	.116	.128	.103	.093	.123
15	18.37	18.15	.252	.276	.479	.617	.701	.756	.803	.833	.856	.868	.878	.889	.909	.928	.954	.339	.866	.743	.658	.537	.383	.240	.147	.138	.144	.114	.111	.144
16	14.53	15.97	.252	.272	.477	.612	.694	.745	.791	.819	.838	.846	.853	.861	.880	.900	.919	.953	.327	.828	.704	.582	.434	.266	.172	.146	.156	.128	.128	.163
17	10.42	14.05	.251	.265	.467	.598	.681	.732	.776	.800	.817	.821	.826	.833	.851	.870	.893	.914	.947	.294	.770	.612	.457	.282	.186	.161	.165	.143	.128	.156
18	5.00	12.08	.243	.252	.449	.579	.661	.710	.753	.775	.789	.793	.794	.800	.814	.832	.856	.876	.895	.929	.273	.689	.448	.303	.197	.162	.169	.156	.144	.167
19	2.05	10.57	.237	.231	.423	.548	.625	.671	.716	.738	.751	.758	.759	.762	.775	.790	.813	.838	.861	.868	.900	.273	.562	.311	.216	.182	.190	.171	.142	.156
20	-0.92	9.79	.217	.198	.387	.506	.578	.628	.670	.652	.707	.714	.718	.721	.734	.750	.776	.804	.823	.832	.831	.869	.233	.465	.253	.211	.213	.154	.167	.162
21	-2.87	9.53	.184	.157	.336	.449	.523	.567	.609	.636	.654	.663	.668	.676	.684	.701	.730	.752	.773	.782	.795	.804	.859	.159	.515	.301	.248	.217	.199	.169
22	-4.12	9.71	.177	.135	.300	.415	.485	.532	.575	.602	.618	.628	.633	.642	.651	.664	.691	.715	.735	.743	.758	.787	.812	.875	.107	.562	.210	.265	.231	.177
23	-4.85	10.14	.166	.118	.270	.384	.455	.499	.541	.570	.588	.596	.603	.611	.618	.634	.658	.685	.701	.709	.724	.747	.789	.835	.893	.128	.555	.319	.246	.199
24	-5.09	10.90	.162	.113	.257	.366	.437	.483	.524	.550	.569	.578	.585	.592	.602	.616	.640	.665	.675	.684	.702	.724	.756	.814	.853	.911	.166	.573	.319	.249
25	-4.95	11.91	.180	.124	.260	.367	.436	.482	.523	.549	.566	.575	.581	.588	.595	.610	.632	.657	.666	.674	.688	.709	.742	.791	.838	.879	.928	.190	.584	.352
26	-4.63	12.88	.169	.116	.249	.353	.423	.468	.506	.533	.552	.561	.568	.575	.581	.595	.617	.641	.648	.657	.668	.687	.720	.777	.816	.862	.893	.937	.197	.649
27	-4.42	13.75	.154	.106	.234	.333	.398	.444	.479	.506	.526	.536	.542	.550	.560	.572	.593	.618	.625	.629	.639	.662	.693	.749	.751	.835	.877	.906	.951	.214

TABLE 5.3.2 ANNUAL CROSSLEVEL AND INTRALEVEL COEFFICIENTS OF LINEAR CORRELATIONS BETWEEN WIND COMPONENTS, SANTA MONICA, CALIFORNIA

TABLE V.17 CROSSLEVEL AND INTRALEVEL COEFFICIENTS OF LINEAR CORRELATIONS BETWEEN WIND COMPONENTS

STATION	ELEVATION MSL (meters)	LOCATION LATITUDE	LOCATION LONGITUDE	PERIOD OF DATA
SANTA MONICA, CALIFORNIA	38	34°01' N	118° 16' W	JAN. 1, 1956 to DEC. 31, 1964

NOTES: ZONAL MEAN VALUES - POSITIVE FOR WIND COMPONENTS FROM WEST, UNIT ms^{-1}
MERIDIONAL MEAN VALUES - POSITIVE FOR WIND COMPONENTS FROM SOUTH, UNIT ms^{-1}
SD - STANDARD DEVIATION, UNIT ms^{-1}

INTRALEVEL CORRELATION COEFFICIENTS
BETWEEN ZONAL AND MERIDIONAL WIND COMPONENTS AT THE SAME ALTITUDES ARE VALUES BETWEEN THE DIAGONAL LINES.
CROSSLEVEL CORRELATION COEFFICIENTS
FOR MERIDIONAL WIND, USE ALTITUDE VALUES ACROSS THE TOP OF THE TABLE WITH ZONAL WIND, GIVEN BY ALTITUDE IN THE VERTICAL COLUMN AT THE LEFT.

ANNUAL

ZONAL AND MERIDIONAL WIND COMPONENT CORRELATIONS

SANTA MONICA, CALIFORNIA

PREPARED FROM NINE YEARS, FOUR TIMES DAILY, SERIALLY COMPLETE RECORDS BY:
TERRESTRIAL ENVIRONMENT BRANCH, AEROSPACE ENVIRONMENT DIVISION
AERO-ASTRODYNAMICS LABORATORY
GEORGE C. MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

NUMBER OF OBSERVATIONS FOR EACH ALTITUDE LEVEL: 13152

ALTITUDE (MSL) km	ZONAL MEAN	SD	SFC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
		MERIDIONAL MEAN	0.24	-0.43	-0.46	-0.59	-0.61	-0.75	-0.79	-0.76	-0.68	-0.45	-0.10	0.40	1.17	1.79	1.90	1.58	1.04	0.50	-0.02	-0.39	-0.59	-0.68	-0.74	-0.72	-0.71	-0.67	-0.71	-0.69
		SD	2.25	3.44	4.87	6.77	8.17	9.37	10.61	11.92	13.40	14.60	15.51	15.81	14.94	13.36	11.49	9.53	7.81	6.27	5.07	4.15	3.53	3.22	3.11	3.10	3.18	3.33	3.59	3.91
SFC	1.06	2.74	.534	.211	.096	.031	-.003	-.025	-.031	-.036	-.034	-.036	-.036	-.044	-.056	-.066	-.086	-.121	-.154	-.173	-.188	-.199	-.205	-.210	-.221	-.219	-.213	-.212	-.210	-.210
1	0.19	3.20	.025	-.144	.085	.091	.066	.046	.037	.037	.048	.061	.063	.054	.039	.014	-.013	-.037	-.058	-.072	-.068	-.057	-.049	-.053	-.057	-.057	-.060	-.070	-.075	-.077
2	1.62	4.81	-.008	-.140	-.030	-.050	-.054	-.060	-.057	-.048	-.031	-.011	-.001	-.007	-.020	-.041	-.075	-.114	-.149	-.174	-.177	-.170	-.162	-.161	-.157	-.151	-.151	-.158	-.161	-.162
3	3.31	6.52	.015	-.083	.041	-.020	-.054	-.070	-.068	-.060	-.040	-.016	-.003	-.008	-.022	-.048	-.087	-.134	-.182	-.223	-.233	-.234	-.226	-.222	-.220	-.214	-.213	-.218	-.223	-.223
4	5.11	7.92	.046	-.036	.101	.041	.001	-.030	-.035	-.028	-.009	.013	.026	.016	-.002	-.029	-.067	-.117	-.165	-.204	-.221	-.225	-.219	-.218	-.218	-.213	-.213	-.217	-.217	-.216
5	6.77	9.32	.049	-.013	.124	.073	.039	.010	-.001	.006	.025	.046	.058	.046	.028	.002	-.039	-.087	-.135	-.171	-.189	-.193	-.190	-.193	-.194	-.190	-.194	-.199	-.200	-.198
6	8.42	10.28	.050	.000	.131	.087	.055	.036	.027	.031	.048	.069	.081	.068	.048	.023	-.020	-.066	-.111	-.148	-.165	-.171	-.172	-.178	-.182	-.179	-.184	-.189	-.189	-.187
7	10.07	11.53	.047	.002	.130	.092	.066	.049	.050	.059	.075	.095	.106	.090	.068	.039	-.005	-.051	-.095	-.131	-.151	-.157	-.159	-.166	-.170	-.169	-.174	-.179	-.178	-.176
8	11.87	12.76	.050	-.005	.126	.095	.070	.056	.059	.076	.098	.118	.128	.110	.085	.052	.007	-.042	-.087	-.124	-.144	-.153	-.156	-.162	-.167	-.168	-.174	-.179	-.179	-.177
9	13.72	13.73	.054	-.011	.119	.097	.074	.059	.062	.080	.107	.133	.144	.126	.100	.063	.016	-.033	-.080	-.118	-.138	-.150	-.154	-.162	-.169	-.171	-.176	-.183	-.183	-.182
10	15.81	14.58	.065	-.019	.108	.089	.068	.053	.058	.076	.105	.134	.151	.139	.111	.071	.021	-.029	-.079	-.121	-.143	-.155	-.162	-.172	-.182	-.183	-.189	-.195	-.195	-.195
11	18.00	15.24	.074	-.023	.101	.083	.060	.045	.049	.067	.095	.126	.145	.141	.122	.081	.025	-.026	-.080	-.124	-.147	-.160	-.170	-.178	-.189	-.192	-.198	-.204	-.205	-.205
12	19.39	14.57	.082	-.018	.102	.083	.057	.040	.043	.057	.082	.112	.130	.126	.113	.087	.031	-.022	-.077	-.122	-.146	-.158	-.167	-.176	-.189	-.193	-.202	-.209	-.210	-.210
13	19.49	13.17	.088	-.011	.107	.087	.062	.044	.043	.055	.075	.100	.116	.114	.098	.082	.043	-.011	-.070	-.119	-.142	-.155	-.162	-.171	-.186	-.194	-.205	-.214	-.216	-.218
14	18.09	11.55	.091	.002	.121	.097	.071	.053	.050	.060	.077	.099	.112	.111	.099	.077	.048	.013	-.049	-.102	-.129	-.143	-.154	-.166	-.181	-.190	-.201	-.211	-.215	-.216
15	15.56	10.22	.098	.020	.138	.110	.083	.064	.059	.066	.081	.104	.116	.114	.104	.086	.046	.017	-.023	-.081	-.113	-.127	-.139	-.150	-.167	-.175	-.187	-.198	-.202	-.204
16	12.53	9.25	.115	.031	.145	.119	.099	.081	.073	.080	.091	.111	.121	.117	.106	.090	.057	.014	-.016	-.048	-.085	-.104	-.116	-.129	-.145	-.154	-.168	-.180	-.185	-.187
17	9.08	8.61	.130	.036	.149	.132	.120	.105	.097	.104	.113	.129	.135	.130	.116	.100	.074	.041	-.007	-.030	-.042	-.066	-.083	-.097	-.115	-.127	-.141	-.153	-.159	-.162
18	5.65	7.98	.128	.038	.155	.135	.126	.116	.109	.114	.121	.131	.130	.122	.107	.091	.069	.044	.010	-.033	-.031	-.020	-.037	-.059	-.078	-.094	-.113	-.127	-.134	-.139
19	2.70	7.42	.110	.029	.149	.126	.114	.107	.104	.107	.114	.120	.114	.099	.080	.065	.045	.024	-.000	-.036	-.060	-.037	-.005	-.039	-.069	-.088	-.110	-.127	-.138	-.143
20	0.39	7.07	.092	.016	.132	.111	.102	.094	.095	.100	.102	.104	.097	.080	.058	.042	.026	.026	-.015	-.038	-.053	-.069	-.039	-.016	-.048	-.080	-.103	-.121	-.134	-.139
21	-1.23	7.05	.070	-.002	.105	.091	.084	.079	.082	.089	.088	.086	.079	.064	.044	.028	.012	-.009	-.027	-.050	-.060	-.068	-.081	-.042	-.020	-.050	-.082	-.102	-.114	-.122
22	-2.23	7.36	.076	.009	.092	.072	.070	.065	.066	.071	.068	.064	.057	.041	.028	.016	.001	-.019	-.035	-.054	-.062	-.060	-.062	-.070	-.040	-.017	-.042	-.070	-.089	-.101
23	-2.73	7.97	.094	.019	.090	.067	.059	.053	.056	.058	.056	.052	.045	.030	.017	.006	-.006	-.026	-.038	-.054	-.060	-.053	-.039	-.038	-.049	-.018	-.000	-.017	-.041	-.056
24	-2.99	8.73	.095	.017	.089	.065	.053	.045	.046	.051	.049	.044	.037	.025	.014	.004	-.001	-.017	-.027	-.040	-.043	-.029	-.006	.011	.007	.005	.033	.053	.038	.016
25	-2.92	9.65	.095	.011	.080	.061	.050	.041	.043	.047	.050	.044	.035	.023	.013	.006	.001	-.012	-.019	-.030	-.026	-.006	.018	.043	.058	.057	.057	.079	.096	.081
26	-2.57	10.74	.092	.009	.074	.055	.043	.036	.039	.042	.043	.037	.029	.017	.006	.004	.002	-.010	-.016	-.024	-.018	-.004	.023	.050	.072	.083	.086	.088	.105	.112
27	-2.10	11.91	.081	.002	.058	.042	.034	.031	.035	.035	.035	.032	.025	.015	.010	.013	.013	.004	-.000	-.007	-.001	.011	.041	.065	.088	.107	.116	.116	.119	.127

Table 5.3.1 gives the annual values of the interlevel and intralevel coefficients of linear correlations between wind components for Cape Kennedy, Florida. To find the interlevel correlation coefficient for meridional wind components, values will be found above and to the right of the diagonal lines, while for zonal wind components, values will be found below and to the left of the diagonal lines. As an example, to find the correlation coefficient between meridional winds at two levels, 13 kilometers and 7 kilometers, use Table 5.3.1. Select the two levels so that the values will be above and to the right of the diagonal line; that is, go across the top to the 13-kilometer altitude, and then down the column to the 7-kilometer row, and find the value of 0.628. Similarly, the correlation coefficient for zonal winds between the same altitudes would be found by going across the 13-kilometer row to the 7-kilometer column to get the value of 0.853. To find the intralevel correlation coefficient between meridional winds and zonal winds at the same altitude, the values are read between the diagonal lines; that is, at 7 kilometers, follow down the 7-kilometer column to the 7-kilometer row, and the value of 0.236 will be found.

Table 5.3.2 gives the annual values of the crosslevel and intralevel coefficients of linear correlations between wind components for Santa Monica, California. To find the crosslevel (between meridional wind components at one altitude level and zonal wind components at a different altitude) correlation coefficients, Table 5.3.2 is entered by columns for the meridional wind components and by rows for the zonal wind components. The values may be either above or below the diagonal lines. As an example, to find the correlation coefficient between meridional component winds at 7 kilometers and zonal component winds at 13 kilometers, enter the table at the top, go across to the 7-kilometer column, and follow down the 7-kilometer column to the 13-kilometer row to find the value of 0.055.

Because of the occurrence of the regular increase of winds with altitude below and the decrease of winds above the 10- to 14-kilometer level, the correlation coefficients decrease with greater altitude separation of the levels being correlated. Likewise, the highest correlation coefficients between components occur in the 10- to 14-kilometer level.

5.3.3.3 Maximum Thickness of Strong Wind Layers (Ref. 5.56).

Wind speeds in the middle latitudes generally increase with altitude to a maximum between 10 and 14 kilometers. Above 14 kilometers, the wind speeds decrease with altitude, then increase at higher altitude, depending upon season and location. Frequently, these winds exceed 50 ms^{-1}

in the "jet stream," a core of maximum winds over the midlatitudes in the 10- to 14-kilometer altitudes. The vertical extent of the core of maximum winds, or the sharpness of the extent of peak winds on the wind profile is important in some vehicle design studies.

Table 5.33 shows the estimated maximum vertical thickness of the wind layers for wind speeds of 50, 75, and 97 ms^{-1} for the Eastern Test Range. Similar data for the Western Test Range is given in Table 5.3.4. At both ranges, the thickness of the layer decreases with increase of wind speed; that is, the sharpness of the peak is greater with greater winds.

TABLE 5.3.3 MAXIMUM THICKNESS OF STRONG WIND LAYERS (6 years record) AT THE EASTERN TEST RANGE

Quasi-Steady-State Wind Speed (± 5 ms^{-1})	Maximum Thickness (km)	Altitude Range (km)
50	5	8.5 to 16.5
75	3	10.5 to 15.5
97	2	10.0 to 14.0

TABLE 5.3.4 MAXIMUM THICKNESS OF STRONG WIND LAYERS (5 years record) AT THE WESTERN TEST RANGE

Quasi-Steady-State Wind Speed (± 5 ms^{-1})	Maximum Thickness (km)	Altitude Range (km)
50	5	8.0 to 16
75	3	9.5 to 14

5.3.4 Exceedance Probabilities.

The probability of inflight winds exceeding or not exceeding some critical wind speed for a specified time duration may be of considerable importance in mission planning, and, in many cases, more information than just the occurrence of critical winds is desired. Perhaps a dual launch, with the second vehicle being launched 1 to 3 days after the first, is planned, and suppose the launch opportunity extends over a 10-day period. What is the probability that below (or above) critical winds will last for the entire 10 days? What is the probability of 2 or 3 consecutive days of favorable winds in the 10-day period? Suppose the winds are favorable on the scheduled launch day, but the mission is delayed for other reasons. Now, what is the probability that the winds will remain favorable for 3 or 4 more days? Answers to these questions could also be used for certain design considerations involving specific vehicles prepared for a given mission and launch window.

5.3.4.1 Empirical Exceedance Probabilities.

To provide inflight wind information useful in mission analysis type studies, the Cape Kennedy serially complete radiosonde wind observations were subjected to statistical analyses described below. All calculations were conducted using the maximum wind speed in the 10- to 15-kilometer altitude layer.

The probability of the maximum wind speed (W) in the 10- to 15-kilometer layer exceeding (and not exceeding) specified values of wind speed (W^*) one or more times in k-consecutive 12-hour periods is presented in Table 5.3.5 (parts A and B). The computational method used in deriving these statistics was a combinational counting procedure. Identical results can also be derived from an analysis of runs (a run is a succession of like events).

The probability of runs and conditional probabilities can be derived from the exceedance probabilities (Table 5.3.5). An example is presented below, and the following definitions are helpful.

Let $P\{B\} = P[W \geqq W^*]$ denote the probability that $W \geqq W^*$ one or more times in k-consecutive 12-hour periods. (These statistics are given in part (B) of (Table 5.3.5); then $[1 - P\{B\}] = P\{B'\}$ is the probability that $W < W^*$ for k-consecutive 12-hour periods. The probability $P\{B'\}$ is also the probability of a run below W^* of length k in units of 12-hour periods.

Let $P\{A\} = P[W < W^*]$ denote the probability that $W < W^*$ one or more times in k-consecutive 12-hour periods (these statistics are given in Table 5.3.5 (A); then $[1 - P\{A\}] = P\{A'\}$ is the probability that $W \geqq W^*$ for k-consecutive 12-hour periods. The probability $P\{A'\}$ is also the probability of a run above W^* of length k in units of 12-hour periods.

Using 50 ms^{-1} for W^* from Table 5.3.5, the January statistics, and the above definitions, the probability of a run above 50 ms^{-1} and a run below 50 ms^{-1} of length k in units of 12-hour periods is illustrated in Table 5.3.6. The computational procedure to derive conditional probabilities from $P\{B'\}$ is also illustrated in Table 5.3.6. The conditional probabilities from $P\{A'\}$ can also be computed in similar fashion.

When W^* is defined as the critical inflight wind speed prohibiting the launch of a vehicle, several statistical inferences in terms of vehicle operations can be made.

a. The probability of $P\{B\} = P[W \geqq W^*]$ as previously defined is the probability of no-launch at least one time in k-consecutive 12-hour periods. From Table 5.3.5 (B) for $W^* = 50\ ms^{-1}$, the probability is 0.504 for k = 1. Stated in another way, there is a 50.4-percent chance of no-launch during an arbitrary 12-hour period during January, under the assumption that, when the wind is critical, it is critical for 12 hours. There is an 80.8-percent chance of no-launch at least once in ten consecutive 12-hour periods (5 days). This probability is also read from Table 5.3.5 (B).

b. The probability $P\{A\} = P[W < W^*]$ as previously defined is the probability of launch at least once in k-consecutive 12-hour periods. From Table 5.3.5 (A) for $W^* = 50\ ms^{-1}$, this probability for k = 10 consecutive 12-hour periods is 0.847.

c. The probability $P\{B'\} = [1 - P\{B\}]$, which can be computed from Table 5.3.5 (B), or can be taken directly from Tables 5.3.7 and 5.3.9, is the probability of launch for k-consecutive 12-hour periods. From Table 5.3.6 for January for $W^* = 50\ ms^{-1}$, there is a 19.2-percent chance that the wind will not be critical for launch for ten consecutive 12-hour periods or for a 5-day period.

d. The probability $P\{A'\} = [1 - P\{A\}]$, which can be computed from Table 5.3.5 (A), or can be taken directly from Table 5.3.8, is the probability of no-launch for k-consecutive 12-hour periods. From Table 5.3.6 for January for $W^* = 50\ ms^{-1}$, there is a 15.3-percent chance that the wind will be critical for launch for ten consecutive 12-hour periods or for a 5-day period.

e. Conditional probabilities can be readily computed from the run statistics $P\{B'\}$ and $P\{A'\}$, as illustrated in Table 5.3.6, or can be taken directly from Tables 5.3.7 through 5.3.10. The January statistics for wind speed <50, <75, and $\geq 50\ ms^{-1}$ for the probabilities of runs above and runs below these specified wind speed values, and the resulting conditional probabilities, are presented in Tables 5.3.6, 5.3.7, 5.3.8, and 5.3.9 respectively. The explanation for the columns for these tables is as follows:

Column 1 is the length of a run in increments of 12-hour periods, that is, k 12-hour periods.

TABLE 5.3.5 PROBABILITY (%) THAT THE MAXIMUM WIND SPEED, W, IN THE 10- TO 15-KILOMETER LAYER WILL OCCUR ONE OR MORE TIMES LESS THAN, EQUAL TO, OR GREATER THAN SPECIFIED VALUES, W*, FOR k-CONSECUTIVE 12-HOUR PERIODS AT CAPE KENNEDY, FLORIDA

MONTH---JANUARY
Number of Observations---496

[A] SPEED --less than---05, 10, . . . 110---ms^{-1}

W*	05	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	100	110	Min. Speed	No. Occ.
K 1	0.0	0.0	0.0	0.0	2.0	6.3	12.5	21.0	34.3	49.6	64.9	76.4	84.1	88.9	94.0	96.6	98.4	99.8	99.8	100.0	21	1
K 2	0.0	0.0	0.0	0.0	3.0	8.9	16.3	27.0	42.7	58.5	73.6	83.5	88.5	93.1	96.4	98.6	99.4	100.0	100.0	100.0	21	1
K 3	0.0	0.0	0.0	0.0	4.0	10.7	19.4	31.9	49.0	65.3	79.0	87.9	91.5	95.8	98.0	99.4	99.8	100.0	100.0	100.0	21	1
K 4	0.0	0.0	0.0	0.0	5.0	12.5	22.2	36.1	54.2	69.8	83.1	91.1	93.8	96.8	99.8	99.8	100.0	100.0	100.0	100.0	21	2
K 5	0.0	0.0	0.0	0.0	6.0	14.1	24.4	39.9	58.3	73.6	86.3	93.5	95.2	97.4	99.4	100.0	100.0	100.0	100.0	100.0	21	3
K 6	0.0	0.0	0.0	0.2	7.1	15.7	26.6	43.1	61.5	76.4	88.5	95.4	96.4	97.8	99.8	100.0	100.0	100.0	100.0	100.0	15	1
K 7	0.0	0.0	0.0	0.6	8.3	17.1	28.8	46.4	64.3	79.0	90.1	96.6	97.2	98.2	100.0	100.0	100.0	100.0	100.0	100.0	15	1
K 8	0.0	0.0	0.0	1.0	9.3	18.5	30.8	49.0	66.5	81.3	91.3	97.6	98.0	98.6	100.0	100.0	100.0	100.0	100.0	100.0	15	1
K 9	0.0	0.0	0.2	1.4	10.3	20.0	32.9	51.4	68.5	83.3	92.3	98.4	98.6	99.0	100.0	100.0	100.0	100.0	100.0	100.0	13	1
K 10	0.0	0.0	0.4	1.8	11.3	21.4	34.5	53.2	70.4	84.7	93.1	99.2	99.2	99.4	100.0	100.0	100.0	100.0	100.0	100.0	13	1

[B] SPEED --equal to or greater than---ms^{-1}

W*	05	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	100	110	Max. Speed	No. Occ.
K 1	100.0	100.0	100.0	100.0	98.0	93.8	87.5	79.0	65.7	50.4	35.1	23.6	15.9	11.1	6.0	3.4	1.6	0.2	0.2	0.0	101	1
K 2	100.0	100.0	100.0	100.0	98.8	96.4	91.3	84.5	73.8	59.5	44.2	30.8	20.6	15.5	8.5	5.4	2.6	0.4	0.4	0.0	101	1
K 3	100.0	100.0	100.0	100.0	99.4	97.6	94.0	87.3	78.2	65.3	50.8	35.9	24.4	19.0	10.9	7.7	3.8	0.6	0.6	0.0	101	1
K 4	100.0	100.0	100.0	100.0	99.6	97.8	95.6	89.1	80.8	69.4	55.4	39.7	28.0	22.4	12.9	9.5	4.8	1.0	0.8	0.0	101	1
K 5	100.0	100.0	100.0	100.0	99.6	98.0	96.4	90.7	83.5	72.2	58.9	42.9	31.3	25.2	14.9	11.3	5.8	1.2	1.0	0.0	101	1
K 6	100.0	100.0	100.0	100.0	99.6	98.2	97.2	92.1	85.7	74.4	61.5	45.8	34.7	27.8	16.5	12.9	6.9	1.4	1.2	0.0	101	1
K 7	100.0	100.0	100.0	100.0	99.6	98.2	97.6	93.1	87.3	76.6	63.7	48.4	37.9	30.6	18.1	14.5	7.9	1.6	1.4	0.0	101	1
K 8	100.0	100.0	100.0	100.0	99.6	98.2	97.8	93.8	88.7	78.2	65.7	50.4	40.3	33.1	19.8	16.1	8.9	1.8	1.6	0.0	101	1
K 9	100.0	100.0	100.0	100.0	99.6	98.2	98.0	94.4	89.7	79.8	67.5	52.0	42.5	35.3	21.2	17.5	9.9	2.0	1.8	0.0	101	1
K 10	100.0	100.0	100.0	100.0	99.6	98.2	98.0	95.0	90.7	80.8	69.2	53.2	44.2	37.3	22.6	18.8	10.7	2.2	2.0	0.0	101	1

TABLE 5.3.6 AN EXAMPLE FOR JANUARY IN THE COMPUTATION OF PROBABILITIES OF RUNS AND CONDITIONAL PROBABILITIES FOR MAXIMUM WIND IN THE 10- TO 15-KILOMETER LAYER AT CAPE KENNEDY, FLORIDA

k 12-hr Periods (k)	P{B} P[W ≥ 50[a]] (%)	P{A} P[W< 50[a]] (%)	P{B'} [1-P{B}] (%)	P{A'} [1-P{A}] (%)	Comparison with a Random Variable	Conditional Probabilities (%), from P{B'} P_k/P_i, $i \leq k$. i= 1	i= 2	i= 3	i= 4
1	50.4	49.6	49.6	50.4	50.0	100			
2	59.5	58.5	40.5	41.5	25.0	82	100		
3	65.3	65.3	34.7	34.7	12.5	70	86	100	
4	69.4	69.8	30.6	30.2	6.25	62	76	88	100
5	72.2	73.6	27.8	26.4	3.12	56	69	80	91
6	74.4	76.4	25.6	23.6	1.56	52	63	74	84
7	76.6	79.0	23.4	21.0	0.78	47	58	67	76
8	78.2	81.3	21.8	18.8	0.39	44	54	63	71
9	79.8	83.3	20.2	16.7	0.20	41	50	58	66
10	80.8	84.7	19.2	15.3	0.10	39	47	55	63
	From Table 5.3.5(B)	From Table 5.3.5(A)	runs below	runs above					

a Units, ms^{-1}

Column 2 is the number of runs of length k. (This is the absolute frequency of a run of length k; N_{rk}.

Column 3 is the number of observations of length k or greater. (This is the cumulative absolute frequency of runs of length k; denote this column by N_k.)

Column 4 is the number of observations in the sample. This is a fixed value for each month corresponding to the number of observations for the given month in the 8-year data sample.

Column 5 is the probability of having a run of length k or greater. Denote this column by P_k, where

$$P_k = \frac{N_k}{N} \quad . \qquad (1)\ 5.3.4$$

TABLE 5.3.7 RUNS AND CONDITIONAL PROBABILITIES FOR THE MAXIMUM WIND IN THE 10- TO 15-KILOMETER LAYER BEING <50 ms^{-1} FOR JANUARY, CAPE KENNEDY, FLORIDA

k	N_{rk}	N_k	N	P_k	P_{c1}	P_{c2}	P_{c3}	P_{c4}	P_{c5}	P_{c6}	P_{c7}	P_{c8}	P_{c9}	P_{c10}	P_{c11}	P_{c12}	P_{c13}	P_{c14}	P_{c15}	P_{c16}
1	16	246	496	0.496	1.0															
2	9	201	496	0.405	0.82	1.0														
3	7	172	496	0.347	0.70	0.86	1.0													
4	3	152	496	0.306	0.62	0.76	0.88	1.0												
5	0	138	496	0.278	0.56	0.69	0.80	0.91	1.0											
6	3	127	496	0.256	0.52	0.63	0.74	0.84	0.92	1.0										
7	1	116	496	0.234	0.47	0.58	0.67	0.76	0.84	0.91	1.0									
8	3	108	496	0.218	0.44	0.54	0.63	0.71	0.78	0.85	0.93	1.0								
9	1	100	496	0.202	0.41	0.50	0.58	0.66	0.72	0.79	0.86	0.93	1.0							
10	0	95	496	0.192	0.39	0.47	0.55	0.63	0.69	0.75	0.82	0.88	0.95	1.0						
11	0	91	496	0.183	0.37	0.45	0.53	0.60	0.66	0.72	0.78	0.84	0.91	0.96	1.0					
12	1	87	496	0.175	0.35	0.43	0.51	0.57	0.63	0.69	0.75	0.81	0.87	0.92	0.96	1.0				
13	0	83	496	0.167	0.34	0.41	0.48	0.55	0.60	0.65	0.72	0.77	0.83	0.87	0.91	0.95	1.0			
14	1	80	496	0.161	0.33	0.40	0.47	0.53	0.58	0.63	0.69	0.74	0.80	0.84	0.88	0.92	0.96	1.0		
15	1	77	496	0.155	0.31	0.38	0.45	0.51	0.56	0.61	0.66	0.71	0.77	0.81	0.85	0.89	0.93	0.96	1.0	
16	0	75	496	0.151	0.30	0.37	0.44	0.49	0.54	0.59	0.65	0.69	0.75	0.79	0.82	0.86	0.90	0.94	0.97	1.0

k = Number of 12-hr periods (run).

N_{rk} = Number of runs of exact length k.

P_k = The probability that run of length k or greater will occur.

N_k = Number of occurrences of runs equal to or greater than i.

N = Number of possible outcomes.

P_c = Conditional probability.

TABLE 5.3.8 RUNS AND CONDITIONAL PROBABILITIES FOR THE MAXIMUM WIND IN THE 10- TO 15-KILOMETER LAYER BEING <75 ms^{-1} FOR JANUARY, CAPE KENNEDY, FLORIDA

k	N_{rk}	N_k	N	P_k	P_{c1}	P_{c2}	P_{c3}	P_{c4}	P_{c5}	P_{c6}	P_{c7}	P_{c8}	P_{c9}	P_{c10}	P_{c11}	P_{c12}	P_{c13}	P_{c14}	P_{c15}	P_{c16}
1	1	466	496	0.940	1.0															
2	2	454	496	0.915	0.97	1.0														
3	0	442	496	0.891	0.95	0.97	1.0													
4	2	432	496	0.871	0.93	0.95	0.98	1.0												
5	0	422	496	0.851	0.91	0.93	0.95	0.98	1.0											
6	0	414	496	0.835	0.89	0.91	0.94	0.96	0.98	1.0										
7	1	406	496	0.819	0.87	0.89	0.92	0.94	0.96	0.98	1.0									
8	0	398	496	0.802	0.85	0.88	0.90	0.92	0.94	0.96	0.98	1.0								
9	0	391	496	0.788	0.84	0.86	0.88	0.91	0.93	0.94	0.96	0.98	1.0							
10	0	384	496	0.774	0.82	0.85	0.87	0.89	0.91	0.93	0.95	0.96	0.98	1.0						
11	2	377	496	0.760	0.81	0.83	0.85	0.87	0.89	0.91	0.93	0.95	0.96	0.98	1.0					
12	1	370	396	0.746	0.79	0.81	0.84	0.86	0.88	0.89	0.91	0.93	0.95	0.96	0.98	1.0				
13	1	365	496	0.736	0.78	0.80	0.83	0.84	0.86	0.88	0.90	0.92	0.93	0.95	0.97	0.99	1.0			
14	1	361	496	0.728	0.77	0.80	0.82	0.84	0.86	0.87	0.89	0.91	0.92	0.94	0.96	0.98	0.99	1.0		
15	0	358	496	0.722	0.77	0.79	0.81	0.83	0.85	0.86	0.88	0.90	0.92	0.93	0.95	0.97	0.98	0.99	1.0	
16	0	355	496	0.716	0.76	0.78	0.80	0.82	0.84	0.86	0.87	0.89	0.91	0.92	0.94	0.96	0.97	0.98	0.99	1.0

k = Number of 12-hr periods (run).

N_{rk} = Number of runs of exact length k.

P_k = The probability that run of length i or greater will occur.

N_k = Number of occurrences of runs equal to or greater than k.

N = Number of possible outcomes.

P_c = Conditional probability.

TABLE 5.3.9 RUNS AND CONDITIONAL PROBABILITIES FOR THE MAXIMUM WIND IN THE 10- TO 15-KILOMETER LAYER BEING ≥ 50 ms^{-1} FOR JANUARY, CAPE KENNEDY, FLORIDA

k	N_{rk}	N_k	N	P_k	P_{c1}	P_{c2}	P_{c3}	P_{c4}	P_{c5}	P_{c6}	P_{c7}	P_{c8}	P_{c9}	P_{c10}	P_{c11}	P_{c12}	P_{c13}	P_{c14}	P_{c15}	P_{c16}
1	11	250	496	0.504	1.0															
2	12	206	496	0.415	0.82	1.0														
3	3	172	496	0.347	0.69	0.83	1.0													
4	5	150	496	0.302	0.60	0.73	0.87	1.0												
5	1	131	496	0.264	0.52	0.64	0.76	0.87	1.0											
6	2	117	496	0.236	0.47	0.57	0.68	0.78	0.89	1.0										
7	1	104	496	0.210	0.42	0.50	0.60	0.69	0.79	0.89	1.0									
8	3	93	496	0.188	0.37	0.45	0.54	0.62	0.71	0.79	0.89	1.0								
9	1	83	496	0.167	0.33	0.40	0.48	0.55	0.63	0.71	0.80	0.89	1.0							
10	2	76	496	0.153	0.30	0.37	0.44	0.51	0.58	0.65	0.73	0.82	0.92	1.0						
11	0	70	496	0.141	0.28	0.34	0.41	0.47	0.53	0.60	0.67	0.75	0.84	0.92	1.0					
12	0	66	496	0.133	0.26	0.32	0.38	0.44	0.50	0.56	0.63	0.71	0.80	0.87	0.94	1.0				
13	1	62	496	0.125	0.25	0.30	0.36	0.41	0.47	0.53	0.60	0.67	0.75	0.82	0.89	0.94	1.0			
14	2	58	496	0.117	0.23	0.28	0.34	0.39	0.44	0.50	0.56	0.62	0.70	0.76	0.83	0.88	0.94	1.0		
15	0	55	496	0.111	0.22	0.27	0.32	0.37	0.42	0.47	0.53	0.59	0.66	0.72	0.79	0.83	0.89	0.95	1.0	
16	0	54	496	0.109	0.22	0.26	0.31	0.36	0.41	0.46	0.52	0.58	0.65	0.71	0.77	0.82	0.87	0.93	0.98	1.0

k = Number of 12-hr periods (run).

N_{rk} = Number of runs of exact length k.

P_k = The probability that run of length k or greater will occur.

N_k = Number of occurrences of runs equal to or greater than i.

N = Number of possible outcomes.

P_c = Conditional probability.

TABLE 5.3.10 RUNS AND CONDITIONAL PROBABILITIES FOR THE MAXIMUM WIND IN THE 10- TO 15-KILOMETER LAYER BEING ≥75 ms^{-1} FOR JANUARY, CAPE KENNEDY, FLORIDA

k	N_{rk}	N_k	N	P_k	P_{c1}	P_{c2}	P_{c3}	P_{c4}	P_{c5}	P_{c6}
1	4	30	496	0.060	1.0					
2	4	18	496	0.036	0.60	1.0				
3	1	10	496	0.020	0.33	0.56	1.0			
4	1	6	496	0.012	0.20	0.33	0.60	1.0		
5	1	3	496	0.006	0.10	0.17	0.30	0.50	1.0	
6	1	1	496	0.002	0.03	0.06	0.10	0.17	0.33	1.0

k = Number of 12-hr periods (run).

N_{rk} = Number of runs of exact length k.

P_k = The probability that run of length i or greater will occur.

N_k = Number of occurrences of runs equal to or greater than k.

N = Number of possible outcomes.

P_c = Conditional probability.

Column 6 and all other columns are the conditional probabilities

$$P_{c(k,i)} = \frac{N_k}{N_i}, \quad \begin{matrix} i \le k \\ i = 1,2,3\ldots \end{matrix}, \qquad (2)\ 5.3.5$$

where column 6 is for i = 1, column 7 is for i = 2, etc.

Conditional probabilities provide information on the persistence of the wind, that is, the probability of the wind remaining in its present category for some time interval. For example, if the wind speed is observed below critical at some time prior to launch, what is the probability that it will remain below critical through launch time?

Clearly, if the wind is observed to be less than 50 ms^{-1}, the probability of this event occurring at a given time is 1.00, or as indicated in Table 5.3.6, 100 percent. Based upon this information, the predicted occurrence of the event 2 days hence is 56 percent (read from Table 5.3.7 at i = 1 and k = 5); whereas, there was only a 49.6-percent chance of the wind being less than 50 ms^{-1} on any arbitrary observation during the month. To continue the example, suppose the wind is observed 12 hours later (corresponding to i = 2) and it is still below 50 ms^{-1}, then, the probability that the wind will be below 50 ms^{-1} 24 hours in the future is 76 percent. This value is read from the table at P_{c2}, k = 4.

By comparing P{B'} and P{A'} with the statistics of a random variable (see Table 5.3.6), it is concluded that the wind sample is not stochastically independent. What happens to the conditional probabilities for the random series? The conditional probabilities remain 0.50.

From an analysis independent of that for exceedance probabilities, the run probabilities and conditional probabilities for the same data sample (the maximum wind speed 10 to 15 km over Cape Kennedy) were computed for specified wind speeds. Since these statistics were determined at different times and using different techniques, the notation is slightly different. The most satisfying feature is that the resulting statistics are identical, thus giving rise to confidence in the correctness of the computation processes, as well as providing an independent approach to the same problem. Figure 5.3.5 is a useful graphic form to display the probabilities of runs.

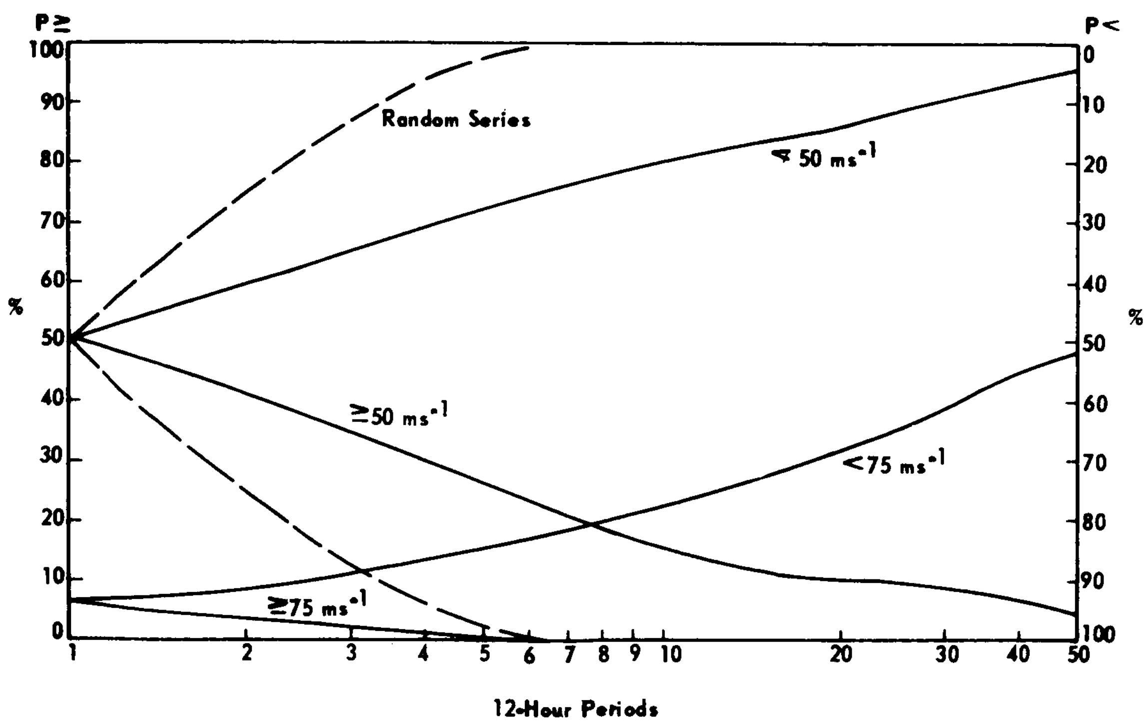


FIGURE 5.3.5 PROBABILITY OF THE MAXIMUM WIND SPEED IN THE 10- TO 15-KILOMETER LAYER BEING LESS THAN, EQUAL TO, OR GREATER THAN SPECIFIED VALUES FOR k-CONSECUTIVE 12-HOUR PERIODS DURING JANUARY AT CAPE KENNEDY, FLORIDA

From the definitions presented in the preceding paragraphs, an inverse operation can be performed to calculate the exceedance probabilities from the probabilities of runs given in Tables 5.3.7 through 5.3.10. For example, the probability that the maximum wind speed in the 10- to 15-kilometer layer will exist for ten consecutive 12-hour periods at a magnitude $\geqq$ 50 ms^{-1} in January is 0.153 (Table 5.3.9, column 5, corresponding to k = 10). In symbols, this statement is expressed as $P\{W \geqq 50\ ms^{-1}\}$.

The probability that the wind speed will not exceed 50 ms^{-1} at least one time in ten consecutive 12-hour periods is 0.847 (1 - 0.153 = 0.847). The probability that the wind speed will exceed 50 ms^{-1} at least one time in 10 consecutive 12-hour periods in January is obtained from Table 5.3.7 (1 - 0.192 = 0.808).

To cover multiple launches, the computations were extended to derive the probability of 2, 3, 4, . . . i (i = 20) launch opportunities in k-consecutive 12-hour periods. These statistics are referred to as the probability of i successes in J periods: P{ i successes in J periods}.

The probable number of launch opportunities (wind speed < critical) in a given number of periods expressed in terms of i successes (where success is the occurrence of wind speed < critical) in J periods is shown in Table 5.3.11. For example, suppose a mission has a 4-day launch window in January and the vehicle is constrained to wind speeds less than 50 ms^{-1}, the probability that at least one observation of wind speeds < 50 ms^{-1} (one launch opportunity) will occur during the launch window (eight 12-hour periods) is of interest to the mission planner. This probability, 0.813, is read from Table 5.3.11, line 8, column 1. If, however, after considering other factors, it is decided that four successes in the eight periods are required, that probability, 0.550, is read from line 8, column 4. Table 5.3.12 contains similar probability statements, except here it is required that the successes be consecutive. With this additional restriction, the probability of successes will naturally be lower. Using the example above, one obtains 0.431 from Table 5.3.12 versus 0.550 from Table 5.3.11.

The data shown here were extracted from tables covering all months for wind speeds $\geqq$ and < 5, 10, 15, . . . 90 ms^{-1}, where i - 1, 2, 3, . . . 20, and J = 1, 2, 3, . . . 40.

TABLE 5.3.11 P{I Successes in J Periods} MAXIMUM WIND BEING < 50 ms^{-1} IN THE 10- TO 15-KILOMETER LAYER FOR JANUARY, CAPE KENNEDY, FLORIDA

J 12-hr periods	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.496			-												
2	0.585	0.405		-												
3	0.653	0.488	0.347	-												
4	0.698	0.560	0.427	0.306												
5	0.736	0.599	0.504	0.379	0.278											
6	0.764	0.631	0.540	0.464	0.341	0.256										
7	0.790	0.649	0.577	0.506	0.423	0.313	0.234									
8	0.813	0.669	0.591	0.550	0.468	0.399	0.280	0.218								
9	0.833	0.690	0.605	0.565	0.516	0.450	0.369	0.258	0.202							
10	0.847	0.714	0.619	0.583	0.530	0.498	0.425	0.343	0.236	0.192						
11	0.859	0.732	0.641	0.593	0.548	0.510	0.480	0.403	0.315	0.220	0.183					
12	0.867	0.754	0.655	0.611	0.558	0.524	0.492	0.468	0.379	0.288	0.208	0.175				
13	0.875	0.774	0.671	0.621	0.577	0.534	0.506	0.482	0.454	0.351	0.268	0.198	0.167			
14	0.883	0.790	0.692	0.631	0.589	0.548	0.520	0.494	0.470	0.431	0.325	0.254	0.188	0.161		
15	0.889	0.806	0.702	0.653	0.599	0.560	0.532	0.510	0.482	0.458	0.399	0.308	0.240	0.181	0.155	
16	0.891	0.825	0.712	0.667	0.617	0.569	0.546	0.520	0.500	0.472	0.429	0.383	0.288	0.232	0.175	0.151

TABLE 5.3.12 P{I Consecutive Successes in J Periods} MAXIMUM WIND BEING < 50 ms^{-1} IN THE 10- TO 15-KILOMETER LAYER FOR JANUARY, CAPE KENNEDY, FLORIDA

J 12-hr periods	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.496															
2	0.585	0.405														
3	0.653	0.466	0.347													
4	0.698	0.528	0.393	0.306												
5	0.736	0.577	0.440	0.399	0.278											
6	0.764	0.611	0.484	0.371	0.304	0.256										
7	0.790	0.637	0.518	0.401	0.331	0.282	0.234									
8	0.813	0.653	0.540	0.431	0.355	0.308	0.256	0.218								
9	0.833	0.667	0.563	0.460	0.379	0.333	0.278	0.238	0.202							
10	0.847	0.681	0.575	0.482	0.401	0.357	0.298	0.258	0.216	0.192						
11	0.859	0.696	0.585	0.504	0.423	0.379	0.319	0.276	0.230	0.204	0.183					
12	0.867	0.706	0.595	0.518	0.442	0.401	0.337	0.294	0.244	0.216	0.196	0.175				
13	0.875	0.716	0.605	0.530	0.460	0.423	0.355	0.310	0.258	0.228	0.208	0.188	0.167			
14	0.883	0.726	0.615	0.542	0.472	0.442	0.373	0.327	0.270	0.240	0.220	0.200	0.177	0.161		
15	0.889	0.736	0.625	0.554	0.482	0.460	0.391	0.343	0.282	0.250	0.232	0.212	0.188	0.171	0.155	
16	0.891	0.746	0.635	0.567	0.494	0.472	0.407	0.359	0.294	0.260	0.242	0.224	0.198	0.181	0.165	0.151

5.3.4.2 Empirical Multiple Exceedance Probabilities.

The longest succession of maximum wind speed in the 10- to 15-kilometer layer with wind speeds $\geqq 75\ ms^{-1}$ occurred during the winter of 1958. This year would be referred to as a high wind year. In terms of runs, the longest runs $\geqq 75\ ms^{-1}$ by months are given in Table 5.3.13.

TABLE 5.3.13 DATES OF LONGEST RUNS OF WIND SPEEDS GREATER THAN OR EQUAL TO 75 ms^{-1} IN THE 10- TO 15-KILOMETER LAYER AT CAPE KENNEDY, FLORIDA

Max. Length of Run in 12-hr Periods	Date	Dates and Times Inclusive
6	Jan 1958	25, 12Z - 27, 12Z
14	Feb 1958	10, 00Z - 16, 12Z
7	Mar 1958	28, 12Z - 31, 12Z
3	Apr 1958	15, 12Z - 16, 12Z
(There were no values $\geq 75\ ms^{-1}$ for May through Oct)		
6	Nov 1956	25, 03Z - 27, 15Z
4	Dec 1956	29, 03Z - 30, 15Z

The counting rule for runs is as follows: If a run begins in one month and extends into a following month, it is counted as a run for the month in which it begins.

Beginning at 12Z on January 25, 1958, the wind blew at a speed $\geq 75\ ms^{-1}$ for 53 12-hour periods ($26\frac{1}{2}$ days with only six exceptions; There were two single breaks; that is, twice the wind dropped below 75 ms^{-1}, twice the wind dropped below 75 ms^{-1} for two 12-hour periods, and twice the wind dropped below 75 ms^{-1} for three 12-hour periods. For this particular sample period of 53, there was a 77-percent chance that the wind was equal to or greater than 75 ms^{-1}. Yet, for the entire sample of eight Januaries, there was a 6-percent chance that the wind speed was equal to or greater than 75 ms^{-1} in the 10- to 15-kilometer layer.

5.3.5 Wind Speed Profiles for Biasing Tilt Program.

In attempting to maintain a desired flight path for a space vehicle through a strong wind region, the vehicle control system could introduce excessive bending moments and orbit anomalies. To reduce this problem, it is sometimes desirable to wind bias the pitch program, that is, to tilt the vehicle sufficiently to produce the desired flight path and minimize loads with the expected wind profile. Since most inflight strong winds over Cape Kennedy, Florida, are winter westerlies (see Section 5.3.3), it is generally adequate to bias to the monthly or seasonal pitch plane median wind speed profile. It is not usually necessary to bias the vehicle in the yaw plane because of the flight azimuths normally used at Cape Kennedy.

Head and tail wind components and right and left cross wind components from 0- to 60-kilometer altitudes were computed for every 15 degrees of flight azimuth for the Eastern Test Range launch area and were published in Memorandum R-AERO-Y118-66, dated October 25, 1966.* Similar calculations can be readily made for the Western Test Range using available serial complete data records. Extracted and shown as Tables 5.3.14A through 5.3.14D are head and tail wind component data for a 75-degree flight azimuth for the four strong wind months — December, January, February, and March. Pitch and yaw wind components for a 90-degree launch azimuth are shown in Figures 5.3.1A through 5.3.1C and Figures 5.3.2A through 5.3.2C, in Section 5.3.3.1.

5.3.6 Design Wind Speed Profile Envelopes.

Design wind speed profile envelopes are presented in Tables 5.3.15 through 5.3.18 and Figures 5.3.6 through 5.3.9. These are idealized steady-state scalar wind speed profile envelopes. The data is given to 80 kilometers. The wind data given is not expected to be exceeded by the given percentage of time (time as related to the observational interval of the data sample) based upon the windiest monthly reference period. To obtain the profiles, monthly frequency distributions are combined for each percentile level

* Copies are available upon request from

Chief, Aerospace Environment Division
Aero-Astrodynamics Laboratory
NASA George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

TABLE 5.3.14A HEAD AND TAIL WIND COMPONENTS FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 75-DEGREE FLIGHT AZIMUTH — DECEMBER

DATA SOURCE							DECEMBER
TYPE OF DATA	ELEVATION RANGE	STATION	ELEVATION MSL (meters)	LOCATION LATITUDE	LOCATION LONGITUDE	PERIOD OF DATA	EASTERN TEST RANGE (CAPE KENNEDY, FLORIDA)
SERIAL COMPLETED RAWINSONDE	0 to 27 km	PATRICK AFB, FLORIDA	7	28° 14' N	80° 36' W	JAN. 1, 1956 to NOV. 17, 1956	
SERIAL COMPLETED RAWINSONDE	0 to 27 km	CAPE KENNEDY, FLORIDA	5	28° 29' N	80° 33' W	NOV. 18, 1956 to DEC. 31, 1963	
ROCKETSONDE	28 km up	CAPE KENNEDY, FLORIDA	5	28° 29' N	80° 33' W	JAN. 1957 to OCT. 1964	

PREPARED BY : TERRESTRIAL ENVIRONMENT BRANCH, AEROSPACE ENVIRONMENT DIVISION, AERO-ASTRODYNAMICS LABORATORY GEORGE C. MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

CUMULATIVE PERCENTAGE FREQUENCY

Wind Speed in m s^{-1}

ALT. (KM)	NUM OBS	MIN SPEED	DIR (DEG)	0.135	1.000	2.280	5.000	15.900	50.000	84.100	95.000	97.720	99.000	99.865	MAX SPEED	DIR (DEG)
SFC	496	-9.0			-7.2	-5.9	-4.3	-2.2	-0.2	+1.8	+3.7	+4.8	+7.0	+9.6	+10.0	
1.0	496	-19.0			-13.0	-11.2	-9.6	-5.8	-0.0	+7.4	+12.6	+14.6	+17.0	+18.3	+19.0	
2.0	496	-15.0			-10.5	-8.8	-6.1	-2.3	+3.0	+10.9	+17.4	+20.6	+24.5	+34.3	+35.0	
3.0	496	-12.0			-6.5	-5.2	-3.5	-0.3	+6.4	+14.5	+21.8	+24.9	+30.0	+35.3	+36.0	
4.0	496	-3.0			-4.6	-3.1	-0.9	+1.5	+10.3	+19.0	+26.4	+28.9	+34.8	+40.3	+41.0	
5.0	496	-14.0			-3.7	-2.4	-0.6	+3.7	+13.6	+22.7	+30.7	+35.8	+40.0	+50.2	+51.0	
6.0	496	-14.0			-3.5	-1.5	+0.4	+6.1	+17.0	+26.9	+34.2	+39.8	+44.0	+53.3	+54.0	
7.0	496	-14.0			-3.3	-0.6	+2.3	+8.2	+20.0	+30.5	+40.2	+43.6	+51.0	+66.3	+67.0	
8.0	496	-10.0			-3.0	-0.6	+2.7	+10.0	+23.6	+36.5	+44.7	+52.6	+58.5	+67.3	+68.0	
9.0	496	-24.0			-3.3	-0.3	+2.9	+11.1	+27.1	+42.0	+51.8	+58.7	+61.0	+69.3	+70.0	
10.0	496	-17.0			-2.3	-0.1	+4.3	+12.4	+30.4	+47.2	+57.0	+63.9	+72.3	+80.3	+81.0	
11.0	496	-5.0			-2.0	+1.6	+5.6	+14.4	+33.2	+49.9	+60.7	+65.6	+70.6	+84.3	+85.0	
12.0	496	-5.0			-0.0	+4.3	+8.1	+17.0	+34.9	+51.2	+63.6	+69.8	+74.0	+79.3	+80.0	
13.0	496	-2.0			+3.9	+7.1	+11.3	+18.9	+35.2	+50.7	+62.0	+69.5	+74.0	+79.6	+80.0	
14.0	496	+1.0			+6.9	+9.8	+12.4	+19.0	+33.2	+47.8	+58.5	+62.9	+72.0	+77.3	+78.0	
15.0	496	+3.0			+5.9	+9.5	+11.5	+18.3	+30.1	+42.7	+51.7	+57.8	+66.5	+74.3	+75.0	
16.0	496	+2.0			+4.9	+7.4	+9.6	+15.9	+25.7	+35.8	+44.3	+49.8	+58.0	+63.3	+64.0	
17.0	496	-1.0			+1.9	+4.5	+7.5	+12.2	+21.4	+29.1	+36.7	+43.3	+47.0	+56.3	+57.0	
18.0	496	-9.0			-0.0	+1.6	+4.1	+8.3	+15.8	+24.3	+29.7	+32.9	+36.5	+40.7	+41.0	
19.0	496	-5.0			-1.0	-0.2	+1.1	+4.4	+10.5	+19.3	+25.1	+29.3	+33.0	+36.3	+37.0	
20.0	496	-5.0			-2.7	-1.4	-0.5	+1.8	+7.2	+15.5	+22.2	+26.6	+31.0	+36.3	+37.0	
21.0	496	-5.0				-3.5	-1.4	+0.7	+6.4	+13.8	+19.5	+25.8	+31.0	+34.3	+35.0	
22.0	496	-9.0			-7.0	-5.1	-1.9	+0.6	+6.3	+13.2	+18.2	+21.5	+23.5	+30.3	+31.0	
23.0	496	-11.0			-7.7	-6.3	-3.4	+0.8	+7.3	+13.8	+19.7	+24.3	+27.6	+32.3	+33.0	
24.0	496	-10.0			-9.6	-6.7	-4.0	+2.1	+8.5	+17.3	+23.2	+27.3	+31.3	+34.7	+35.0	
25.0	496	-20.0			-10.5	-7.5	-4.7	+3.7	+10.7	+19.7	+26.4	+30.2	+32.6	+40.3	+41.0	
26.0	496	-13.0			-10.0	-8.1	-4.7	+3.8	+12.7	+22.0	+28.0	+32.1	+35.3	+39.3	+40.0	
27.0	496	-17.0			-12.4	-9.1	-5.7	+5.2	+14.9	+23.0	+29.2	+33.3	+36.0	+42.3	+43.0	
28.0	33	-29.0					-26.3	-14.5	+9.7	+28.8	+35.6	+40.2	+40.0	+40.8	+41.0	
29.0	33	-22.0					-21.3	-11.0	+15.2	+29.7	+35.3	+44.2	+44.6	+44.8	+45.0	
30.0	33	-22.0					-17.3	-8.0	+15.5	+30.0	+37.3	+39.2	+39.6	+44.9	+40.0	
31.0	34	-13.0						-8.1	+17.0	+30.6	+36.3	+43.2	+43.6	+43.9	+44.0	
32.0	34	-12.0						-6.5	+10.0	+32.2	+42.3	+55.2	+55.6	+55.8	+56.0	
33.0	34	-18.0					-15.2	-7.1	+13.0	+33.8	+37.3	+43.2	+43.6	+43.9	+44.0	
34.0	33	-20.0					-15.3	-6.0	+9.5	+33.4	+43.1	+43.6	+43.8	+44.0	+44.0	
35.0	32	-24.0					-16.3	-11.5	+11.0	+35.5	+42.4	+46.2	+46.6	+47.0	+47.0	
36.0	32	-23.0					-20.3	-13.5	+13.0	+37.4	+42.4	+47.2	+47.6	+47.9	+48.0	
37.0	33	-25.0					-19.3	-12.4	+4.5	+44.0	+55.3	+57.2	+57.6	+57.9	+58.0	
38.0	26	-36.0					-28.6	-16.8	-1.0	+36.8	+44.6	+45.4	+45.7	+45.9	+46.0	
39.0	31	-39.0					-25.4	-20.3	+4.5	+47.9	+56.4	+58.2	+58.6	+58.9	+59.0	
40.0	31	-40.0					-26.4	-22.2	+3.5	+50.0	+59.4	+63.2	+63.6	+63.9	+64.0	
41.0	33	-36.0					-28.3	-18.5	+13.5	+47.5	+58.6	+64.2	+64.6	+64.9	+65.0	
42.0	31	-42.0					-30.4	-23.5	+10.5	+50.4	+68.4	+76.2	+76.6	+76.9	+77.0	
43.0	32	-38.0					-32.3	-25.0	+3.0	+49.0	+65.3	+73.2	+73.6	+73.9	+74.0	
44.0	32	-38.0					-32.6	-23.6	+11.0	+48.0	+61.4	+75.2	+75.6	+75.9	+76.0	
45.0	32	-39.0					-35.6	-20.4	+14.0	+58.6	+64.3	+74.2	+74.6	+74.9	+75.0	
46.0	30	-39.0					-35.5	-22.8	+15.0	+45.9	+58.5	+71.3	+71.6	+71.9	+72.0	
47.0	30	-40.0					-36.5	-24.1	+15.0	+53.5	+67.7	+70.3	+70.6	+70.9	+71.0	
48.0	29	-42.0					-38.5	-28.4	+11.5	+53.8	+68.5	+72.3	+72.7	+72.9	+73.0	
49.0	28	-43.0					-42.5	-28.4	+14.0	+62.5	+86.5	+92.3	+92.7	+92.9	+93.0	
50.0	26	-39.0					-38.6	-30.1	+4.0	+65.7	+73.6	+86.4	+86.7	+86.9	+87.0	
51.0	23	-43.0					-39.8	-28.5	+8.5	+52.5	+71.8	+93.4	+93.7	+93.9	+94.0	
52.0	23	-42.0					-37.8	-32.0	+10.5	+63.3	+79.8	+101.4	+101.7	+101.9	+102.1	
53.0	24	-49.0					-38.7	-29.6	+13.0	+61.2	+82.7	+92.4	+92.7	+92.9	+93.0	
54.0	23	-42.0						-29.8	+9.5	+56.5	+74.4	+74.7	+74.8	+75.0	+75.0	
55.0	21	-40.0					-39.9	-24.0	+11.5	+61.2	+71.9	+76.5	+76.7	+76.7	+77.0	
56.0	21	-49.0					-32.9	-25.8	+12.7	+56.5	+67.9	+69.5	+69.7	+69.9	+70.0	
57.0	20	-34.0						-22.6	+19.0	+64.0	+94.0	+94.5	+94.7	+94.9	+95.0	
58.0	19	-31.0						-23.5	+23.5	+65.8	+71.5	+71.7	+71.9	+72.0	+72.0	
59.0	15	-33.0						-15.8	+12.5	+68.5	+81.2	+81.6	+81.8	+82.0	+82.0	
60.0	13	-35.0						-12.8	+10.5	+60.5	+92.3	+92.7	+92.8	+93.0	+93.0	

Notes: From Memo No. R-AERO-Y-118-66
Positive (+) is wind from the tail (225°)
Negative (-) is wind from the head (75°)
Blank spaces of missing data at low percentile levels are due to an insufficient number of observations at that altitude. For example, at least 20 observations are required to produce a value at the fifth percentile.

TABLE 5.3.14B HEAD AND TAIL WIND COMPONENTS FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 75-DEGREE FLIGHT AZIMUTH – JANUARY

DATA SOURCE							JANUARY
TYPE OF DATA	ELEVATION RANGE	STATION	ELEVATION MSL (meters)	LOCATION LATITUDE	LOCATION LONGITUDE	PERIOD OF DATA	EASTERN TEST RANGE (CAPE KENNEDY, FLORIDA)
SERIAL COMPLETED RAWINSONDE	0 to 27 km	PATRICK AFB, FLORIDA	7	28° 14' N	80° 36' W	JAN. 1, 1956 to NOV. 17, 1956	
SERIAL COMPLETED RAWINSONDE	0 to 27 km	CAPE KENNEDY, FLORIDA	5	28° 29' N	80° 33' W	NOV. 18, 1956 to DEC. 31, 1963	
ROCKETSONDE	28 km up	CAPE KENNEDY, FLORIDA	5	28° 29' N	80° 33' W	JAN. 1957 to OCT. 1964	

PREPARED BY : TERRESTRIAL ENVIRONMENT BRANCH, AEROSPACE ENVIRONMENT DIVISION, AERO-ASTRODYNAMICS LABORATORY
GEORGE C. MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

Wind Speed in m s^{-1}

ALT. (KM)	NUM OBS	MIN SPEED	DIR (DEG)	0.135	1.000	2.280	5.000	15.900	50.000	84.100	95.000	97.720	99.000	99.865	MAX SPEED	DIR (DEG)
				CUMULATIVE PERCENTAGE FREQUENCY												
SFC	496	-9.0			-6.8	-5.6	-4.2	-2.1	-0.1	+2.7	+4.4	+5.8	+6.7	+9.3	+10.0	
1.0	496	-12.0			-11.5	-9.9	-8.5	-3.2	+2.1	+8.5	+13.8	+15.9	+18.3	+22.3	+23.0	
2.0	496	-10.0			-7.7	-5.7	-3.4	+0.2	+5.6	+13.7	+18.0	+22.4	+25.0	+31.3	+32.0	
3.0	496	-6.0			-3.7	-2.1	-0.2	+3.2	+9.2	+17.7	+24.6	+26.7	+28.3	+34.3	+35.0	
4.0	496	-5.0			-2.0	-0.2	+2.4	+6.4	+12.6	+22.3	+27.6	+30.9	+31.8	+44.3	+45.0	
5.0	496	-3.0			+0.2	+2.1	+4.3	+8.6	+16.2	+26.4	+33.6	+36.9	+41.5	+46.6	+47.0	
6.0	496	-1.0			+3.2	+4.6	+6.9	+11.0	+20.2	+30.5	+38.4	+43.2	+46.0	+51.3	+52.0	
7.0	496	+2.0			+2.9	+5.7	+8.7	+13.2	+23.8	+36.4	+44.1	+49.3	+53.5	+60.3	+61.0	
8.0	496	+1.0			+3.7	+7.0	+9.9	+15.8	+27.7	+40.2	+48.2	+54.8	+59.5	+75.3	+76.0	
9.0	496	-1.0			+4.3	+6.0	+10.5	+17.6	+30.9	+44.3	+55.4	+59.5	+65.5	+81.3	+82.0	
10.0	496	-3.0			+3.9	+6.6	+11.5	+20.1	+35.4	+50.0	+60.8	+67.6	+73.0	+79.3	+80.0	
11.0	496	+3.0				+8.1	+12.9	+21.2	+38.5	+54.6	+68.0	+72.1	+76.0	+96.3	+97.0	
12.0	496	+2.0			+7.2	+10.3	+15.9	+25.1	+42.0	+57.0	+67.5	+72.8	+76.5	+86.3	+87.0	
13.0	496	+10.0			+12.9	+17.0	+19.6	+27.5	+42.0	+55.5	+66.1	+72.3	+75.0	+80.3	+81.0	
14.0	496	+10.0			+13.4	+17.4	+20.5	+27.1	+38.6	+52.8	+63.7	+69.7	+71.5	+86.3	+87.0	
15.0	496	+11.0			+15.4	+16.5	+19.2	+24.7	+34.5	+46.4	+56.3	+62.1	+69.3	+78.3	+79.0	
16.0	496	+5.0			+10.9	+12.4	+16.2	+21.4	+29.8	+40.0	+47.0	+51.9	+57.0	+66.3	+67.0	
17.0	496	+2.0			+7.9	+9.8	+11.4	+15.9	+23.5	+33.1	+40.7	+44.6	+48.0	+56.3	+57.0	
18.0	496	-1.0			-0.0	+5.5	+6.9	+10.4	+16.8	+24.1	+32.6	+39.2	+42.0	+45.3	+46.0	
19.0	496	-5.0			-2.0	-0.2	+1.4	+5.4	+11.3	+18.3	+26.8	+32.3	+37.0	+50.3	+51.0	
20.0	496	-8.0			-4.6	-3.3	-1.5	+0.9	+7.1	+13.4	+20.8	+25.4	+27.6	+40.3	+41.0	
21.0	496	-15.0			-9.6	-7.8	-4.4	-0.7	+4.6	+11.7	+19.2	+21.8	+24.0	+35.3	+36.0	
22.0	496	-27.0			-17.0	-10.4	-7.4	-2.6	+3.2	+10.3	+17.6	+24.6	+30.0	+45.3	+46.0	
23.0	496	-19.0			-14.5	-12.1	-9.3	-4.5	+2.2	+10.3	+19.1	+25.3	+32.0	+37.3	+38.0	
24.0	496	-24.0			-19.0	-14.8	-10.9	-6.0	+1.7	+11.1	+15.3	+25.3	+29.0	+40.3	+41.0	
25.0	496	-23.0			-16.5	-13.6	-10.7	-5.7	+2.4	+12.5	+20.8	+24.7	+30.0	+38.3	+39.0	
26.0	496	-25.0			-19.0	-16.3	-12.6	-6.3	+2.6	+15.0	+25.1	+32.3	+37.0	+49.3	+50.0	
27.0	496	-31.0			-24.0	-19.6	-15.7	-8.0	+2.7	+17.2	+28.4	+36.6	+39.5	+51.3	+52.0	
28.0	43	-36.0					-17.8	-14.0	-1.1	+11.0	+15.9	+36.0	+36.5	+36.9	+37.0	
29.0	42	-23.0					-19.8	-12.3	+0.0	+15.1	+25.9	+36.0	+36.5	+36.9	+37.0	
30.0	43	-49.0					-26.8	-17.1	-2.4	+11.0	+25.8	+42.0	+42.5	+42.9	+43.0	
31.0	41	-43.0					-29.9	-22.4	-0.4	+18.2	+26.9	+35.0	+35.5	+35.9	+36.0	
32.0	41	-41.0					-29.9	-21.4	-0.4	+16.4	+35.9	+50.0	+50.5	+50.9	+51.0	
33.0	43	-37.0					-35.8	-27.1	+3.5	+24.5	+46.8	+47.5	+47.7	+47.9	+48.0	
34.0	41	-47.0					-43.9	-26.4	+3.5	+27.4	+42.9	+47.0	+47.5	+47.9	+48.0	
35.0	42	-52.0					-48.4	-34.3	+5.5	+34.1	+41.9	+48.0	+48.5	+48.9	+49.0	
36.0	40	-62.0					-49.0	-40.6	+5.0	+31.3	+48.0	+49.0	+49.5	+49.9	+50.0	
37.0	40	-67.0					-63.0	-32.6	+5.5	+32.8	+46.0	+46.5	+46.7	+46.9	+47.0	
38.0	35	-69.0					-60.6	-46.4	+15.5	+36.4	+44.6	+47.2	+47.6	+47.9	+48.0	
39.0	42	-62.0					-57.8	-20.3	+22.0	+40.3	+45.9	+47.0	+47.5	+47.9	+48.0	
40.0	42	-60.0					-56.8	-18.6	+25.0	+39.6	+44.9	+51.0	+51.5	+51.9	+52.0	
41.0	43	-59.0					-56.8	-18.1	+26.5	+41.1	+47.9	+61.0	+61.5	+61.9	+62.0	
42.0	43	-60.0					-52.8	-26.0	+18.7	+45.1	+55.8	+62.0	+62.5	+62.9	+63.0	
43.0	42	-62.0					-56.8	-23.3	+18.0	+44.3	+55.9	+61.0	+61.5	+61.9	+62.0	
44.0	39	-59.0						-17.7	+27.1	+48.7	+59.0	+59.5	+59.8	+59.9	+60.0	
45.0	39	-58.0					-52.0	-20.7	+23.5	+52.7	+60.0	+63.1	+63.6	+63.9	+64.0	
46.0	39	-56.0					-50.0	-17.8	+27.7	+53.8	+70.0	+75.1	+75.6	+75.9	+76.0	
47.0	36	-49.0					47.1	-13.2	+27.5	+55.7	+63.1	+68.1	+68.6	+68.9	+69.0	
48.0	37	-53.0					-35.1	-14.5	+28.5	+51.5	+63.5	+65.1	+65.6	+65.9	+66.0	
49.0	36	-52.0					-49.1	-20.2	+31.0	+51.6	+60.7	+70.1	+70.6	+70.9	+71.0	
50.0	33	-53.0					-39.3	-16.7	+32.5	+49.3	+61.1	+61.6	+61.8	+61.9	+62.0	
51.0	33	-36.0					-28.3	-6.7	+27.7	+56.2	+65.3	+68.2	+68.6	+68.9	+69.0	
52.0	29	-31.0					-25.5	-3.3	+29.5	+55.3	+64.5	+65.3	+65.7	+65.9	+66.0	
53.0	32	-30.0					-26.3	-0.9	+31.0	+48.9	+58.6	+65.2	+65.6	+65.9	+66.0	
54.0	29	-30.0					-28.5	-15.3	+37.5	+55.6	+63.5	+67.3	+67.7	+67.9	+68.0	
55.0	30	-14.0					-11.5	-2.2	+41.0	+53.6	+66.5	+71.3	+71.6	+71.9	+72.0	
56.0	28	-10.0					-0.5	+8.2	+37.0	+59.2	+62.5	+75.3	+75.7	+75.9	+76.0	
57.0	26	-5.0						+7.1	+44.0	+59.8	+70.6	+77.4	+77.7	+77.9	+78.0	
58.0	23	+0.0						+15.6	+39.5	+69.1	+71.8	+75.4	+75.7	+75.9	+76.0	
59.0	20	-7.0						+14.1	+42.0	+68.8	+78.0	+78.5	+78.7	+78.9	+79.0	
60.0	12	-7.0						+13.9	+28.0	+70.0	+74.3	+74.7	+74.8	+74.9	+75.0	

Notes: From Memo No. R-AERO-Y-118-66
Positive (+) is wind from the tail (225°)
Negative (-) is wind from the head (75°)
Blank spaces of missing data at low percentile levels are due to an insufficient number of observations at that altitude. For example, at least 20 observations are required to produce a value at the fifth percentile.

TABLE 5.3.14C HEAD AND TAIL WIND COMPONENTS FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 75-DEGREE FLIGHT AZIMUTH — FEBRUARY

DATA SOURCE

FEBRUARY

TYPE OF DATA	ELEVATION RANGE	STATION	ELEVATION MSL (meters)	LOCATION		PERIOD OF DATA
				LATITUDE	LONGITUDE	
SERIAL COMPLETED RAWINSONDE	0 to 27 km	PATRICK AFB, FLORIDA	7	28° 14' N	80° 36' W	JAN. 1, 1956 to NOV. 17, 1956
SERIAL COMPLETED RAWINSONDE	0 to 27 km	CAPE KENNEDY, FLORIDA	5	28° 29' N	80° 33' W	NOV. 18, 1956 to DEC. 31, 1963
ROCKETSONDE	28 km up	CAPE KENNEDY, FLORIDA	5	28° 29' N	80° 33' W	JAN. 1957 to OCT. 1964

EASTERN TEST RANGE (CAPE KENNEDY, FLORIDA)

PREPARED BY : TERRESTRIAL ENVIRONMENT BRANCH, AEROSPACE ENVIRONMENT DIVISION, AERO-ASTRODYNAMICS LABORATORY GEORGE C. MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

Wind Speed in m s^{-1}

ALT. (KM)	NUM ØBS	MIN SPEED	DIR (DEG)	0.135	1.000	2.280	5.000	15.900	50.000	84.100	95.000	97.720	99.000	99.865	MAX SPEED	DIR (DEG)
				CUMULATIVE PERCENTAGE FREQUENCY												
SFC	452	-3.0			-7.2	-6.2	-4.5	-2.5	-0.3	+2.7	+5.4	+7.1	+8.1	+10.3	+11.0	
1.0	452	-12.0			-11.3	-9.1	-6.9	-2.3	+3.0	+9.6	+16.1	+17.7	+21.4	+23.6	+24.0	
2.0	452	-9.0			-8.6	-5.5	-2.3	-0.0	+6.1	+14.4	+20.2	+23.2	+26.7	+30.3	+31.0	
3.0	452	-5.0			-4.1	-2.9	-0.9	+2.6	+9.2	+18.5	+25.5	+29.8	+33.1	+35.3	+36.0	
4.0	452	-3.0			-2.6	-0.8	+0.4	+4.6	+11.6	+23.2	+29.8	+33.9	+38.4	+46.3	+47.0	
5.0	452	-5.0			-0.8	-0.3	+1.7	+6.5	+15.0	+27.3	+34.1	+38.5	+47.4	+60.3	+61.0	
6.0	452	-3.0			-0.9	-0.0	+3.0	+8.4	+18.7	+32.5	+41.0	+44.5	+50.4	+66.3	+67.0	
7.0	452	-7.0			-0.8	+1.6	+4.3	+9.7	+22.3	+37.0	+48.0	+52.8	+65.2	+78.3	+79.0	
8.0	452	-10.0			-0.4	+2.4	+5.3	+11.9	+25.4	+41.8	+54.7	+60.5	+73.4	+87.3	+88.0	
9.0	452	-15.0			-5.4	+0.7	+5.5	+13.1	+29.6	+47.7	+61.2	+67.6	+79.4	+88.3	+89.0	
10.0	452	-14.0			-6.2	-0.3	+6.2	+14.1	+34.3	+54.1	+67.4	+71.9	+76.1	+90.3	+91.0	
11.0	452	-17.0			-5.7	+3.4	+7.7	+16.0	+37.1	+58.0	+73.4	+80.8	+85.4	+93.3	+94.0	
12.0	452	-6.0			-0.4	+5.6	+11.2	+18.9	+39.7	+59.8	+76.1	+86.8	+90.2	+96.3	+97.0	
13.0	452	-3.0			+7.2	+10.3	+15.4	+20.8	+38.1	+58.6	+74.8	+82.3	+85.7	+97.3	+98.0	
14.0	452	-5.0			+6.5	+11.4	+15.5	+21.6	+36.6	+54.5	+62.8	+70.6	+81.1	+82.3	+83.0	
15.0	452	+2.0			+7.5	+10.3	+13.3	+19.4	+31.7	+46.0	+56.3	+59.8	+64.8	+70.3	+71.0	
16.0	452	-2.0			+6.2	+9.3	+11.3	+16.9	+27.3	+39.3	+47.8	+51.9	+55.8	+64.3	+65.0	
17.0	452	-11.0			+1.5	+4.6	+8.0	+12.7	+21.9	+32.1	+40.0	+42.6	+44.8	+56.3	+57.0	
18.0	452	-3.0			-2.4	+0.3	+2.7	+8.0	+15.2	+24.4	+31.6	+36.2	+40.2	+49.3	+50.0	
19.0	452	-9.0			-1.7	-0.9	-0.0	+2.7	+8.9	+17.9	+26.1	+29.8	+31.8	+46.3	+47.0	
20.0	452	-12.0			-10.1	-7.3	-5.0	-1.0	+4.5	+12.9	+19.1	+23.4	+26.4	+40.3	+41.0	
21.0	452	-15.0			-11.7	-9.9	-8.0	-3.2	+1.6	+8.8	+15.2	+18.8	+25.2	+28.3	+29.0	
22.0	452	-25.0			-15.4	-11.9	-11.0	-4.8	+0.1	+7.1	+11.8	+14.7	+19.4	+35.3	+36.0	
23.0	452	-30.0			-16.4	-13.5	-11.5	-6.0	-0.1	+5.8	+12.1	+15.2	+17.7	+22.3	+23.0	
24.0	452	-22.0			-20.4	-15.8	-12.5	-5.8	-0.0	+5.8	+11.2	+12.6	+16.2	+18.3	+19.0	
25.0	452	-26.0			-20.7	-15.9	-13.4	-7.1	-0.1	+6.5	+10.4	+12.7	+14.7	+24.3	+25.0	
26.0	452	-35.0			-22.2	-18.3	-14.3	-7.2	+0.5	+6.6	+11.6	+13.9	+14.9	+27.3	+28.0	
27.0	452	-45.0			-23.7	-20.2	-13.7	-7.8	+1.2	+7.2	+11.7	+13.8	+16.4	+23.6	+24.0	
28.0	14	-13.0						-4.7	+3.0	+9.3	+13.3	+13.6	+13.8	+13.9	+14.0	
29.0	14	-16.0						-8.7	+5.0	+8.8	+16.2	+16.6	+16.8	+16.9	+17.0	
30.0	14	-18.0						-8.7	+0.0	+8.7	+22.2	+22.6	+22.8	+22.9	+23.0	
31.0	17	-15.0						-5.2	+2.2	+16.2	+45.1	+45.6	+45.8	+45.9	+46.0	
32.0	19	-18.0						-4.9	+7.5	+18.6	+45.0	+45.5	+45.8	+45.9	+46.0	
33.0	21	-17.0					-10.9	-0.8	+8.5	+18.6	+47.9	+59.5	+59.7	+59.9	+60.0	
34.0	21	-12.0					-11.9	-0.6	+11.7	+28.6	+40.9	+42.5	+42.7	+42.9	+43.0	
35.0	23	-20.0					-18.8	-13.3	+12.5	+23.7	+37.8	+40.4	+40.7	+40.9	+41.0	
36.0	25	-27.0						-0.0	+12.7	+25.0	+36.7	+38.4	+38.7	+38.9	+39.0	
37.0	22	-27.0					-20.8	-2.5	+16.0	+24.7	+28.9	+33.4	+33.7	+33.9	+34.0	
38.0	18	-27.0						-3.1	+19.0	+32.1	+35.0	+35.5	+35.8	+35.9	+36.0	
39.0	24	-26.0					-17.7	-0.7	+20.0	+33.1	+37.3	+37.7	+37.8	+37.9	+38.0	
40.0	25	-30.0					-29.7	+1.9	+23.7	+34.0	+37.7	+68.4	+68.7	+68.9	+69.0	
41.0	26	-44.0					-24.6	-0.8	+22.0	+34.8	+47.6	+64.4	+64.7	+64.9	+65.0	
42.0	26	-36.0					-34.6	+0.5	+22.0	+36.7	+50.6	+64.4	+64.7	+64.9	+65.0	
43.0	25	-35.0					-21.7	-0.0	+21.5	+42.0	+48.7	+65.4	+65.7	+65.9	+66.0	
44.0	27	-44.0					-23.6	+3.2	+26.7	+41.7	+48.6	+71.3	+71.7	+71.9	+72.0	
45.0	26	-33.0						+6.1	+25.5	+41.8	+50.6	+72.4	+72.7	+72.9	+73.0	
46.0	25	-35.0					-10.7	+3.9	+27.2	+40.0	+50.7	+52.4	+52.7	+52.9	+53.0	
47.0	24	-49.0					-16.7	+2.8	+28.0	+36.5	+57.7	+72.4	+72.7	+72.9	+73.0	
48.0	23	-37.0					-3.8	+13.6	+29.7	+42.3	+60.8	+68.4	+68.7	+68.9	+69.0	
49.0	22	-38.0					-3.8	+15.4	+31.0	+43.5	+61.9	+72.4	+72.7	+72.9	+73.0	
50.0	22	-23.0					+3.0	+15.4	+31.0	+39.8	+54.9	+77.4	+77.7	+77.9	+78.0	
51.0	22	-30.0					+7.0	+15.4	+35.0	+44.5	+50.9	+76.4	+76.7	+76.9	+77.0	
52.0	22	-24.0					+8.0	+21.4	+35.0	+47.2	+49.9	+65.4	+65.7	+65.9	+66.0	
53.0	21	-30.0					+12.0	+26.3	+39.5	+49.8	+56.9	+67.5	+67.7	+67.9	+68.0	
54.0	19	-35.0						+33.0	+43.5	+49.9	+74.0	+74.5	+74.8	+74.9	+75.0	
55.0	18	-38.0						+25.8	+44.0	+52.1	+74.0	+74.5	+74.8	+74.9	+75.0	
56.0	16	-43.0						+35.2	+47.0	+57.2	+75.1	+75.6	+75.8	+75.9	+76.0	
57.0	14	-37.0						+40.2	+49.5	+57.7	+68.2	+68.6	+68.8	+68.9	+69.0	
58.0	14	-53.0						+44.2	+51.5	+64.3	+76.2	+76.6	+76.8	+76.9	+77.0	
59.0	12	-47.0						+26.9	+52.0	+68.0	+68.6	+68.8	+68.9	+68.9	+69.0	
60.0	10	-50.0						+24.5	+47.5	+65.4	+69.5	+69.7	+69.8	+69.9	+70.0	

Notes: From Memo No. R-AERO-Y-118-66
Positive (+) is wind from the tail (225°)
Negative (-) is wind from the head (75°)
Blank spaces of missing data at low percentile levels are due to an insufficient number of observations at that altitude. For example, at least 20 observations are required to produce a value at the fifth percentile.

TABLE 5.3.14D HEAD AND TAIL WIND COMPONENTS FOR CAPE KENNEDY (ETR), FLORIDA, FOR A 75-DEGREE FLIGHT AZIMUTH — MARCH

DATA SOURCE							MARCH
TYPE OF DATA	ELEVATION RANGE	STATION	ELEVATION MSL (meters)	LOCATION LATITUDE	LOCATION LONGITUDE	PERIOD OF DATA	EASTERN TEST RANGE (CAPE KENNEDY, FLORIDA)
SERIAL COMPLETED RAWINSONDE	0 to 27 km	PATRICK AFB, FLORIDA	7	28° 14' N	80° 36' W	JAN. 1, 1956 to NOV. 17, 1956	
SERIAL COMPLETED RAWINSONDE	0 to 27 km	CAPE KENNEDY, FLORIDA	5	28° 29' N	80° 33' W	NOV. 18, 1956 to DEC. 31, 1963	
ROCKETSONDE	28 km up	CAPE KENNEDY, FLORIDA	5	28° 29' N	80° 33' W	JAN. 1957 to OCT. 1964	

PREPARED BY : TERRESTRIAL ENVIRONMENT BRANCH, AEROSPACE ENVIRONMENT DIVISION, AERO-ASTRODYNAMICS LABORATORY GEORGE C. MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

CUMULATIVE PERCENTAGE FREQUENCY — Wind Speed in m s^{-1}

ALT. (KM)	NUM OBS	MIN SPEED	DIR (DEG)	0.135	1.000	2.280	5.000	15.900	50.000	84.100	95.000	97.720	99.000	99.865	MAX SPEED	DIR (DEG)
SFC	496	-10.0			-9.2	-5.6	-4.4	-2.6	-0.4	+2.2	+5.0	+6.6	+7.5	+9.6	+10.0	
1.0	496	-19.0			-14.0	-8.9	-6.5	-2.7	+2.6	+9.4	+15.2	+17.1	+18.7	+22.3	+23.0	
2.0	496	-13.0			-6.6	-3.9	-2.1	-0.0	+6.1	+13.7	+18.8	+21.2	+24.0	+33.3	+34.0	
3.0	496	-15.0			-3.0	-1.1	-0.1	+2.4	+9.2	+18.3	+23.5	+26.9	+30.5	+48.3	+49.0	
4.0	496	-14.0			-2.6	-0.6	+1.3	+5.0	+13.0	+21.9	+29.0	+33.6	+37.5	+49.3	+50.0	
5.0	496	-17.0			-2.0	+1.1	+3.6	+8.1	+16.8	+27.2	+34.3	+39.6	+43.6	+62.3	+63.0	
6.0	496	-20.0			-0.0	+3.3	+6.3	+10.9	+21.1	+30.7	+37.9	+42.8	+47.0	+63.3	+64.0	
7.0	496	-19.0			-0.0	+4.6	+8.1	+14.3	+24.7	+35.9	+43.8	+49.3	+54.0	+63.3	+64.0	
8.0	496	-20.0			-0.0	+6.6	+9.6	+17.6	+28.3	+40.5	+50.2	+55.2	+60.5	+66.3	+67.0	
9.0	496	-17.0			+0.9	+7.3	+11.6	+19.6	+32.3	+44.8	+56.7	+61.3	+71.0	+86.3	+87.0	
10.0	496	-18.0			+0.4	+9.0	+13.2	+22.4	+36.2	+50.1	+61.6	+69.8	+78.0	+89.3	+90.0	
11.0	496	-20.0			+2.4	+9.1	+14.6	+25.9	+39.5	+55.2	+64.7	+76.2	+85.0	+93.3	+94.0	
12.0	496	-12.0			+4.9	+11.3	+18.8	+28.9	+42.4	+57.9	+70.5	+77.6	+86.0	+103.3	+104.0	
13.0	496	-5.0			+10.9	+14.6	+21.2	+28.9	+43.0	+56.8	+66.2	+76.6	+83.0	+87.3	+88.0	
14.0	496	-2.0			+10.9	+16.6	+20.7	+27.5	+39.5	+51.5	+59.6	+65.6	+73.0	+78.3	+79.0	
15.0	496	+0.0			+10.9	+15.3	+18.2	+23.9	+34.0	+43.9	+53.6	+59.3	+65.5	+70.7	+71.0	
16.0	496	-4.0			+5.4	+9.4	+14.1	+18.8	+29.5	+36.9	+43.8	+48.2	+52.0	+67.3	+68.0	
17.0	496	-5.0			+2.4	+7.2	+9.3	+14.0	+23.3	+31.7	+37.5	+41.1	+44.0	+54.3	+55.0	
18.0	496	-2.0			+0.3	+2.1	+4.4	+8.7	+16.5	+24.4	+31.2	+34.3	+37.0	+45.3	+46.0	
19.0	496	-10.0			-5.6	-3.2	-0.4	+2.7	+8.7	+17.0	+23.5	+27.3	+30.5	+37.3	+38.0	
20.0	496	-13.0			-9.5	-7.4	-3.7	-0.3	+4.5	+12.0	+18.2	+22.6	+26.6	+33.3	+34.0	
21.0	496	-17.0			-14.0	-10.5	-7.7	-2.7	+1.7	+7.9	+12.5	+15.6	+17.5	+22.3	+23.0	
22.0	496	-32.0			-17.5	-10.4	-7.6	-3.8	-0.0	+5.4	+10.0	+13.9	+20.0	+43.3	+44.0	
23.0	496	-35.0			-18.6	-14.4	-9.0	-5.0	-0.7	+3.4	+7.8	+11.6	+17.0	+34.3	+35.0	
24.0	496	-33.0			-21.0	-16.8	-11.3	-5.7	-0.8	+3.6	+8.2	+10.9	+13.5	+16.3	+17.0	
25.0	496	-34.0			-26.0	-22.6	-12.6	-5.7	-0.5	+4.3	+9.5	+13.2	+18.3	+24.3	+25.0	
26.0	496	-35.0			-26.5	-20.3	-13.0	-5.3	-0.0	+5.7	+10.4	+13.6	+19.0	+29.3	+30.0	
27.0	496	-43.0			-32.0	-24.8	-15.7	-6.1	+0.1	+6.4	+9.9	+14.2	+20.5	+21.8	+22.0	
28.0	39	-29.0					-27.0	-7.9	-0.5	+6.1	+7.0	+15.1	+15.6	+15.9	+16.0	
29.0	40	-36.0					-25.0	-7.6	-0.1	+6.9	+11.0	+13.0	+13.6	+13.9	+14.0	
30.0	40	-29.0					-22.0	-5.8	-0.3	+8.1	+8.8	+18.0	+18.6	+18.9	+19.0	
31.0	40	-25.0					-23.0	-7.6	-0.3	+8.6	+18.0	+20.0	+20.6	+20.9	+21.0	
32.0	40	-27.0					-18.0	-6.3	+0.0	+12.6	+20.0	+22.0	+22.6	+22.9	+23.0	
33.0	41	-29.0					-11.9	-4.7	+2.5	+11.4	+12.9	+20.0	+20.5	+20.9	+21.0	
34.0	41	-32.0					-9.9	-4.4	+3.5	+9.6	+15.9	+17.5	+17.7	+17.9	+18.0	
35.0	43	-37.0					-11.0	-3.8	+5.0	+11.8	+16.0	+26.0	+26.6	+26.9	+27.0	
36.0	41	-40.0					-10.9	-6.2	+4.7	+13.7	+17.4	+23.0	+23.5	+23.9	+24.0	
37.0	39	-39.0					-19.0	-5.8	+6.5	+13.7	+21.0	+28.1	+28.6	+28.9	+29.0	
38.0	36	-41.0					-19.1	-4.2	+9.0	+20.2	+26.5	+38.1	+38.6	+38.9	+39.0	
39.0	41	-46.0					-14.4	-1.7	+6.8	+20.4	+22.9	+26.5	+26.7	+26.9	+27.0	
40.0	43	-51.0					-16.0	-2.8	+13.0	+19.3	+24.0	+42.0	+42.5	+42.9	+43.0	
41.0	43	-43.0					-14.8	-3.5	+12.5	+22.5	+29.8	+38.0	+38.5	+38.9	+39.0	
42.0	42	-31.0					-14.8	-9.1	+11.0	+24.5	+34.9	+39.5	+39.7	+39.9	+40.0	
43.0	42	-15.0					-13.8	-8.3	+10.0	+26.3	+33.9	+43.0	+43.5	+43.9	+44.0	
44.0	42	-20.0					-12.8	-8.1	+14.0	+27.3	+31.9	+42.0	+42.5	+42.9	+43.0	
45.0	42	-18.0					-14.8	-6.3	+10.0	+26.3	+38.9	+42.0	+42.5	+42.9	+43.0	
46.0	40	-12.0					-8.5	-1.3	+13.0	+28.6	+40.5	+41.0	+41.5	+41.9	+42.0	
47.0	41	-13.0					-8.9	-2.4	+17.5	+34.4	+43.4	+87.0	+87.5	+87.9	+88.0	
48.0	40	-6.0					-5.0	+2.3	+17.0	+32.6	+43.0	+81.0	+81.5	+81.9	+82.0	
49.0	39	-6.0					-4.0	+2.2	+20.2	+35.8	+42.5	+81.1	+81.6	+81.9	+82.0	
50.0	40	-2.0						+8.3	+19.5	+35.8	+46.0	+78.0	+78.5	+78.9	+79.0	
51.0	40	-9.0					-2.0	+5.3	+19.3	+33.8	+47.0	+77.0	+77.5	+77.9	+78.0	
52.0	38	-6.0					-2.0	+1.0	+18.0	+33.9	+45.0	+78.1	+78.6	+78.9	+79.0	
53.0	38	-6.0					-3.0	+1.3	+19.0	+36.4	+49.5	+76.1	+76.6	+76.9	+77.0	
54.0	32	-9.0					-6.3	+6.0	+19.6	+31.9	+48.4	+63.2	+63.6	+63.9	+64.0	
55.0	31	-10.0					-5.4	+4.4	+20.5	+40.0	+53.4	+59.2	+59.6	+59.9	+60.0	
56.0	29	-7.0					+2.4	+4.6	+21.8	+41.3	+48.5	+62.3	+62.7	+62.9	+63.0	
57.0	27	+7.0						+9.6	+22.5	+39.8	+63.6	+68.3	+68.7	+68.9	+69.0	
58.0	25	+0.0					+3.2	+6.9	+25.2	+43.0	+62.7	+64.4	+64.7	+64.9	+65.0	
59.0	27	+3.0						+14.1	+29.0	+44.8	+60.0	+60.5	+60.7	+60.9	+61.0	
60.0	15	-1.0						+10.3	+30.5	+51.6	+56.2	+56.6	+56.8	+56.9	+57.0	

Notes: From Memo No. R-AERO-Y-118-66
Positive (+) is wind from the tail (225°)
Negative (-) is wind from the head (75°)
Blank spaces of missing data at low percentile levels are due to an insufficient number of observations at that altitude. For example, at least 20 observations are required to produce a value at the fifth percentile.

TABLE 5.3.15 DESIGN SCALAR WIND SPEED PROFILE ENVELOPES (steady-state) FOR THE EASTERN TEST RANGE

Geometric Altitude (km)	Wind Speed (ms^{-1}) for Various Percentiles				
	Percentile				
	50	75	90	95	99
1	10	14	18	21	27
10	47	57	68	75	97
14	47	57	68	75	97
20	16	18	22	25	40
23	16	18	22	25	40
60	93	107	119	126	140
80	93	107	119	126	140

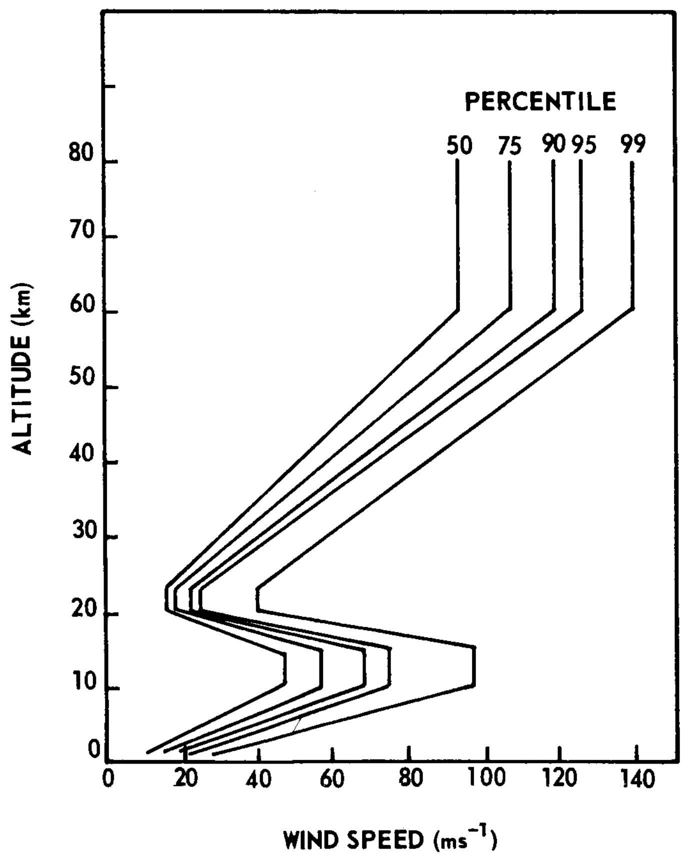


FIGURE 5.3.6 DESIGN SCALAR WIND SPEED PROFILE ENVELOPES (steady-state) FOR THE EASTERN TEST RANGE

TABLE 5.3.16 DESIGN SCALAR WIND SPEED PROFILE ENVELOPES (steady-state) FOR WESTERN TEST RANGE

Geometric Altitude (km)	Wind Speed (ms^{-1}) for Various Percentiles				
	Percentile				
	50	75	90	95	99
1	12	16	19	22	28
9					80
10		46	60	68	
11	34				
13	34	46	60	68	80
19	10	13	17	21	27
23	10	13	17	21	27
60	95	113	126	134	150
80	95	113	126	134	150

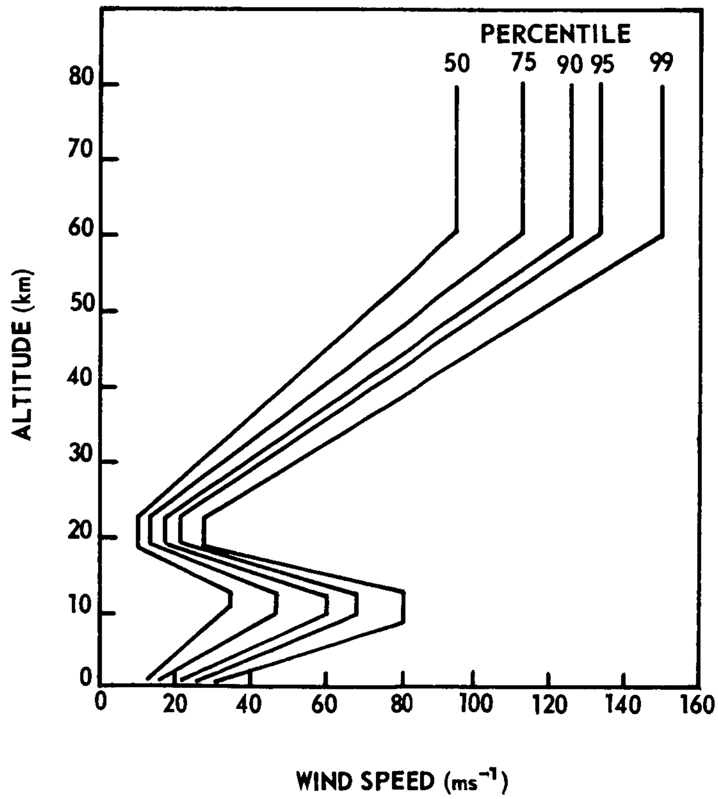


FIGURE 5.3.7. DESIGN SCALAR WIND SPEED PROFILE ENVELOPES (steady-state) FOR WESTERN TEST RANGE

TABLE 5.3.17 DESIGN SCALAR WIND SPEED PROFILE ENVELOPES (steady-state) FOR WALLOPS TEST RANGE

Geometric Altitude (km)	Wind Speed (ms^{-1}) for Various Percentiles				
	Percentile				
	50	75	90	95	99
1	11	15	20	24	30
9.5	44	56	67	75	88
10.5	44	56	67	75	88
20	10	20	26	30	33
23	10	20	26	30	33
53	102	119	134	142	158
80	102	119	134	142	158

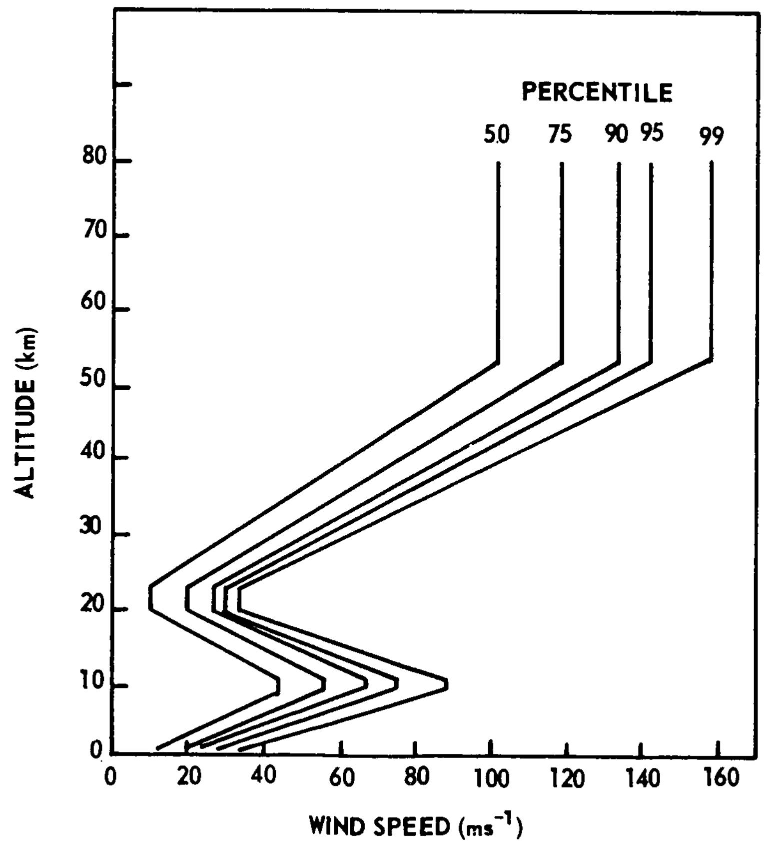


FIGURE 5.3.8. DESIGN SCALAR WIND SPEED PROFILE ENVELOPES (steady-state) FOR WALLOPS TEST RANGE

TABLE 5.3.18 DESIGN SCALAR WIND SPEED PROFILE ENVELOPES (steady-state) FOR WHITE SANDS MISSILE RANGE

Geometric Altitude (km)	Wind Speed (ms^{-1}) for Various Percentiles				
	Percentile				
	50	75	90	95	99
2.5	7	11	14	20	28
11	42	55	71	79	86
13	42	55	71	79	86
19	11	15	19	25	31
23	11	15	19	25	31
50	95	115	128	135	150
80	95	115	128	135	150

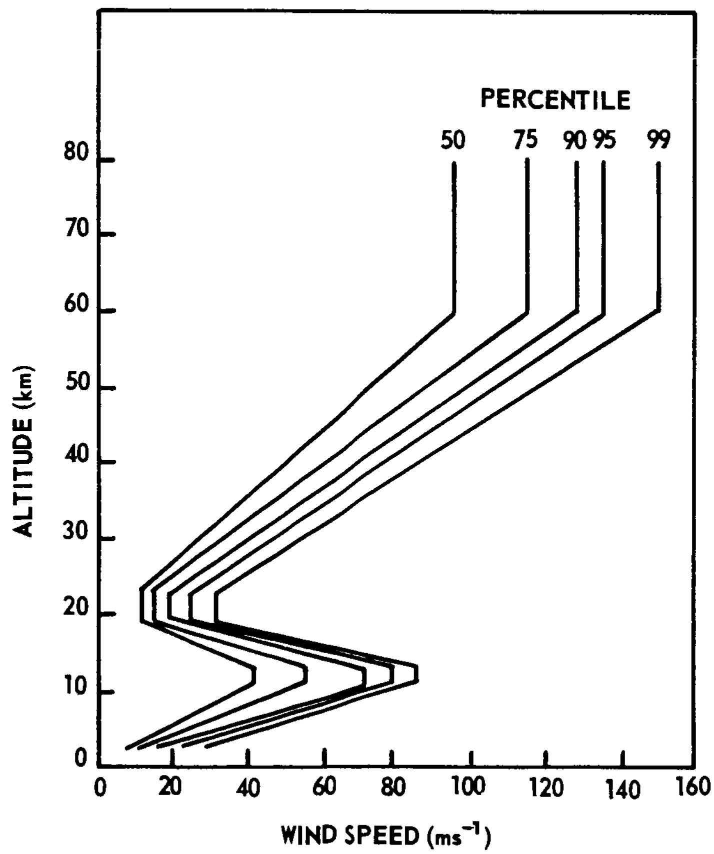


FIGURE 5.3.9. DESIGN SCALAR WIND SPEED PROFILE ENVELOPES (steady-state) FOR WHITE SANDS MISSILE RANGE

to give the envelope of the annual data. The profiles represent horizontal wind flow, referenced to the earth's surface. Vertical wind flow is negligible except as represented in the gust or turbulence considerations. These speeds are normally applied without regard to flight directions to establish the initial design requirements. Directional wind criteria for use with the synthetic wind profile techniques should be applied with care and specific knowledge of the vehicle mission and flight path, since severe wind constraints could result for other flight paths and missions. This section provides design nondirectional wind data for various percentiles; therefore, the specific percentile wind speed envelope applicable to design should be specified in the appropriate space vehicle specification documentation. For engineering convenience the design wind speed profile envelopes are given as linear segments between altitude levels; therefore, the tabular values would be connected, when graphed, by straight lines between the points.

The sources of the data used to prepare the design wind profiles are given in Table 5.3.19.

TABLE 5.3.19 SOURCE OF DATA FOR DESIGN WIND PROFILE ENVELOPES

Station	0 to 30 Kilometers Standard Rawinsonde	Above 30 Kilometers Standard Rocketsonde
Cape Kennedy, Fla. (Eastern Test Range)	Twice Daily Serial Complete Data	Conventional Data
Santa Monica, Calif.* (Western Test Range)	Four Times Daily Serial Complete Data	Conventional Data
Wallops Island, Va. (Wallops Test Range)	Daily Serial Complete Data	Conventional Data
El Paso, Texas* (White Sands Missile Range, New Mexico)	Conventional Data	Conventional Data

* Representative locations for WTR launch and WSMR site.

5.3.7 Wind Speed Change (Shear) Envelopes.

This section provides representative information on scalar wind speed change (shear) for scales-of-distances between 100 and 5000 meters and vector wind speed change (shear) for scale-of-distances between 1000 and 5000 meters. Vector wind speed change is defined as the magnitude of the vector difference in the wind velocities between the top and the bottom of a specified layer, while the scalar change is the total magnitude (speed) change for the same layer, regardless of wind direction. Wind shear is the wind speed change divided by the altitude interval. Values of wind speed change applied to space vehicle criteria are referred to as wind buildup rates. The term wind backoff must also be introduced in conjunction with wind buildup. Both terms refer to changes in wind speed either above (backoff) or below (buildup) any altitude level where an initial wind speed is known. Thus a buildup wind value is the change in wind speed experienced while ascending vertically through a specified layer to the known altitude. Backoff magnitudes describe the decrease in wind speed above the chosen level. Vector buildup and backoff wind speed change data are presented in this section along with scalar data. Wind buildup may be determined for a vehicle with other than a vertical flight path by multiplying the wind speed change by the cosine of the angle between the vertical axis and the vehicle trajectory.

An envelope of the 99 percentile scalar buildup wind is used currently in constructing synthetic wind profiles. For most design studies, the continued use of this 99 percentile scalar buildup wind shear data is still warranted. The other envelopes for backoff shears and for vector shears have application to certain design studies and should be considered where appropriate. These envelopes are not meant to imply perfect correlation between shears for the various scales-of-distance; however, certain correlations do exist, depending upon the scale-of-distance and the wind speed magnitude considered. This method of describing the wind shear for vehicle design has proven acceptable since the dynamic response of the vehicle's structure or control system in these various modes is essentially influenced by specific wave lengths as represented by a given wind shear.

Wind speed change (shear) statistics for the various locations vary somewhat partly because of data sample size, accuracy of basic data, prevailing meteorological conditions, and orographic features. For the purpose of this engineering document, the data presented will be considered representative of all locations. In addition to revised scalar buildup data, curves of scalar backoff, vector buildup, and vector backoff rates are also presented. Most of the data that appear in Figures 5.3.10 through 5.3.13

and Tables 5.3.20 through 5.3.23 resulted from recent studies of the wind speed changes in the 0- to 27-kilometer region over Cape Kennedy, Florida, and Santa Monica, California. Until additional studies are made using FPS-16/ Jimsphere wind data, the vector buildup and vector backup data for scales-of-distances less than 1000 meters cannot be adequately defined for this document. Some pertinent conclusions from these analyses are as follows:

a. Vector buildup and vector backoff wind speed changes are higher than corresponding scalar differences.

b. The Kennedy Space Center wind sample contains higher speed values than data measured at Santa Monica.

c. Vector and scalar buildup winds tend to be of greater magnitude at Santa Monica than respective values at Kennedy Space Center.

d. Vector and scalar backoff wind speed changes at Kennedy Space Center are generally greater than respective buildup values.

e. The jet stream region (usually within 10- to 15-km) contributes most of the high wind speeds and wind speed changes in the data sample.

In view of the significant differences often found between vector and scalar wind statistics, as well as in buildup and backoff changes, the user of such data should determine what type of information is most applicable to a particular problem. Assistance on this effort is available upon consultation with Aerospace Environment Division personnel.

Studies by Camp and Susko (Ref. 5.44) and Camp and Fox (Ref. 5.45) provide extensive information on probabilities of occurrence of various time dependent wind changes when the month, altitude layer, and initial wind speed and direction are known.

In this revision, the variation of shears is considered with respect to scale-of-distance and wind magnitude. Although the values of shear were also divided with respect to altitude in the previous document (Ref. 5.46), the higher altitude shears were for higher wind speeds, and therefore they were consider to be an extension of the wind magnitude variation. Reference 5.46 further substantiates that the shear data presented in this document are valid for higher altitudes.

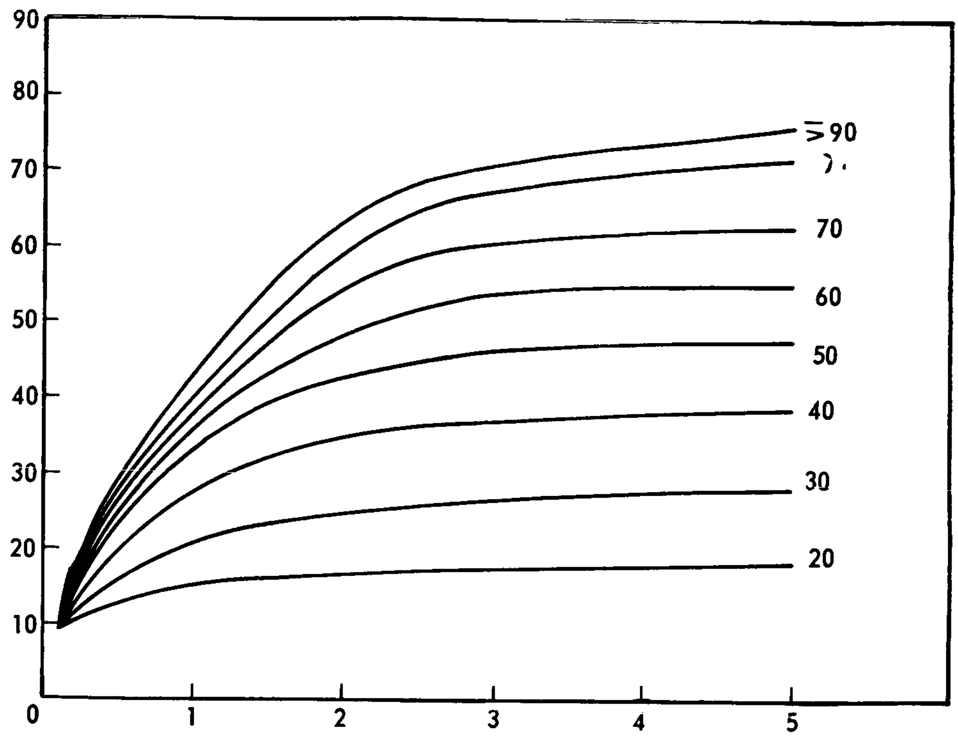


FIGURE 5.3.10 IDEALIZED ENVELOPES* OF 99 PERCENTILE SCALAR BUILDUP WIND SPEED CHANGE FOR VARIOUS SCALES-OF-DISTANCE AND CORRESPONDING WIND SPEEDS AT THE TOP OF THE LAYER IN THE 1- TO 80-KILOMETER ALTITUDE REGION FOR ALL LOCATIONS

TABLE 5.3.20 IDEALIZED ENVELOPES* OF 99 PERCENTILE SCALAR BUILDUP WIND SPEED CHANGE FOR VARIOUS SCALES-OF-DISTANCE AND CORRESPONDING WIND SPEEDS AT THE TOP OF THE LAYER IN THE 1- TO 80-KILOMETER ALTITUDE REGION FOR ALL LOCATIONS

Wind Speed at Top of Altitude Layer (ms^{-1})	Wind Speed Change (ms^{-1}) for Various Scales-of-Distance									
	Scales-of-Distance (m)									
	5000	4000	3000	2000	1000	800	600	400	200	100
≥ 90	75.8	73.1	70.5	62.9	43.0	37.5	32.0	26.3	18.5	9.0
80	70.7	69.5	67.0	58.8	40.4	35.5	30.3	24.7	17.0	9.0
70	62.2	61.6	60.4	54.4	38.2	33.7	29.0	23.2	15.5	9.0
60	55.0	54.5	53.5	48.0	35.7	32.1	27.3	21.8	14.4	9.0
50	47.4	46.8	45.9	42.5	33.4	30.0	25.5	20.0	13.5	9.0
40	38.5	37.7	36.8	34.9	27.8	24.8	21.2	17.1	12.1	9.0
30	28.0	27.5	26.5	24.5	20.8	19.2	17.2	14.5	11.2	9.0
20	18.5	17.8	17.5	16.7	15.4	14.4	13.3	11.8	10.0	9.0

* RECOMMENDED FOR DESIGN APPLICATIONS.

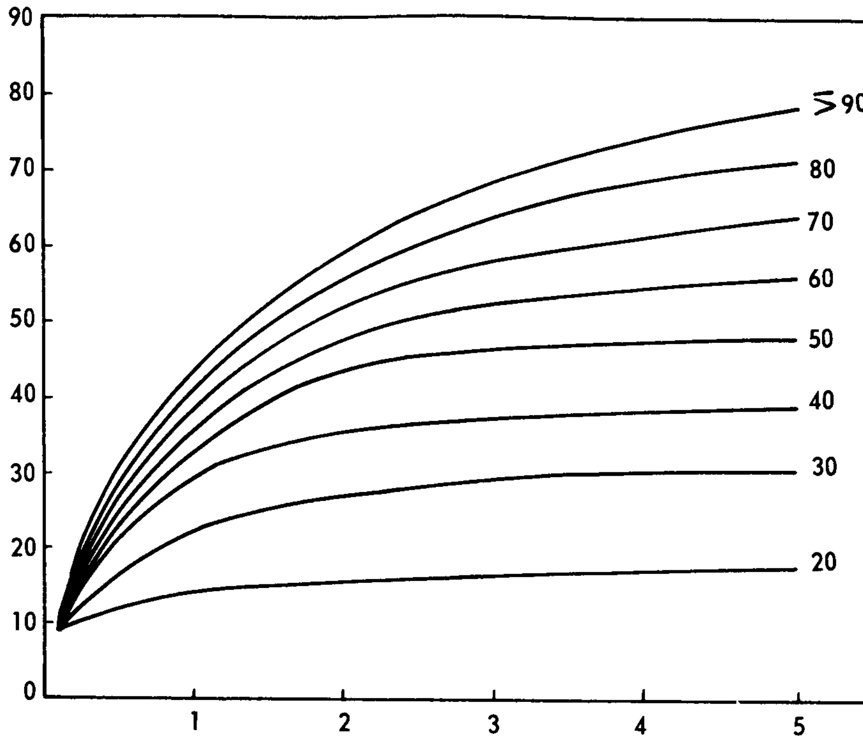


FIGURE 5.3.11 IDEALIZED ENVELOPES* OF 99 PERCENTILE SCALAR BACKOFF WIND SPEED CHANGE FOR VARIOUS SCALES-OF-DISTANCE AND CORRESPONDING WIND SPEEDS AT THE BOTTOM OF THE LAYER IN THE 1- TO 80-KILOMETER ALTITUDE REGION FOR ALL LOCATIONS

TABLE 5.3.21 IDEALIZED ENVELOPES* OF 99 PERCENTILE SCALAR BACKOFF WIND SPEED CHANGE FOR VARIOUS SCALES-OF-DISTANCE AND CORRESPONDING WIND SPEEDS AT THE BOTTOM OF THE LAYER IN THE 1- TO 80-KILOMETER ALTITUDE REGION FOR ALL LOCATIONS

Wind Speed at Top of Altitude Layer (ms^{-1})	Wind Speed Change (ms^{-1}) for Various Scales-of-Distance									
	Scales-of-Distance (m)									
	5000	4000	3000	2000	1000	800	600	400	200	100
$\geq$ 90	78.2	74.4	68.0	59.3	43.8	39.2	34.2	28.5	18.5	9.0
80	71.2	68.6	63.8	56.0	41.0	37.2	32.5	25.8	16.5	9.0
70	64.0	61.1	57.9	52.0	38.8	34.5	29.8	23.6	15.0	9.0
60	56.0	54.7	52.3	47.4	36.0	32.0	27.0	21.0	13.9	9.0
50	47.5	47.0	46.2	43.8	33.0	29.0	24.8	19.4	12.9	9.0
40	39.0	38.0	37.0	35.3	29.5	26.5	22.9	17.4	11.9	9.0
30	30.6	30.0	29.4	26.9	22.6	20.6	18.0	14.9	11.1	9.0
20	18.0	17.5	16.7	15.7	14.2	13.5	12.5	11.5	9.9	9.0

* RECOMMENDED FOR DESIGN APPLICATIONS.

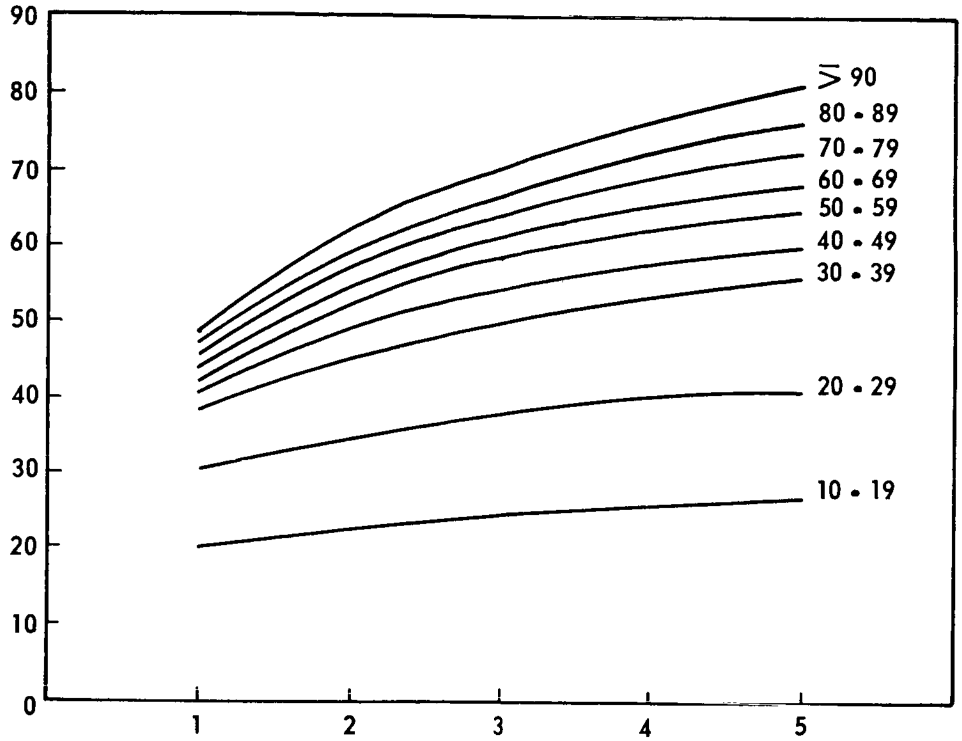


FIGURE 5.3.12 IDEALIZED ENVELOPES OF 99 PERCENTILE VECTOR BUILDUP WIND SPEED* CHANGE FOR VARIOUS SCALES-OF-DISTANCE AND CORRESPONDING WIND SPEEDS AT THE TOP OF THE LAYER IN THE 1- TO 80-KILOMETER ALTITUDE REGION FOR ALL LOCATIONS

TABLE 5.3.22 IDEALIZED ENVELOPES OF 99 PERCENTILE VECTOR BUILDUP WIND SPEED* CHANGE FOR VARIOUS SCALES-OF-DISTANCE AND CORRESPONDING WIND SPEEDS AT THE TOP OF THE LAYER IN THE 1- TO 80-KILOMETER ALTITUDE REGION FOR ALL LOCATIONS

Wind Speed at Top of Altitude Layer (ms^{-1})	Wind Speed* Change (ms^{-1}) for Various Scales-of-Distance				
	Scales-of-Distance (m)				
	5000	4000	3000	2000	1000
≥ 90	81.0	76.3	70.0	61.7	48.3
80-89	76.2	72.2	66.5	58.8	46.8
70-79	72.0	69.0	63.5	56.5	45.0
60-69	67.9	65.2	60.8	54.0	43.5
50-59	64.5	62.0	58.2	51.8	41.9
40-49	59.8	57.3	54.0	48.5	40.0
30-39	56.0	53.2	49.5	44.8	38.0
20-29	40.8	40.0	37.5	34.0	30.3
10-19	27.0	25.8	24.5	22.4	20.0

* Magnitude of vector resultant.

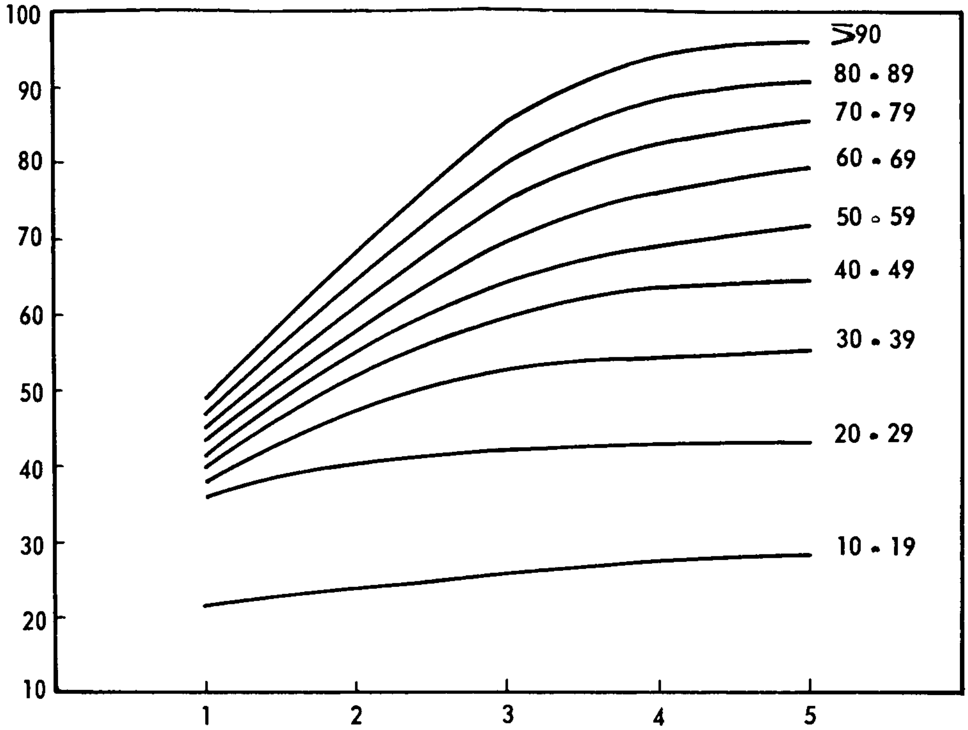


FIGURE 5.3.13 IDEALIZED ENVELOPES OF 99 PERCENTILE VECTOR BACKOFF WIND SPEED* CHANGE FOR VARIOUS SCALES-OF-DISTANCE AND CORRESPONDING WIND SPEEDS AT THE BOTTOM OF THE LAYER IN THE 1- TO 80-KILOMETER ALTITUDE REGION FOR ALL LOCATIONS

TABLE 5.3.23 IDEALIZED ENVELOPES OR OF 99 PERCENTILE VECTOR BACKOFF WIND SPEED* CHANGE FOR VARIOUS SCALES-OF-DISTANCE AND CORRESPONDING WIND SPEEDS AT THE BOTTOM OF THE LAYER IN THE 1- TO 80-KILOMETER ALTITUDE REGION FOR ALL LOCATIONS

Wind Speed at Top of Altitude Layer (ms^{-1})	Wind Speed* Change (ms^{-1}) for Various Scales-of-Distance				
	Scales-of-Distance				
	5000	4000	3000	2000	1000
≥ 90	96.3	94.0	85.5	68.3	48.5
80-89	91.0	88.3	79.8	64.6	46.8
70-79	85.9	82.5	75.0	62.0	44.8
60-69	79.8	76.2	69.5	57.5	43.0
50-59	72.0	69.2	64.4	55.0	41.2
40-49	64.8	63.5	59.8	51.9	39.5
30-39	55.5	54.5	52.8	47.3	37.6
20-29	43.6	43.0	42.3	40.4	35.5
10-19	29.0	27.6	26.0	24.0	21.5

* Magnitude of vector resultant.

5.3.8 Gusts.

The steady-state inflight wind speed envelopes presented in Section 5.3.6 of this report do not contain the gust (high frequency content) portion of the wind profile. The steady-state wind profile measurements have been defined as those obtained by the rawinsonde system (see Section 5.3.2.1). These measurements represent wind speeds averaged over approximately 600 meters in the vertical and, therefore, eliminate features with smaller scales. These smaller scale features are represented in the detailed profiles measured by the FPS-16 radar/Jimsphere system (see Section 5.3.2.2).

A number of attempts have been made to represent the high frequency content of vertical wind profiles in a suitable form for use in vehicle design studies. Most of the attempts resulted in gust information that could be used for specific applications, but, to date, no universal gust representation has been formulated. Although discrete gusts are still widely used by various design organizations, the use of continuous gust representations in vehicle design studies is being intensively investigated. Information on discrete and continuous gusts is given below.

5.3.8.1 Discrete Gusts.

Discrete gusts are specified in an attempt to represent, in a physically reasonable manner, characteristics of small scale motions associated with vertical wind velocity profiles. Gust structure usually is quite complex and it is not always understood. For use in vehicle design studies, discrete gusts are usually idealized because of their complexity and in order to enhance their utilization. Two examples of discrete gusts in nature are given in Figures 5.3.14 and 5.3.15. (Fig. 5.3.23 in Section 5.3.10 illustrates a sinusoidal gust of 3.5-km length.)

Well defined, sharp edged, and repeated sinusoidal gusts are important types in terms of their influence upon space vehicles. Quasi-square-wave gusts with amplitudes of approximately 9 ms^{-1} have been measured. These gusts are frequently referred to as embedded jets or singularities in the vertical wind profile. By definition gust is a wind speed in excess of the defined steady-state value; therefore, these gusts are employed on top of the steady-state wind profile values.

Figure 5.3.16 is a schematic representation of the design quasi-square-wave gust with wavelengths varying between 60 and 300 meters with an amplitude of 9 ms^{-1}. The mean shear buildup rate at the leading and trailing

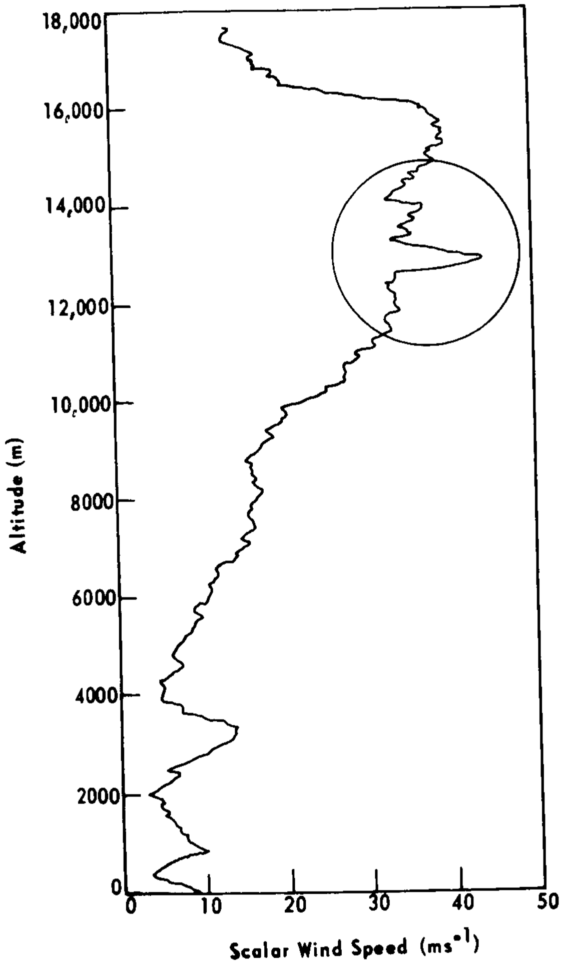


FIGURE 5.3.14 EXAMPLE OF A DISCRETE GUST OBSERVED BY A JIMSPHERE RELEASED AT 2103Z ON NOVEMBER 8, 1967, AT THE EASTERN TEST RANGE

edges of the gust is 9 ms^{-1} per 30 meters. The relationship of the gust to the idealized wind speed envelope and the wind buildup envelope is shown in the figure.

Another form of discrete gusts that has been observed is approximately sinusoidal in nature, where gusts occur in succession. Figure 5.3.17 illustrates the estimated number of consecutive sinusoidal gusts that may occur and their respective amplitudes for design purposes. It is extremely important when applying these gusts in vehicle studies to realize that these are pure sinusoidal representations that have never been observed in nature. The degree of purity of these sinusoidal features on the vertical wind profiles has not been established. These gusts should be superimposed symmetrically upon the steady-state profile. The data presented here on sinusoidal discrete gusts are at best preliminary and should be treated as such in design studies.

5.3.8.2 Spectra.

In general, the small scale motions associated with vertical detailed wind profiles are characterized by a superposition of discrete gusts and many random frequency components. Spectral methods have been employed to specify the characteristics of this superposition of small scale motions.

A digital filter was developed to separate small scale motions from the steady-state wind profile. The steady-state wind profile defined by the separation process approximates those obtained by the rawinsonde system. * Thus, a spectrum of small scale motions

* This definition was selected to enable use of the much larger rawinsonde data sample in association with a continuous type gust representation.

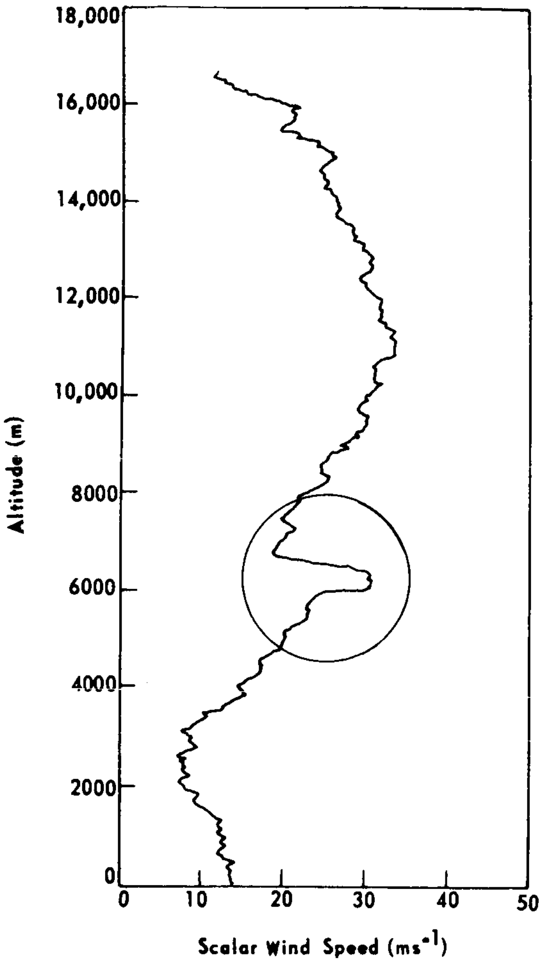


FIGURE 5.3.15 EXAMPLE OF A DISCRETE GUST OBSERVED AT 1300Z ON JANUARY 21, 1968, AT THE EASTERN TEST RANGE

is representative of the motions included in the FPS-16 radar/Jimsphere measurements, which are not included in the rawinsonde measurements. Therefore, a spectrum of these motions should be added to the steady-state wind profiles to obtain a representation of the detailed wind profile. Spectra of the small scale motions associated with zonal, meridional, and scalar wind profiles for various probability levels have been determined and are presented in Figures 5.3.18A through 5.3.18C. The spectra were computed from approximately 1200 detailed wind profile measurements by computing the spectra associated with each profile, then determining the probabilities of spectral density as a function of frequency. Thus the spectra represent envelopes of spectral density for the given probability levels. Spectra associated with each profile were computed over the altitude range between approximately 4 and 16 kilometers. It has been shown that energy (variance) of the small scale motions is not homogeneous; that is, it is not constant with altitude. The energy content over limited altitude intervals and for limited frequency bands may be much larger than that represented by the spectra in Figures 5.3.18A through 5.3.18C. This should be kept in mind when interpreting the significance of vehicle responses when employing the spectra of small scale motions. Additional details on this subject are available upon request. Envelopes of spectra for detailed profiles without filtering (solid lines) are also shown in Figures 5.3.18A through 5.3.18C. These spectra are well represented over wave numbers of 20 cy/4000 meters and less, by the equation,

$$E(k) = E_0 k^{-p} \quad , \qquad (1)\ 5.3.8$$

where E is the spectral density at any wave number k between 1 and 20, $E_0 = E(1)$, and p is a constant for any particular percentile level of occurrence of the power spectrum. Properties of all the spectra are summarized in Table 5.3.24. Data presented in this table show that the small scale motions associated with the meridional profiles (generally cross wind component in yaw plane) contain more energy than those associated with either the zonal or scalar profiles for the 50 and 90 percentile spectra. Because of computational difficulties, the spectra do not extend to wavelengths longer than 4000 meters. However, this wavelength encompasses the significant characteristic structural and control mode frequencies for most vertically rising vehicles of interest. Spectra of the total wind speed profiles may be useful in control systems and other slow response parametric studies for which the spectra of small scale motions may not be adequate.

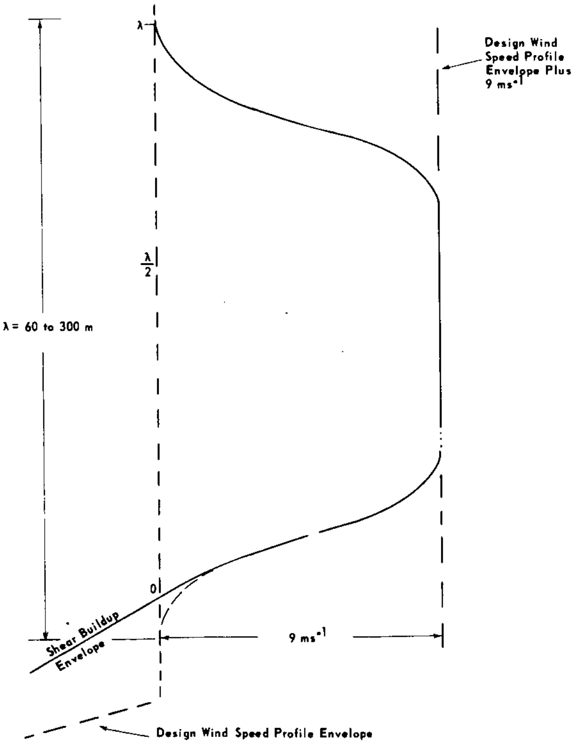


FIGURE 5.3.16 RELATIONSHIP BETWEEN DISCRETE GUST AND/OR EMBEDDED JET CHARACTERISTICS (quasi-square wave shape) AND THE DESIGN WIND SPEED PROFILE ENVELOPE

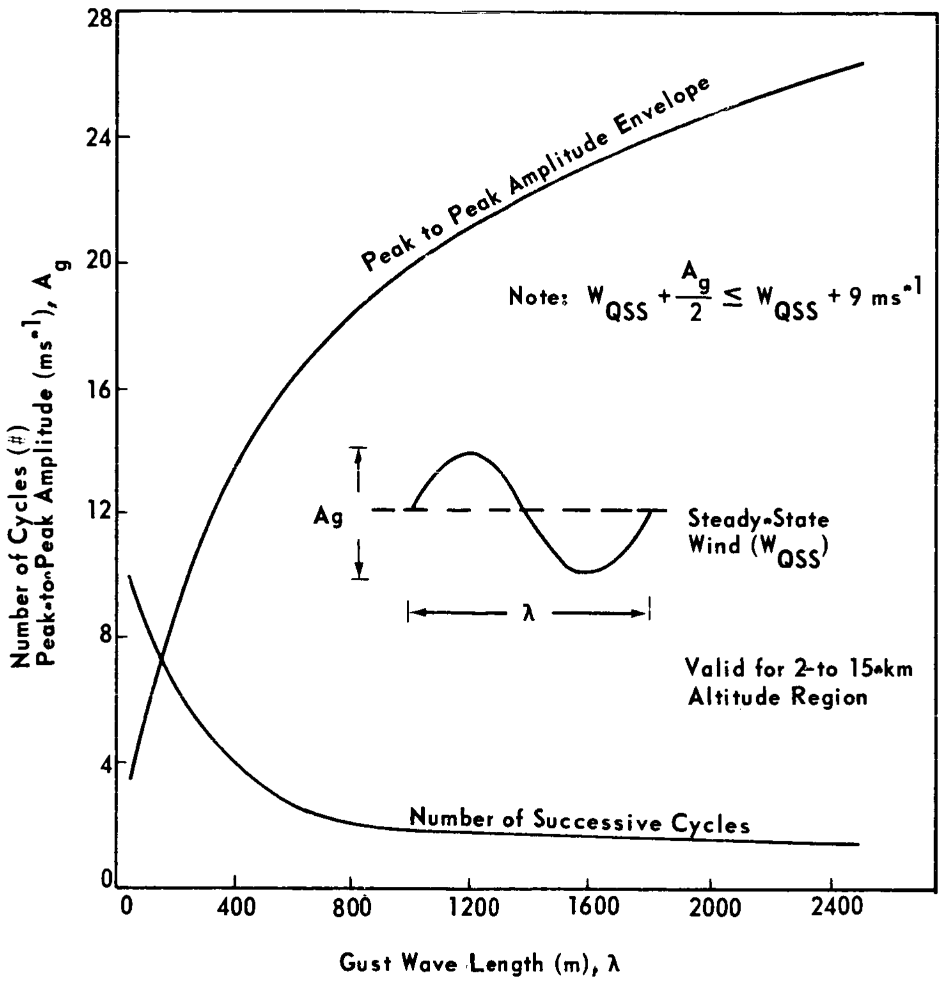


FIGURE 5.3.17 BEST ESTIMATE OF EXPECTED (≧99 percentile) GUST AMPLITUDE AND NUMBER OF CYCLES AS A FUNCTION OF GUST WAVELENGTHS

The power spectrum recommended for use in elastic body studies is given by the following expression:

$$E(k) = \frac{777.2\,(4000k)^{1.62}}{1 + 0.0067\,(4000k)^{4.05}} \qquad \text{(1a) 5.3.8}$$

where the spectrum E(k) is defined so that integration over the domain $0 \leq k \leq \infty$ yields the variance of the turbulence. In this equation E(k) is now the power spectral density ($m^2\,s^{-2}$ / (cycles per meter)) at wave number k ($meter^{-1}$). This function represents the 99th percentile scalar wind spectra for small scalar motions given by the dashed curve and its solid line extension into the high wave number region in Figure 5.3.18A. The associated design turbulence loads shall be obtained by multiplying the load standard deviations by a factor of three.

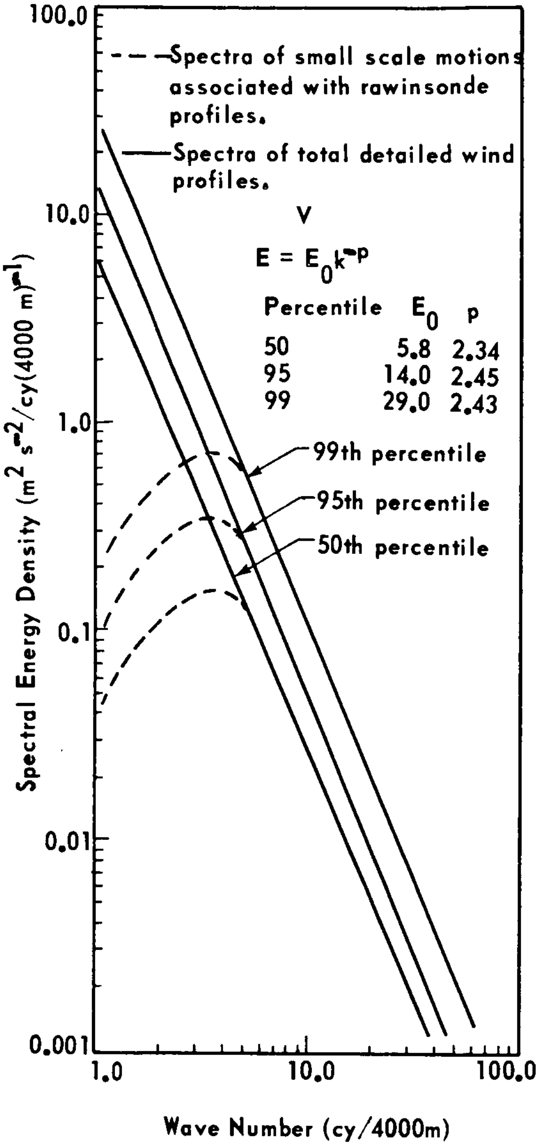


FIGURE 5.3.18A SPECTRA OF DETAILED WIND PROFILES — SCALAR

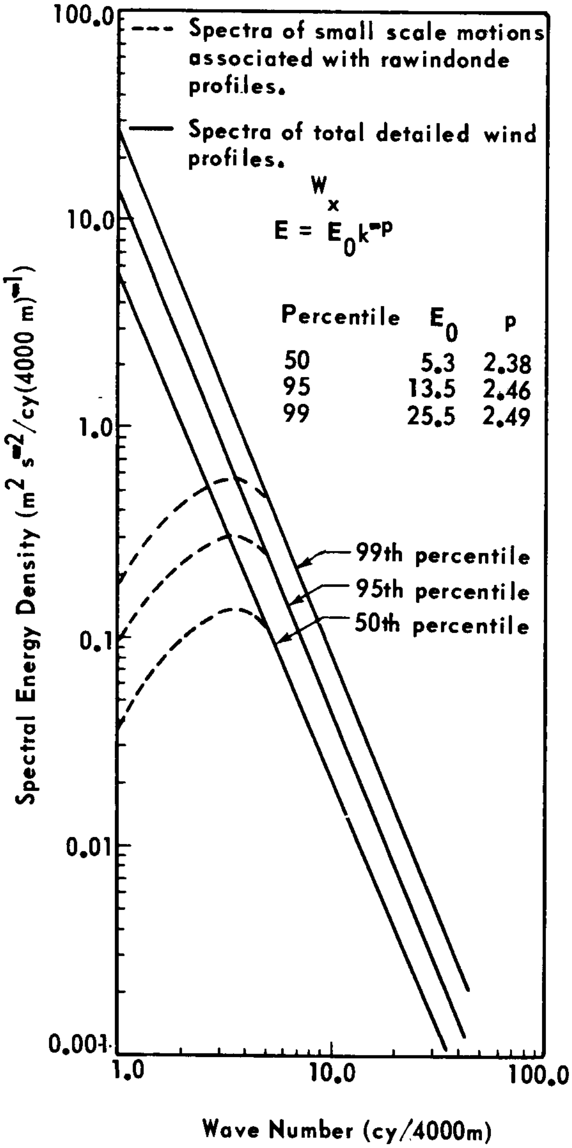


FIGURE 5.3.18B SPECTRA OF DETAILED WIND PROFILES — ZONAL

TABLE 5.3.24 PARAMETERS DEFINING SPECTRA OF DETAILED WIND PROFILES [E_0 - $m^2 s^{-2}$ (cycles (4000 m)$^{-1}$)$^{-1}$]

Percentile	W_x		W_z		V	
	E_0	p	E_0	p	E_0	p
50	5.3	2.38	7.2	2.39	5.8	2.34
90	13.5	2.46	15.5	2.42	14.0	2.45
99	25.5	2.49	28.5	2.46	29.0	2.43

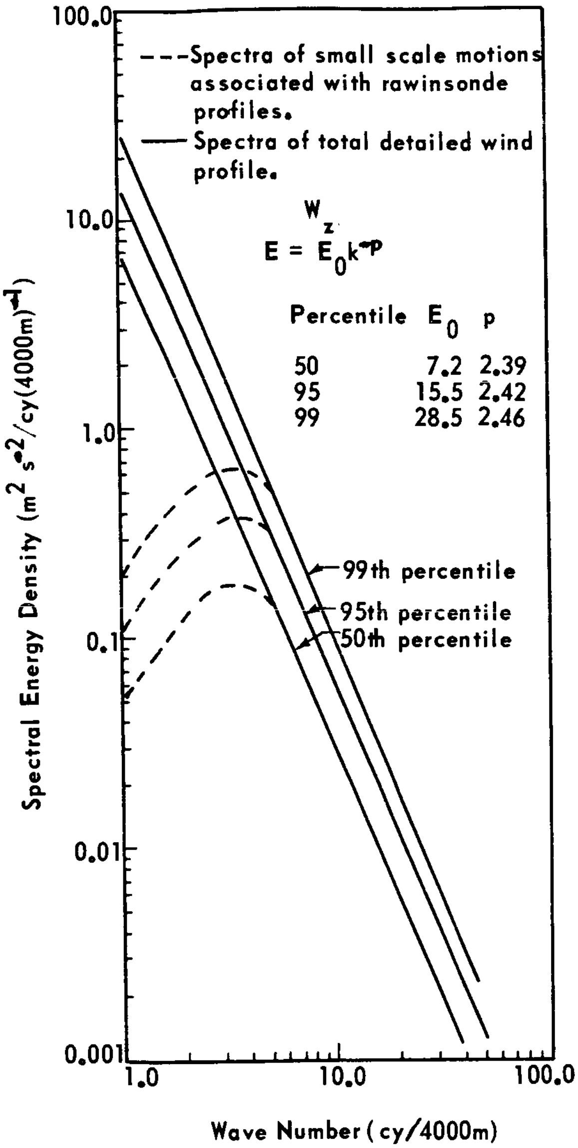


FIGURE 5.3.18C SPECTRA OF DETAILED WIND PROFILES — MERIDIONAL

5.3.9 Synthetic Wind Speed Profiles.

Two methods of constructing synthetic wind speed profiles are described in this section. The first method uses design wind speed profile envelopes (Section 5.3.6), wind shear (wind speed change) envelopes (Section 5.3.7), and discrete gusts (Section 5.3.8.1) without considering any possible correlation or lack of correlation between the wind speeds, shears, and gusts. The second method takes into account the relationships between the various wind profile characteristics.

5.3.9.1 Construction of Synthetic Wind Speed Profiles.

Without considering any correlations between the design wind speed profile envelope and wind shear envelope, the method that follows is used. See Figure 5.3.19 for an example using the 95 percentile design wind speed profile and the 99 percentile scalar wind speed buildup envelope.

a. Start with a speed on the design wind speed profile envelope at a selected (reference) altitude.

b. Subtract the amount of the shear (wind speed change) for each required altitude layer from the value of the wind speed profile envelope at the selected altitude. For example, in Figure 5.3.19, using the selected altitude of 12 kilometers on the wind speed profile envelope, to determine the point at 11 kilometers on the shear buildup envelope, a value of wind speed change of 39.3 ms^{-1} is obtained from Table 5.3.20 for 70 to 79 ms^{-1} wind speed

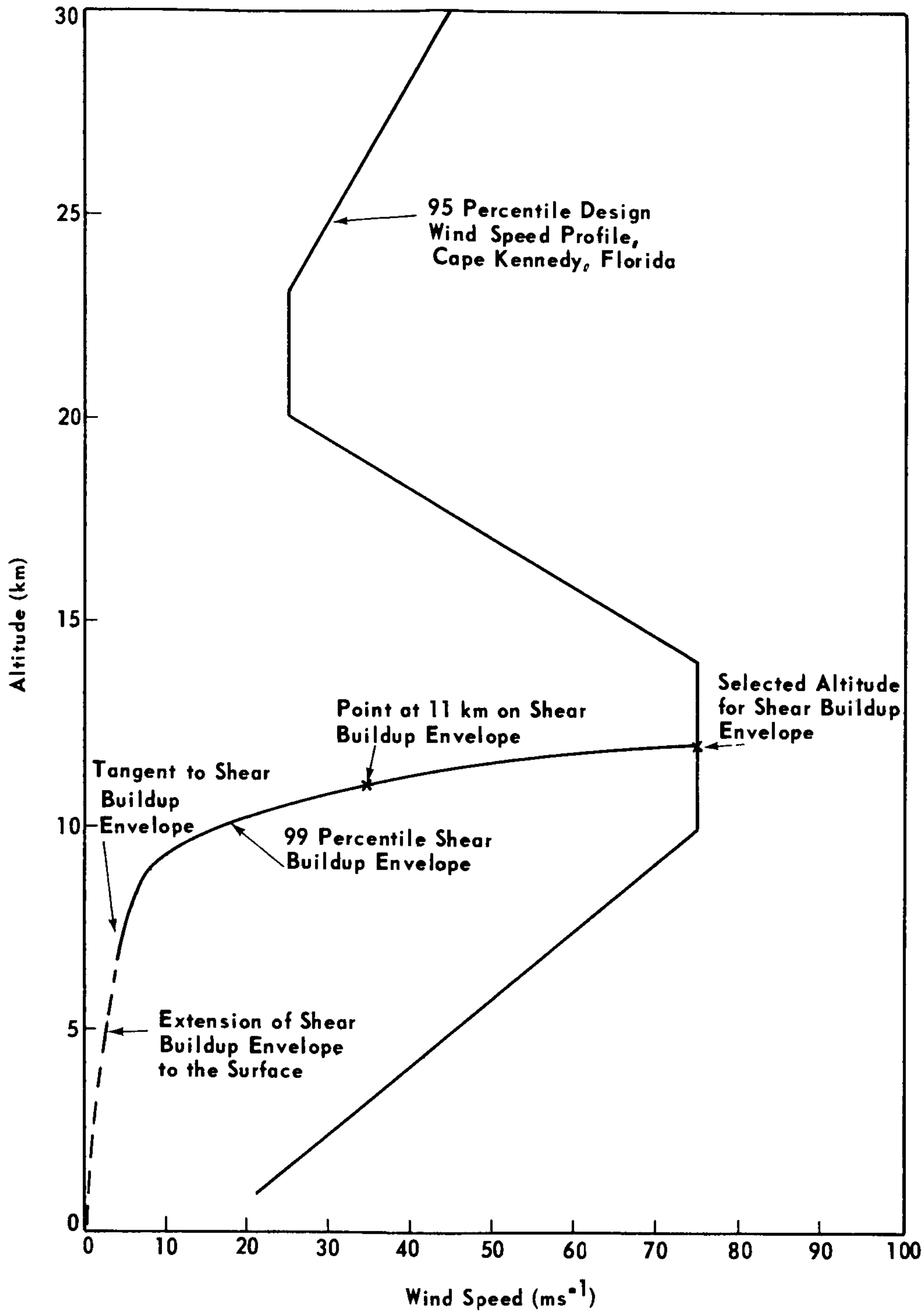


FIGURE 5. 3. 19 EXAMPLE OF SYNTHETIC WIND PROFILE CONSTRUCTION, WITHOUT ADDITION OF GUST

and 1000 meters scale-of-distance Subtracting 39.3 ms^{-1} from 75 ms^{-1}, the value of the wind speed profile envelope, a value of 35.7 ms^{-1} is obtained.

c. Values obtained for each altitude layer are plotted at the corresponding altitudes. (The value of 35.7 ms^{-1}, obtained in the example above in b, would be plotted at 11 kilometers.) Continue plotting values until a 5000-meter layer is reached (5000 below the selected altitude).

d. Draw a smooth curve through the plotted points starting at the selected altitude on the wind speed profile envelope. The lowest point is extended from the origin with a straight line* * * tangent to the plotted shear buildup curve. This curve then becomes the shear buildup envelope.

e. The gust is then superimposed upon the profile, as shown in Figure 5.3.16.

5.3.9.2 Construction of Synthetic Wind Speed Profiles Considering Relationships Between Speeds, Shears, and Gusts.

This construction is shown in Figure 5.3.20. Studies have shown that gusts and shears (wind speed change) calculated over small altitude intervals* are poorly correlated with steady-state wind speeds, while shears over large altitude intervals ($\gtrsim$ 1 km) and steady-state wind speeds have a high positive correlation. However, shears and gusts show poor correlation over all altitude intervals. Although functional relationships between wind speeds, shears, and gusts have not been explicitly defined, reasonable approximations can be used to construct more realistic synthetic profile relationships.

In the construction of a synthetic wind speed profile, the relationship between the wind parameters can be taken into account by considering shears and gusts to be independent and then multiplying the shears (wind speed changes) (Section 5.3.7) and the quasi-square-wave discrete gusts (Section 5.3.8) by a factor of 0.85 before constructing the synthetic wind profile. This is equivalent, as an engineering approximation,** to taking the combined 99 percentile gust and shear combination rather than the separate addition of the 99 percentile values for the gusts and shears in a correlated manner. To eliminate the problem of exaggerated vehicle responses when a discontinuous function made up of straight lines is applied to a vehicle, the gust should be represented by a modified one-minus-cosine shape to round the corners as shown in Figure 5.3.21.

* Few hundred meters.

** This approach was used successfully in the Apollo Saturn vehicle development program.

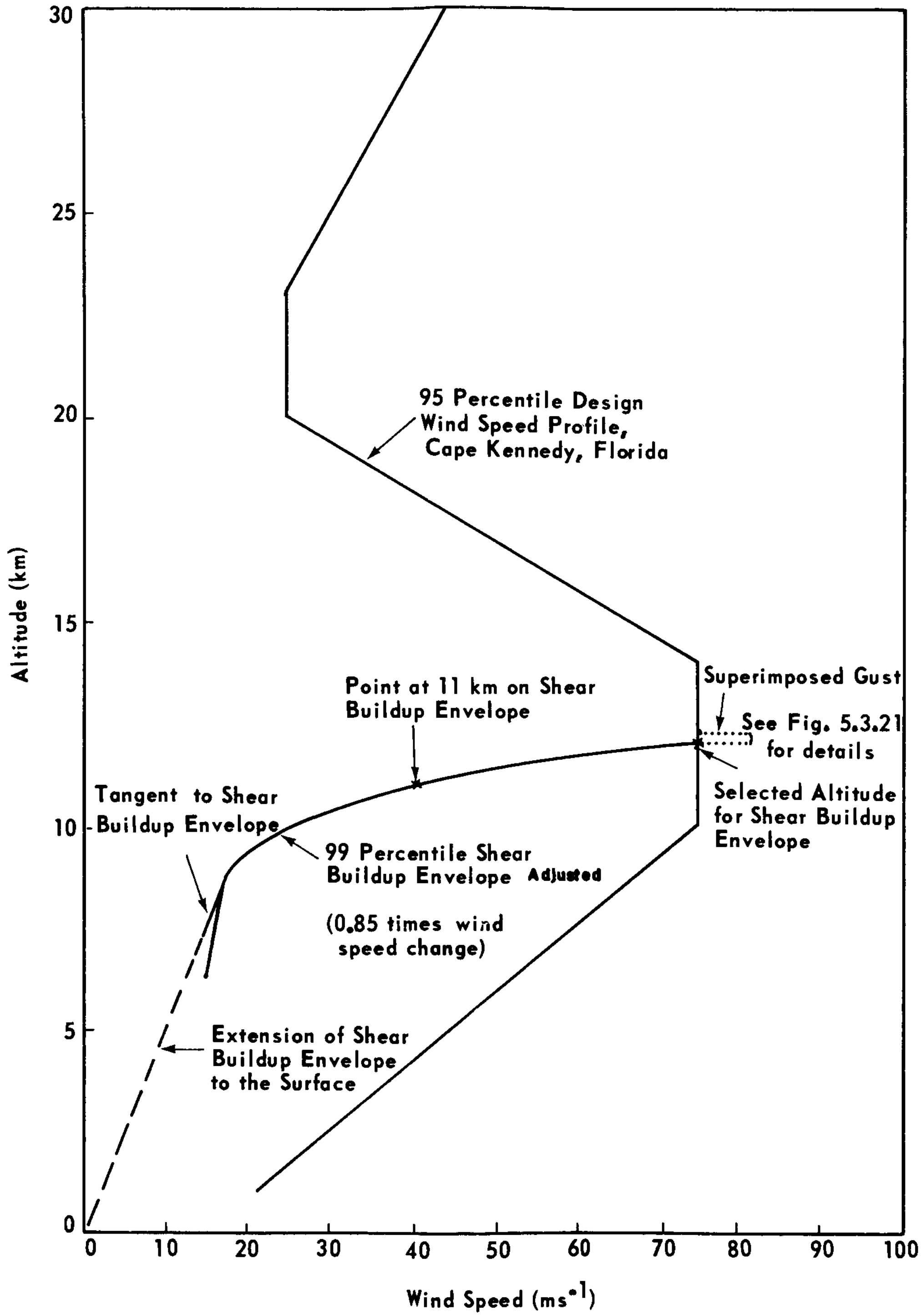


FIGURE 5.3.20 EXAMPLE OF SYNTHETIC WIND PROFILE CONSTRUCTION, WITH RELATIONSHIP OF WIND SHEARS AND GUSTS ASSUMED

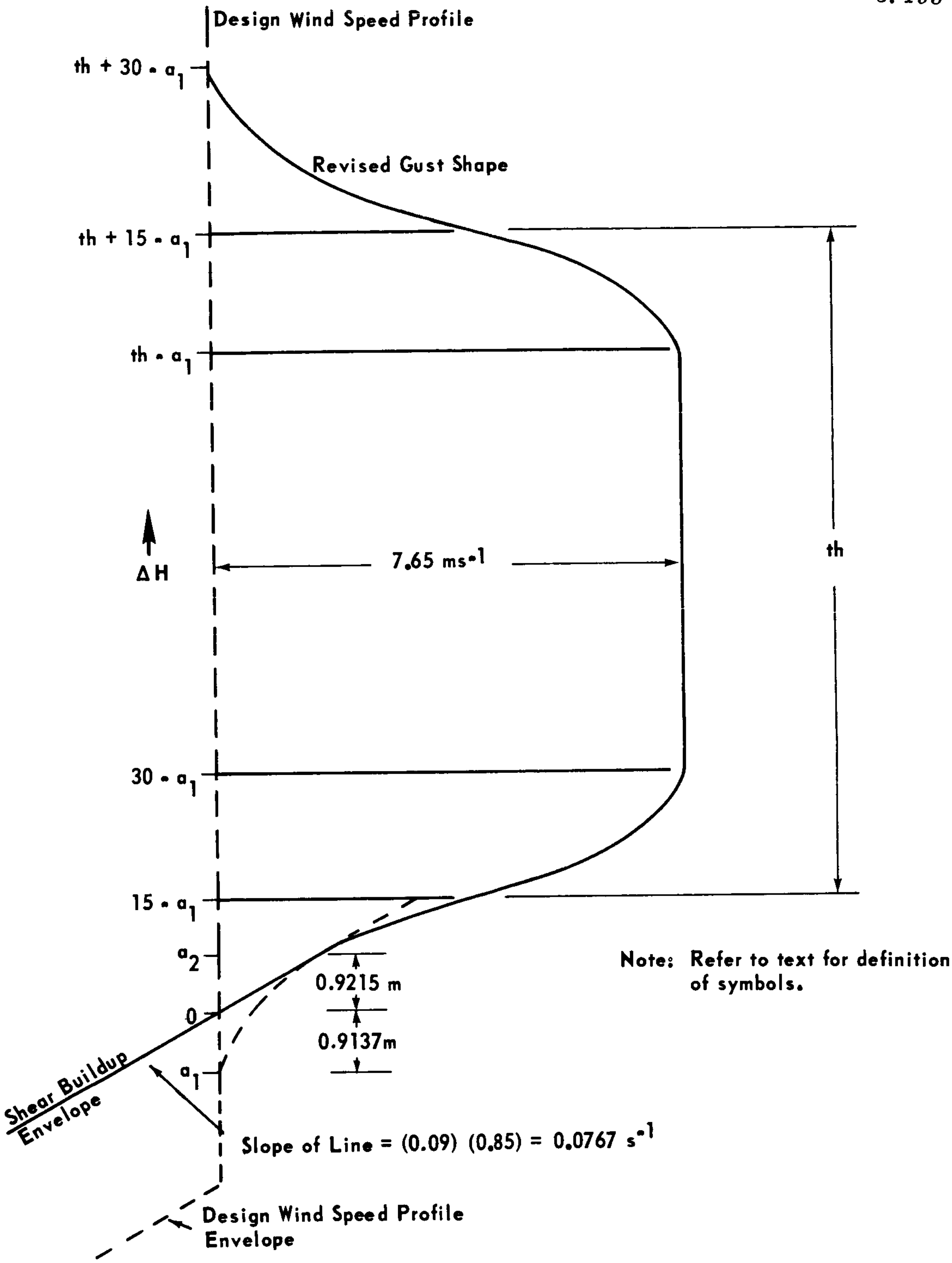


FIGURE 5.3.21 RELATIONSHIP BETWEEN REVISED GUST SHAPE, DESIGN WIND SPEED ENVELOPE, AND SPEED BUILDUP ENVELOPE

Thus, to construct the synthetic wind speed profiles, considering relationships between shears, speeds, and gusts, using the design wind speed envelopes given in Section 5.3.6, the procedure that follows is used. See Figures 5.3.20 and 5.3.21 for an example using the 95 percentile design wind speed profile envelop, the 99 percentile wind speed buildup envelope, and the modified one-minus-cosine discrete gust shape.

a. Construct the shear buildup envelope in the same way described in Section 5.3.9.1, except that the values of wind speed change used for each scale-of-distance will be multiplied by 0.85. (In the example for the selected altitude of 12 kilometers, the point at 11 kilometers will be found by using the wind speed change of 39.3 times 0.85 or 33.4 ms^{-1}. This value subtracted from 75 ms^{-1} then gives a value of 41.6 ms^{-1} for the point plotted at 11 kilometers instead of the value of 35.7 ms^{-1}.)

b. The superimposed gust is added by extending the shear buildup envelope until it becomes tangent to the one-minus-cosine shaped gust. As shown in Figure 5.3.21, the extension of the shear buildup envelope is made with the same slope as that of the last 100-meter layer segment before it meets the design wind speed profile. Details of the one-minus-cosine shaped gust are as follows:

1. The gust consists of the linear extension of the shear buildup envelope from the design wind speed envelope, the buildup to the peak gust speed on a one-minus-cosine curve (first half of curve) in 30 meters of altitude (a half-wavelength), a constant velocity plateau of from 0 meter to 215 meters, and a tail off, which is on the second half of the one-minus-cosine curve, also in 30 meters altitude. The amplitude of the gust (total wind speed increase) from the design wind speed envelope to the constant velocity plateau is equal to $0.85 \times 9\ ms^{-1} = 7.6\ ms^{-1}$. The one-minus-cosine curve has a half-wavelength of 30 meters (altitude).

2. Starting at the point where the shear buildup envelope meets the design wind speed envelope as the zero (0) point, the 99 percentile gust (see Fig. 4.3.21) is described by the following equations:

$0 \le \Delta H \le a_2$	$\Delta W_G = (0.09)\ (0.85)\Delta H = 0.0765\Delta H$
$a_2 \le \Delta H \le 30 - a_1$	$\Delta W_G = 3.825\{1 - \cos[\frac{\pi}{30}(\Delta H + a_1)]\}$
$30 - a_1 \le \Delta H \le th - a_1$	$\Delta W_G = 7.65$
$th - a_1 \le \Delta H \le th + 30 - a_1$	$\Delta W_G = 3.825\{1 - \cos[\frac{\pi}{30}(\Delta H + 30 + a_1 - th)]\}$

$th + 30 - a_1 \leq \Delta H \qquad \Delta W_G = 0$

where

ΔH is altitude difference (m)

ΔW_G is gust wind speed (ms^{-1})

a_1 is the shift of the one-minus-cosine buildup required to a tangential changeover from the shear buildup envelope and the gust (m)

a_2 is the tangent point of the shear buildup envelope and the gust (m)

th is the "thickness" of the gust (m)

$a_1 = 0.9137$ m , $a_2 = 0.9215$ m

The range of thickness (th) of the gust is

$30 \text{ m} \leq \text{gust thickness (th)} \leq 240 \text{ m}$

c. When the gust ends at the design wind speed envelope, the synthetic wind profile follows the design wind speed envelope or shear backoff.

5.3.10 Characteristic Wind Profiles to a Height of 18 Kilometers.

5.3.10.1 Features of Wind Profiles.

A significant problem of space vehicles is to provide assurance of an adequate design for flight through wind profiles of various configurations. During the major design phase of a space vehicle, the descriptions of various characteristics of the wind profile are employed in determining the applicable vehicle response requirement. Since much of the vehicle is in a preliminary status of design and the desired detail data on structural dynamic modes and other characteristics are not known at this time, the use of characteristic (statistical and synthetic) representations of the wind profile are desirable. However, after the vehicle design has been finalized and tests have been conducted to establish certain dynamic capabilities and parameters, it is desirable to evaluate the total system by simulated dynamic flight through wind profiles containing adequate frequency resolution (Ref. 5.57). The profiles shown in Figures 5.3.22 through 5.3.25 are actual scalar values of wind velocities measured by the FPS-16 radar/Jimsphere wind measuring system, and they illustrate the following:

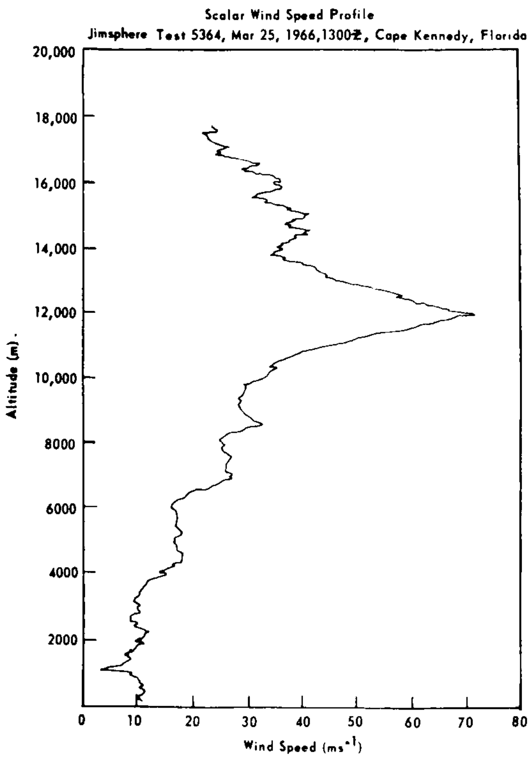


FIGURE 5.3.22 EXAMPLE OF JET STREAM WINDS

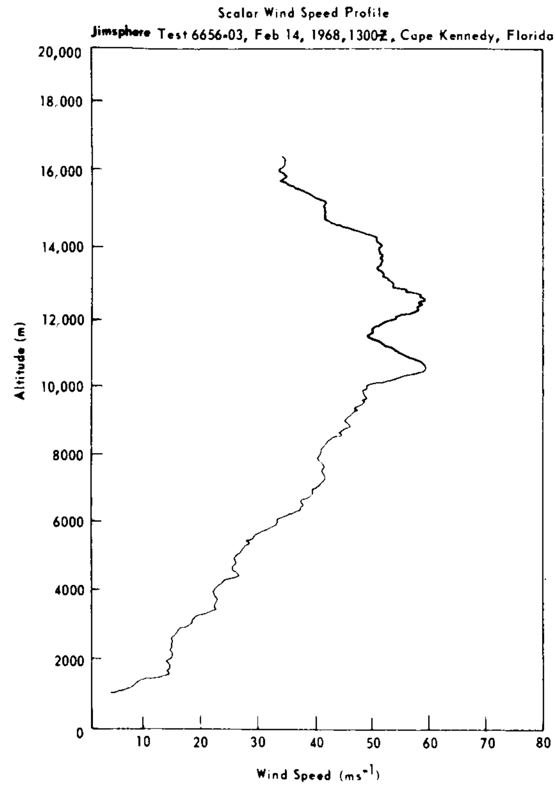


FIGURE 5.3.23 EXAMPLE OF SINE WAVE FLOW IN THE 10- TO 14-KILOMETER ALTITUDE REGION

a. Jet stream winds

b. Sinusoidal variation in wind with height

c. High winds with broad altitude band

d. Light wind speeds.

These profiles show only a few of the possible wind profiles that can occur. Jet stream winds (Fig. 5.3.22) are quite common to the various test ranges during the winter months and can reach magnitudes in excess of 100 ms^{-1}. These winds occur over a limited altitude range, making the wind shears very large. Figure 5.3.23 depicts winds having sinusoidal behavior in the 10- to 14-kilometer region. These types of winds can create excessive loads upon a vertically rising vehicle, particularly if the reduced forcing

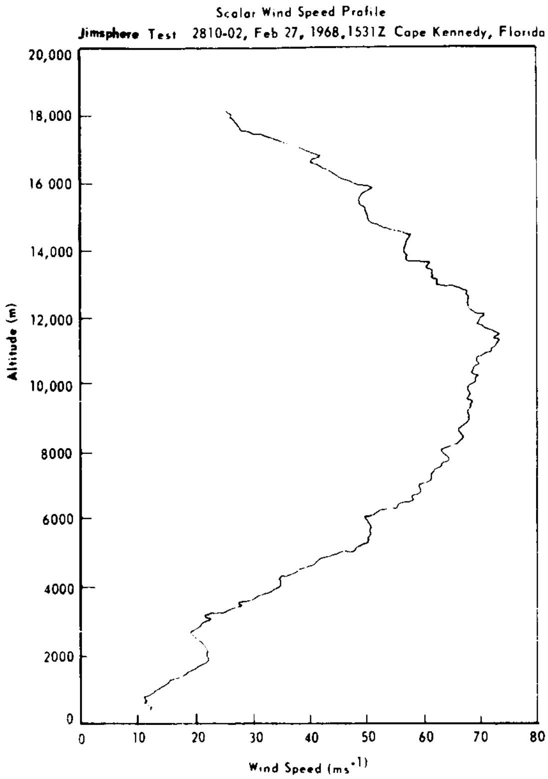


FIGURE 5.3.24 EXAMPLE OF HIGH WIND SPEEDS OVER A DEEP ALTITUDE LAYER

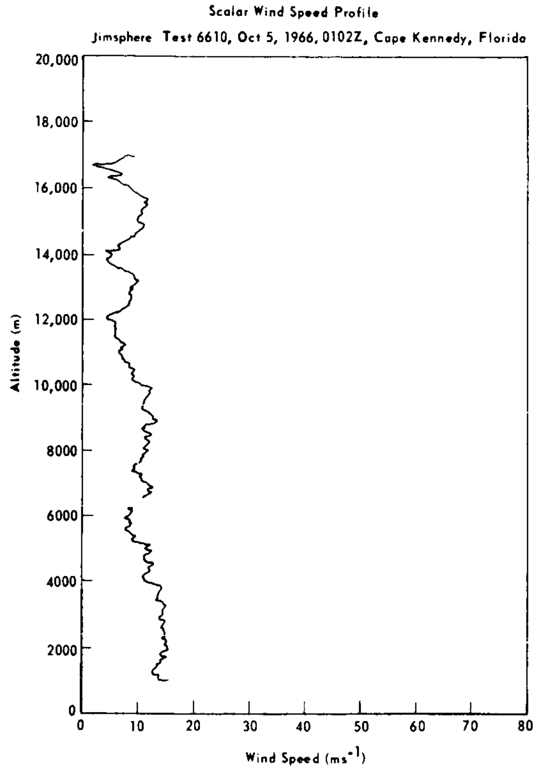


FIGURE 5.3.25 EXAMPLE OF LOW WIND SPEEDS

frequencies couple with the vehicle control frequencies and result in additive loads. It is not uncommon to see periodic variations occur in the vertical winds. Some variations are of more concern than others, depending upon wavelength and, of course, amplitude. Figure 5.3.24 is an interesting example of high wind speeds that persisted over 6.0 kilometers in depth. Such flow is not uncommon for the winter months. The last example shows (Fig. 5.3.25) the scalar winds of very low values. These winds were generally associated with easterly flow over the entire altitude interval (SFC to 16.0 kms) at Kennedy Space Center, Florida.

5.3.10.2 Selection of Representative Wind Profiles.

There are several points to consider in selecting a specific number of profiles for use in vehicle simulation studies. No unique small sample of wind profiles that will provide the desired simulation results for the various problems of interest in vehicle design and operational studies is in existence. Selection of the number of profiles depends upon the engineering problems to which they are to be applied. For example, it may be desired to select a number of profiles that will represent the frequency content associated with the vehicle's first or second bending moment. Another problem may be to select a number of profiles to study the vehicle's control system response. Because of the difference in frequency response, the profiles selected should emphasize different characteristics, and they will probably be a different selection. Therefore, a selection should be made jointly between the engineering user and a qualified aerospace meteorologist to help avoid misinterpretation of the study results.

5.3.11 Availability of Wind Data.

5.3.11.1 Availability of FPS-16 Radar/Jimsphere Wind Velocity Profiles.

There are currently 2200 profiles from Cape Kennedy, Florida; 300 profiles from Point Mugu, California; 230 profiles from White Sands Missile Range, New Mexico; 260 profiles from Green River, Utah; and 160 profiles from Wallops Island, Virginia, which have been reduced and edited. Additional data are being acquired. Some of these profile data have been published (Ref. 5.31). All the data are available on magnetic tapes. A master tape has been prepared to make the data readily accessible to engineers for use in space vehicle design and operation studies. These data, which are on magnetic tape, will be made available to aerospace, scientific, and engineering organizations upon request to the Chief, Aerospace Environment Division, Aero-Astrodynamics Laboratory, NASA-George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama 35812.

5.3.11.2 Availability of Rawinsonde Wind Velocity Profiles.

Serially complete, edited, and corrected rawinsonde wind profile data are available for 10 years, two observations per day for Cape Kennedy, Florida (Eastern Test Range), and for 9 years, four observations per day for Santa Monica, California (Western Test Range Area). These data are available on magnetic tapes. Qualified requestors in aerospace, scientific, and engineering organizations may obtain these data, which are on magnetic tapes, upon request to the Chief, Aerospace Environment Division, Aero-Astrodynamics Laboratory, NASA-George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama 35812. They are also available as card deck 600, along with data from various worldwide locations, from the National Weather Records Center, ESSA, Asheville, North Carolina 28801.

5.3.11.3 Availability of Rocketsonde Wind Velocity Profiles.

Rocketsonde wind profile data have been collected for approximately 10 years from various launch sites around the world. These data can be obtained from the World Data Center A, Asheville, North Carolina 28801.

5.3.11.4 Availability of Smoke Trail Wind Velocity Profiles.

A limited amount of wind velocity data has been obtained by the use of smoke trail techniques to determine the small scale variations of wind velocity with altitude. NASA TN D-3289 (Ref. 5.47) and NASA TN D-4480 (Ref. 5.48) should be consulted for obtaining such data.

5.3.11.5 Utility of Data.

All wind profile data records should be checked carefully by the user before employing them in any vehicle response calculations. Wherever practical, the engineer-designer should become familiar with the representativeness of the data and frequency content of the profile used, as well as the measuring system and reduction schemes employed in handling the data. For those organizations that have aerospace-meteorology oriented groups or individuals on their staffs, consultations should be held with them. Otherwise, various government groups concerned with aerospace vehicle design and operation can be of assistance. Such action by the user can prevent expensive misuse and error in interpretation of the data relative to the intended application.

5.3.12 Atmospheric Turbulence Criteria for Horizontally Flying Vehicles.

In this section we present a preliminary set of environmental design wind criteria for aerospace vehicles that will have the capability to fly both horizontally and vertically through the atmosphere. Recently discussed concepts for a space shuttle vehicle have this mixed mode capability. This vehicle may be launched vertically and ascend through the atmosphere into earth orbit with its cargo and personnel in the usual space vehicle mode. After performing its mission in earth orbit, the vehicle will deorbit; however, during the latter portion of let-down phase of the mission, the vehicle will fly horizontally, and thus it will be subjected to loads resulting from atmospheric turbulence. In this section we present a model of turbulence for the calculation of gust loads.

To a reasonable degree of approximation, inflight atmospheric turbulence experienced by horizontally flying vehicles can be assumed to be homogeneous, stationary, Gaussian, and isotropic. Under some conditions, these assumptions might appear to be drastic, but for engineering purposes they seem to be appropriate, except for flight at low level over rough terrain. It has been found that the spectrum of turbulence first suggested by Von Karman appears to be a good analytical representation of atmospheric turbulence. The longitudinal spectrum is given by

$$\Phi_u(\Omega, L) = \sigma^2 \frac{2L}{\pi} \frac{1}{[1 + (1.339\ L\Omega)^2]^{5/6}} , \qquad (1)\ 5.3.12$$

where σ^2 is the variance of the turbulence, L is the scale of turbulence, and Ω is the wave number in units of radians per unit length. The spectrum is defined so that

$$\sigma^2 = \int_0^\infty \Phi_u(\Omega, L)\, d\Omega \ . \qquad (2)\ 5.3.12$$

The theory of isotropic turbulence predicts that the spectrum Φ_w of the lateral and vertical components of turbulence are related to the longitudinal spectrum though the differential equation

$$\Phi_w = \frac{1}{2}\left(\Phi_u - \Omega \frac{d\Phi_u}{d\Omega}\right) \ . \qquad (3)\ 5.3.12$$

Substitution of Equation (1) 5.3.12 into Equation (3) 5.3.12 yields

$$\Phi_w = \sigma^2 \frac{L}{\pi} \frac{1 + \frac{8}{3}(1.339\, L\,\Omega)^2}{[1 + (1.339\, L\,\Omega)^2]^{11/6}} \ . \qquad (4)\ 5.3.12$$

The dimensionless quantities $2\pi\Phi_u/\sigma^2 L$ and $2\pi\Phi_v/\sigma^2 L$ are depicted in Figure 5.3.26 as function of ΩL. As $L\Omega \to \infty$, Φ_u and Φ_w asymptatically behave like

$$\Phi_u \sim \sigma^2 \frac{2L}{\pi} \frac{(L\Omega)^{-5/3}}{(1.339)^{5/3}} \quad (L\Omega \to \infty) \qquad (5)\ 5.3.12$$

$$\Phi_w \sim \sigma^2 \frac{2L}{\pi} \frac{(L\Omega)^{-5/3}}{(1.339)^{5/3}} \quad (L\Omega \to \infty) \ , \qquad (6)\ 5.3.12$$

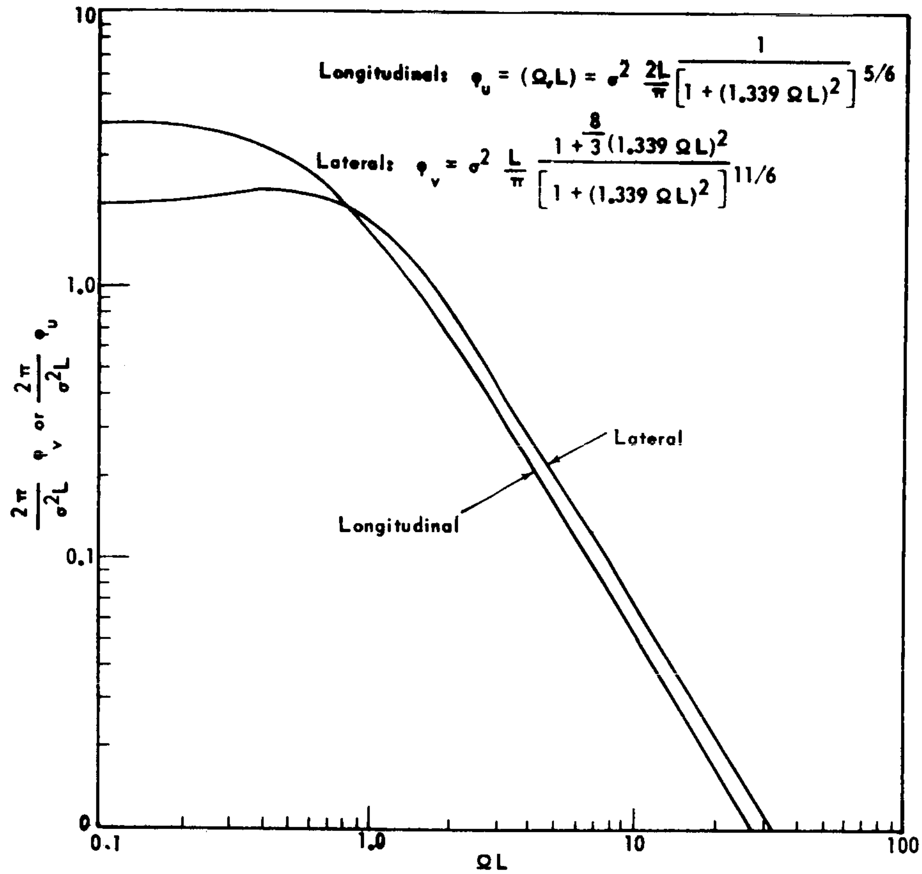


FIGURE 5.3.26 THE DIMENSIONLESS LONGITUDINAL AND LATERAL $\frac{2\pi\Phi_u}{\sigma^2 L}$ AND $\frac{2\pi\Phi_w}{\sigma^2 L}$ SPECTRA AS FUNCTIONS OF THE DIMENSIONLESS FREQUENCY $L\Omega$

consistent with the concept of the Kolmogorov inertial subrange. In addition, $\Phi_w/\Phi_u \rightarrow 4/3$ as $\Omega L \rightarrow \infty$. Design values of the scale of turbulence L are given in Table 5.3.25. Experience indicates that the scale of turbulence increases as height increases in the first 2500 feet* of the atmosphere, and typical values of L range from 600 feet near the surface to 2000 feet at approximately a 2500-foot altitude. Above the 2500-foot level, typical values of L are in the

* U.S. Customary Units are used in this section to maintain continuity with source of data — Air Force Flight Dynamics Laboratory and other documentation.

order of 3000 to 6000 feet. Thus, the scales of turbulence in Table 5.3.25 are probably low, and they would be expected to give a somewhat conservative or high number of load or stress exceedances per unit length of flight.

The power spectrum analysis approach is applicable only to stationary Gaussian continuous turbulence, but atmospheric turbulence is neither statistically stationary nor Gaussian over long distances. The statistical quantities used to describe turbulence vary with altitude, wind direction, terrain roughness, atmospheric stability, and a host of other variables. Nevertheless, it appears that the observed power spectrum of the vertical velocity from 1000 to 40000 feet above terrain is reasonably invariant. Accordingly, it is recommended that atmospheric turbulence be considered locally Gaussian and stationary and that the total flight history of a horizontally flying vehicle be considered to be made up of an ensemble of exposures to turbulence of various intensities, all using the same power spectrum shape. Thus, it is recommended that the following statistical distribution of rms gust intensities be used

$$p(\sigma) = \frac{P_1}{b_1}\sqrt{\frac{2}{\pi}}\exp\left\{-\frac{\sigma^2}{2b_1^2}\right\} + \frac{P_2}{b_2}\sqrt{\frac{2}{\pi}}\exp\left\{-\frac{\sigma^2}{2b_2^2}\right\},$$

(7) 5.3.12

where b_1 and b_2 are the standard deviations of σ in nonstorm and storm turbulence. The quantities P_1 and P_2 denote the fractions of flight time or distance flown in nonstorm and storm turbulence. It should be noted that if P_0 is the fraction of flight time or distance in smooth air, then

$$P_0 + P_1 + P_2 = 1 \quad . \qquad (8)\ 5.3.12$$

The recommended design values of P_1, P_2, b_1, and b_2 are given in Table 5.3.25. Note that over rough terrain b_2 can be extremely large in the first 1000 feet above the terrain and that the b's for the vertical, the lateral, and the longitudinal standard deviations of the turbulence are not equal. Thus in the first 1000 feet of the atmosphere above rough terrain, turbulence is significantly anisotropic and this anisotropy must be taken into account in engineering calculations.

An exceedance model of gust loads and stresses can be developed with the above information. Let y denote any load quantity that is a dependent variable in a linear system of response equations, for example, bending moment at a particular wind station. This system is forced by the longitudinal,

TABLE 5.3.25 PARAMETERS FOR THE TURBULENCE MODEL FOR HORIZONTALLY FLYING VEHICLES

Altitude (ft)	Mission Segment[a]	Turbulence Component[b]	P_1	b_1 ($ft\ s^{-1}$)	P_2	b_2 ($ft\ s^{-1}$)	L (ft)
0 - 1000	Low Level Contour (rough terrain)	V	1.00	2.7	10^{-5}	10.65	500
0 - 1000	Low Level Contour (rough terrain)	L, L	1.00	3.1	10^{-5}	14.06	500
0 - 1000	C, C, D	V, L, L	1.00	2.51	0.005	5.04	500
1000 - 2500	C, C, D	V, L, L	0.42	3.02	0.0033	5.94	1750
2500 - 5000	C, C, D	V, L, L	0.30	3.42	0.0020	8.17	2500
5000 - 10000	C, C, D	V, L, L	0.15	3.59	0.00095	9.22	2500
10000 - 20000	C, C, D	V, L, L	0.062	3.27	0.00028	10.52	2500
20000 - 30000	C, C, D	V, L, L	0.025	3.15	0.00011	11.88	2500
30000 - 40000	C, C, D	V, L, L	0.011	2.93	0.000095	9.84	2500
40000 - 50000	C, C, D	V, L, L	0.0046	3.28	0.000115	8.81	2500
50000 - 60000	C, C, D	V, L, L	0.0020	3.82	0.000078	7.04	2500
60000 - 70000	C, C, D	V, L, L	0.00088	2.93	0.000057	4.33	2500
70000 - 80000	C, C, D	V, L, L	0.00038	2.80	0.000044	1.80	2500
above 80000	C, C, D	V, L, L	0.00025	2.50	0	0	2500

a Climb, cruise, and descent (C, C, D).

b Vertical, lateral, and longitudinal (V, L, L).

lateral, and vertical components of turbulence, and upon producing the Fourier transform of the system, it is possible to obtain the spectrum of y . This spectrum will be proportional to the input turbulence spectra, the function of proportionality being the system transfer function. Upon integrating the spectrum of y over the domain $0 < \Omega < \infty$, we obtain the relationship

$$\sigma_y = A\sigma \quad , \tag{(9) 5.3.12}$$

where A is a positive constant that depends upon the system parameters and the scale of turbulence, and where σ_y is the standard deviation of y.

If the output y is considered to be Gaussian for a particular value of σ, then the expected number of fluctuations of y that exceed y^* with positive slope per unit distance with reference to a zero mean is

$$N(y^*) = N_0 \exp\left\{ - \frac{{y^*}^2}{2\sigma_y^2} \right\} , \tag{(10) 5.3.12}$$

where N_0 is the expected number of zero crossings of y per unit distance with positive slope and is given by

$$N_0 = \frac{1}{2\pi\sigma_y} \left[\int_0^\infty \Omega^2 \Phi_y(\Omega)\, d\Omega \right]^{1/2} . \tag{(11) 5.3.12}$$

In this equation, Φ_y is the spectrum of y and

$$\sigma_y = \left[\int_0^\infty \Phi_y(\Omega)\, d\Omega \right]^{1/2} . \tag{(12) 5.3.12}$$

The standard deviation of σ_y is related to standard deviation of turbulence through Equation (9) 5.3.12, and σ is distributed according to Equation (7) 5.3.12. Accordingly, the number of fluctuations of y that exceed y^* for standard deviations of turbulence in the interval σ to $\sigma + d\sigma$ is $N(y^*)\,p(\sigma)\,d\sigma$, so that integration over the domain $0 < \sigma < \infty$ yields

$$\frac{M(y^*)}{N_0} = P_1 \exp\left\{ - \frac{|y^*|}{b_1 A} \right\} + P_2 \exp\left\{ - \frac{|y^*|}{b_2 A} \right\} , \tag{(13) 5.3.12}$$

where $M(y^*)$ is the overall expected number of fluctuations of y that exceed y^* with positive slope. To apply this equation, the engineer needs only to calculate A and N_0 and specify the risk of failure he wishes to accept. The appropriate values of P_1, P_2, b_1, and b_2 are given in Table 5.3.25. Figures

5.3.27 and 5.3.28 give plots of $M(y^*)/N_0$ as a function of $|y^*|/A$ for the various altitudes for the design data given in Table 5.3.25. Table 5.3.26 provides a summary of the units of the various quantities in this model.

It should be noted that $M(y^*)$ and N_0 in Equation (13) 5.3.12 can have the units of inverse time (i.e. seconds^{-1}) provided $M(y^*)$ and N_0 both have the same units. This amounts to transforming Ω in Equation (11) 5.3.12 to a frequency (radians per second) through a Jacobian transformation.

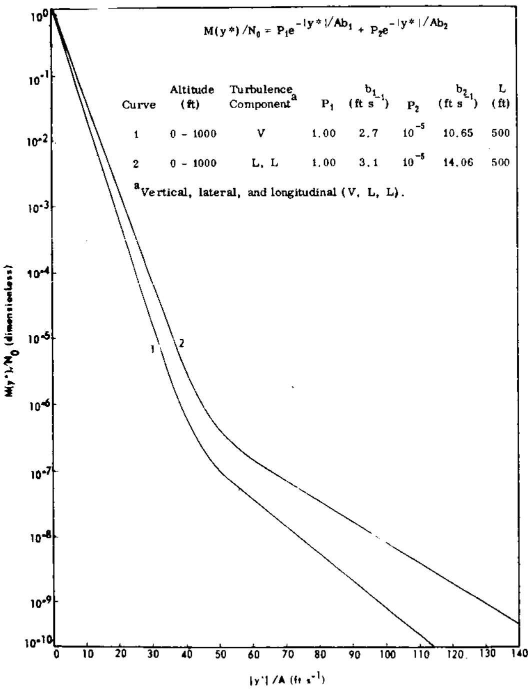


FIGURE 5.3.27 EXCEEDANCE CURVES FOR THE VERTICAL, LATERAL, AND LONGITUDINAL COMPONENTS OF TURBULENCE FOR THE 0- TO 1000-FOOT ALTITUDE RANGE

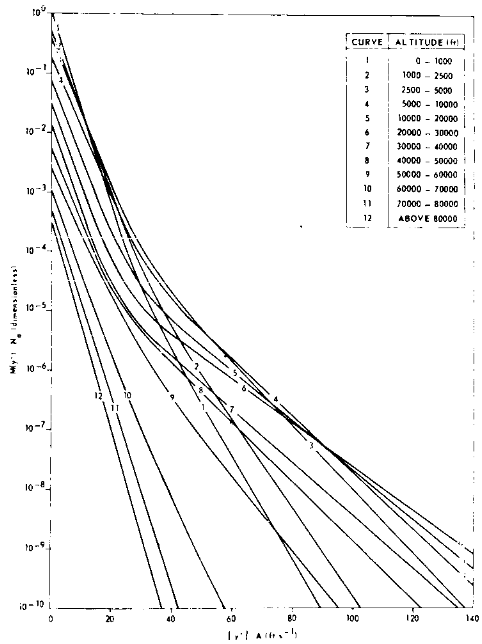


FIGURE 5.3.28 EXCEEDANCE CURVES FOR THE VERTICAL, LATERAL, AND LONGITUDINAL COMPONENTS OF TURBULENCE FOR VARIOUS ALTITUDE RANGES

TABLE 5.3.26 METRIC AND U.S. CUSTOMARY UNITS OF VARIOUS QUANTITIES IN THE TURBULENCE MODEL FOR HORIZONTALLY FLYING VEHICLES

Quantity	Metric Units	U. S. Customary Units
Ω	rad m^{-1}	rad ft^{-1}
Φ_u, Φ_w	m^{2}s^{-2}/rad m^{-1}	ft^{2}s^{-2}/rad ft^{-1}
σ^2	m^{2}s^{-2}	ft^{2}s^{-2}
L	m	ft
b_1, b_2	ms^{-1}	ft s^{-1}
P_1, P_2	dimensionless	dimensionless
σ_y/A	ms^{-1}	ft s^{-1}
$\lvert y^*\rvert/A$	ms^{-1}	ft s^{-1}
N_0, N, M	m^{-1}	ft^{-1}

5.3.12.1 Application of Power Spectral Model

To apply equation (13) 5.3.12, the engineer can either calculate A and N_0 and calculate the load quantity y^* for a specified value of $M(y^*)$, or calculate A and calculate the load quantity y^* for a specified value of $M(y^*)/N_0$ In a recent study performed by the Lockheed-California Company for the FAA (Ref. 5.61), design values of $M(y^*)$ and $M(y^*)/N_0$ were calculated. These design criteria were consistent with the limit load capabilities of present day commercial aircraft. The criterion in which $M(y^*)$ is specified is suitable for a mission analysis approach to the design problem. The criterion in which $M(y^*)/N_0$ is specified is suitable for a design envelope approach to aircraft design.

In the design envelope approach, it is assumed that the airplane operates 100 percent of the time at its critical design envelope point. A new vehicle is designed on a limit load basis for a specified value of M/N_0. According to the authors of Ref. 5.61, $M/N_0 \;\; 6 \times 10^{-9}$ is suitable for the design of commercial aircraft. To apply this criterion, all critical altitudes, weights, and weight distributions are specified and associated values of A are calculated. The limit loads are calculated for each of the specified configurations with equation (13) 5.3.12 for $M/N_0 \;\; 6 \times 10^{-9}$.

In the mission analysis approach, a new aircraft is designed on a limit load basis according to Ref. 5.61 for $M \;\; 2 \times 10^{-5}$ load exceedances per hour. To apply this criterion, the engineer must construct an ensemble of flight profiles which define the expected range of payloads and the variation with time of speed, altitude, gross weight, and center of gravity position. These profiles are divided into mission segments, or blocks, for analysis, and average or effective values of the pertinent parameters defined for each segment. For each mission segment, values of A and N_0 are determined by dynamic analysis. A sufficient number of load and stress quantities are included in the dynamic analysis to assure that stress distributions throughout the structure are realistically or conservatively defined. Now the contribution to $M(y^*)$ from the i^{th} flight segment is $t_i M_i(y^*)/T$ where t_i is the amount of time spent in the i^{th} flight regime (mission segment), T is the total time flown by the vehicle over all mission segments, and $M_i(y^*)$ is the exceedance rate associated with the i^{th} segment. The total exceedance rate for all mission segments, k say, is

$$M(y^*) = \sum_{i=1}^{k} \frac{t_i}{T} N_{0_i} \left\{ P_1 e^{-|y^*|/b_1 A} + P_2 e^{-|y^*|/b_2 A} \right\} , \qquad (14)\ 5.3.12$$

where subscript i denotes the i^{th} mission segment. The limit gust load quantity $|y^*|$ can be calculated with this formula upon setting $M(y^*)$ 2×10^{-5} exceedances per hour.

The above mentioned limit load design criteria were derived for commercial aircraft which are normally designed for 50,000 hour lifetimes. Therefore, to apply these criteria to horizontally flying aerospace vehicles which will have relatively short lifetimes would be too conservative. However, it is possible to modify these criteria so that they will reflect a shorter vehicle lifetime. The probability F_p that a load will be exceeded in a given number of flight hours T is

$$F_p \quad 1 - e^{-TM} \tag{(15)5.3.12}$$

Let us assume that the limit load criterion M 2×10^{-5} exceedances per hour is associated with an aircraft with a lifetime T equal to 50,000 hours. This means that F_p 0.63, i.e., there is a 63 percent chance that an aircraft designed for a 50,000 hour operating lifetime will exceed its limit load capability at least once during its operating lifetime. This high failure probability, based on limit loads, is not excessive in view of the fact that an aircraft will receive many inspections on a routine basis during its operating lifetime. In addition, after applying safety factors to the design limit loads the ultimate load exceedance rate will be on the order of 10^{-8} exceedances per hour. Substitution of this load exceedance rate into (15)5.3.13 for T 50,000 hours yields a failure probability, on an ultimate load basis, of F_p 0.0005. This means that there will only be a 0.05 percent chance that an aircraft will exceed its ultimate load capability at least once during its operating lifetime of 50,000 hours. Thus, a failure probability of F_p 0.63 on a limit load basis is reasonable for design. Let us now assume that F_p is our design failure probability so that equation (15)5.3.12 can be used to calculate design values of M associated with a specified vehicle lifetime. Thus, for example, if we expect a vehicle to fly only 100 hours, then according to (15)5.3.12, we have M 10^{-2} exceedances per hour. Similarly, if we expect a vehicle to be exposed to the atmosphere for 1,000 hours of flight, then M 10^{-3} exceedances per hour.

The corresponding design envelope criterion can be obtained by dividing the above calculated values of M by an appropriate value of N_o. In the case of the 50,000 hours criterion, we have $M/N_o = 6 \times 10^{-9}$ and M 2×10^{-5} exceedances per hour so that an estimate of N_o for purposes of obtaining a design criterion is N_o 0.333×10^4 hr^{-1}. Thus, upon solving (15)5.3.12 for M and dividing by N_o 0.333×10^4 hr^{-1}, the design envelope criterion takes the form

$$\frac{M}{N_o} \quad \frac{3 \times 10^{-4}}{T} \tag{(16)5.3.12}$$

where we have used $F_p = 0.63$. Thus, for a 100 hour aircraft, the design envelope criterion is $M/N_o = 3 \times 10^{-6}$ and for a 1,000 hour aircraft $M/N_o = 3 \times 10^{-7}$.

It is recommended that the power spectral approach be used in place of the standard discrete gust methods. Reasonably discrete gusts undoubtedly occur in the atmosphere; however, there is accumulating evidence that the preponderence of gusts are better described in terms of continuous turbulence models. It has long been accepted that clear air turbulence at moderate intensity levels is generally continuous in nature. Thunderstorm gust velocity profiles are now available in considerable quantity, and they almost invariably display the characteristics of continuous turbulence. Also, low level turbulence is best described with power spectral methods. A power spectral method of load analysis is not necessarily more difficult to apply than a discrete gust method. The present static load pluge-only discrete gust methods can, in fact, be converted to a power spectral basis by making a few simple modifications in the definitions of the gust alleviation factor and the design discrete gust. To be sure, this simple rigid-airplane analysis does not exploit the full potentiality of the power spectral approach. But it does account more realistically for the actural mix of gust gradient distances in the atmosphere and the variation of gust intensity with gradient distance.

5.4 Mission Analysis

Wind information is useful in the following three general cases of mission analysis:

a. Mission Planning. Since this activity will normally take place well in advance of the mission, the statistical attributes of the wind are used.

b. Prelaunch Operations. Although wind statistics are useful at the beginning of this period, the emphasis is placed upon forecasting and wind monitoring.

c. Postflight Evaluation. The effect of the observed winds on the flight is analyzed.

5.4.1 Mission Planning.

From wind climatology, the optimum time (month and time of day) and place to conduct the operation can be identified (see Ref. 5.49). Missions with severe wind constraints may have such a low probability of success that the risk is unacceptable. Feasibility studies based upon wind statistics can identify these problem areas and answer questions such as, "Is the mission feasible as planned?"; "If the probable risk of mission delay or failure is unacceptably high, can it be reduced by rescheduling to a lighter wind period ?"

The following examples are given to illustrate the use of some of the many wind statistics available to the mission planner.

Perhaps it is necessary to remove the wind loads damper from a large launch vehicle for a number of hours and this operation must be scheduled some days in advance; the well known diurnal ground wind variation (illustrated in Figs. 5.2.1 through 5.2.4 should be considered for this problem. If, for example, 20 knots were the critical wind speed, Figure 5.2.4 shows a 1-percent risk at 0600 EST, but a 13-percent risk at 1500 EST in July. Obviously the midday period should be avoided for this operation. Since these figures were constructed from hourly peak winds, all probability values apply to 1-hour exposure periods. It is important to recognize that the wind risk depends not only upon wind speed but also upon exposure time. From Figure 5.4.1, the risk in percentage associated with a 30-knot wind at 10 meters in February at Cape Kennedy can be obtained for various exposure times. The upper curve shows the risk increasing from 1 percent for 1-hour exposure

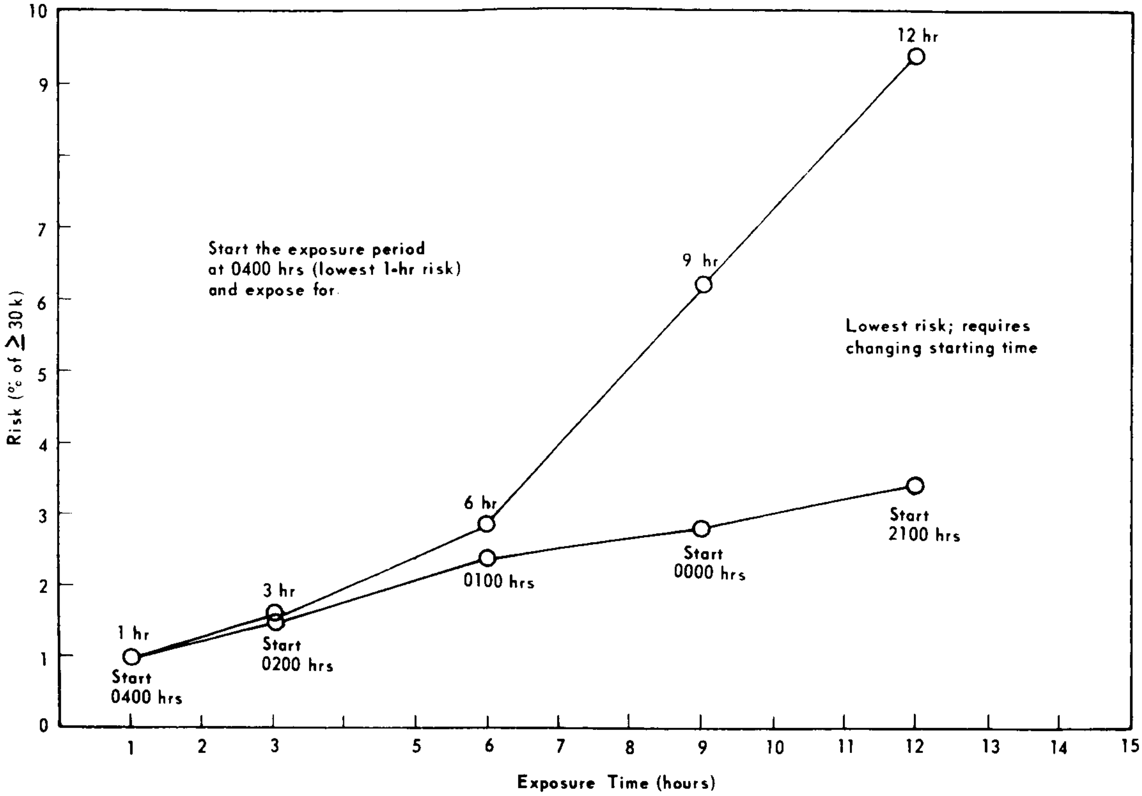


FIGURE 5.4.1 EXAMPLE OF WIND RISK FOR VARIOUS EXPOSURE TIMES

starting at 0400 EST to 9.3 percent for 12-hour exposure starting at 0400 EST. In this case the exposure period extends through the high risk part of the day. The lower curve illustrates the minimum risk associated with each exposure period. The lowest risk, of course, is realized by changing the starting times to avoid the windy portion of the day. Although there is not space here for the tabulation, wind risk probabilities by month and starting hour for exposure periods from 1 hour to 365 days are available upon request.

When considering winds aloft for mission planning purposes, again the first step might be to acquire general climatological information on the area of concern. From Figures 5.4.2, 5.4.3, 5.4.4, it is readily apparent that for the Eastern Test Range most strong winds occur during winter in the 10- to 15-kilometer altitude region (this applies also to nearly all midlatitude locations). It is also true that these strong winds are usually from a westerly direction.

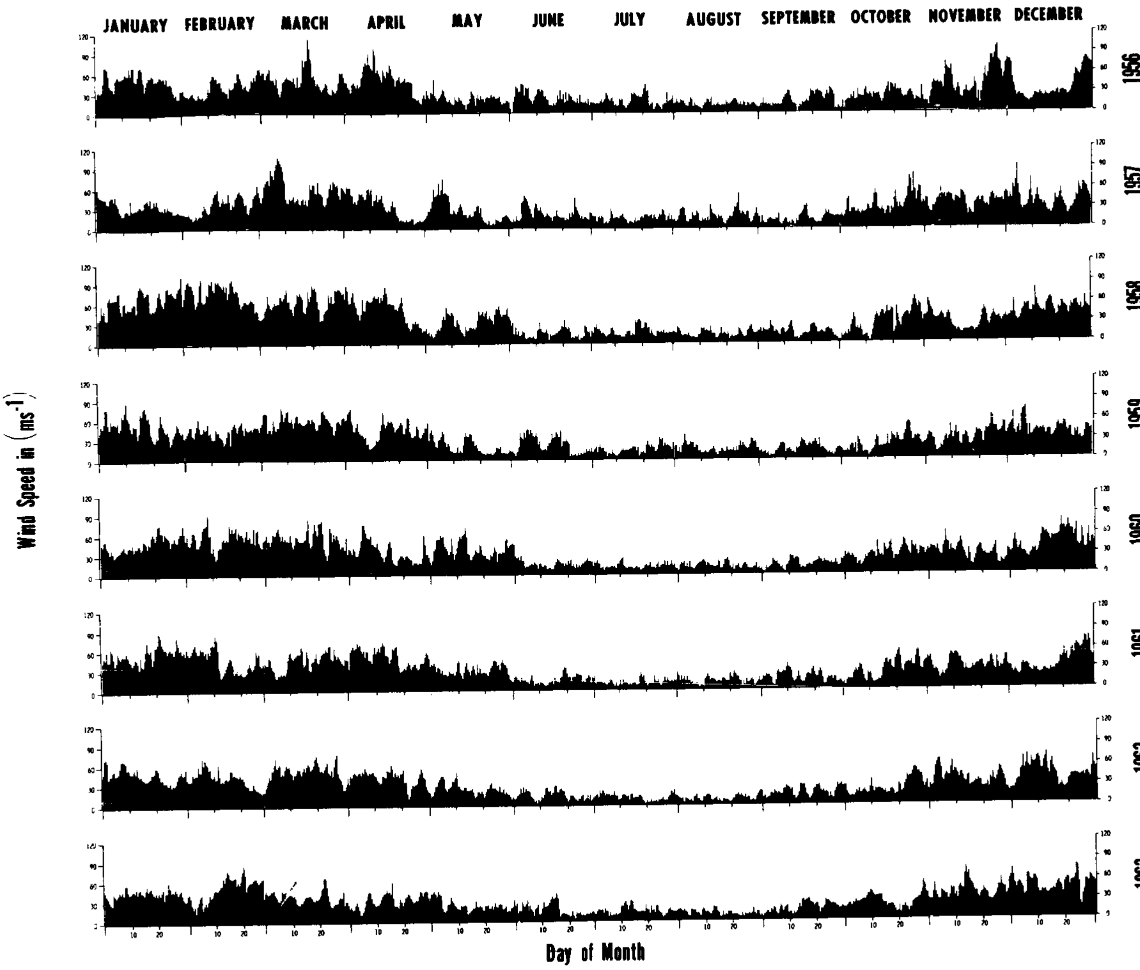


FIGURE 5.4.2 TWICE DAILY MAXIMUM WIND SPEED IN THE 10- TO 15-KILOMETER LAYER AT CAPE KENNEDY, FLORIDA

Next, the mission analyst might ask if a particular mission is feasible. If, for example, the flight is to take place in January and 10- to 15-kilometer altitude winds $\geqq 50$ ms^{-1} are critical, from Table 5.3.5, Section 5.3.4, the probability of favorable winds on any day in January is 0.496. With such a low probability of success, this mission may not be feasible. But, to continue the example, if it is necessary that continuously favorable winds exist for 3 days — perhaps for a dual launch — the probability of success will decrease to 0.256. Obviously an alternate mission schedule must be planned or else the scheduled space vehicle must be provided additional capability through redesign.

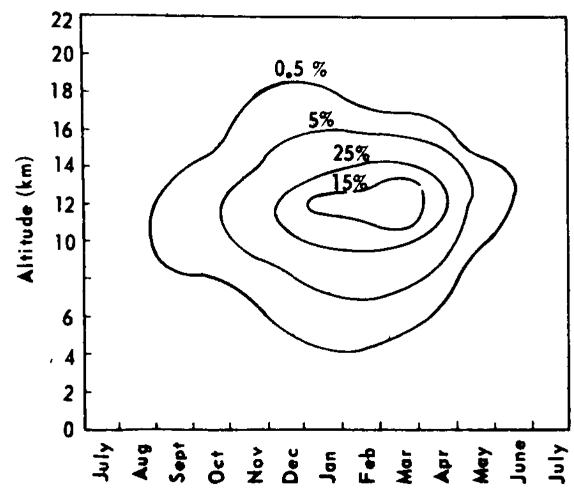


FIGURE 5.4.3 FREQUENCY OF SCALAR WIND SPEED EXCEEDING 50 ms^{-1} AS A FUNCTION OF ALTITUDE AND MONTHS FOR THE YEARS 1956 THROUGH 1963 AT CAPE KENNEDY, FLORIDA

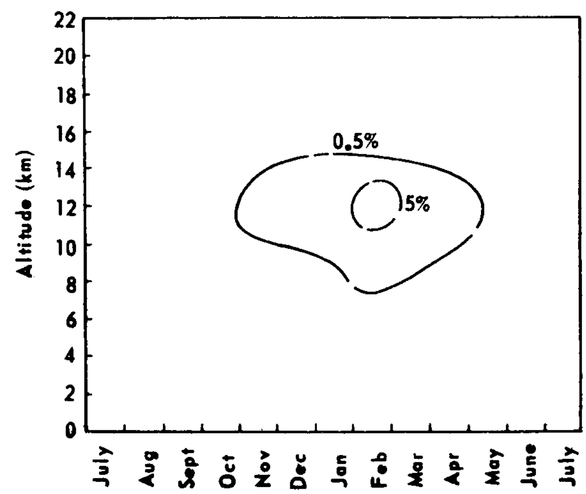


FIGURE 5.4.4 FREQUENCY OF SCALAR WIND SPEED EXCEEDING 75 ms^{-1} AS A FUNCTION OF ALTITUDE AND MONTH FOR THE YEARS 1956 THROUGH 1963 AT CAPE KENNEDY, FLORIDA

Perhaps the vehicle can remain on the pad in a state of near readiness awaiting launch for several days. In this case it would be desirable to know the probability of occurrence of at least one favorable wind speed, for example, in a 4 day period (eight 12-hour periods). From Table 5.3.5, Section 5.3.4, the probability is 0.813. If greater flexibility of operation is desired, one might require four favorable opportunities in 4 days. This probability, 0.550, can be obtained from line 8, column 4, of Table 5.3.11. Now, if consecutive favorable opportunities are required; for example, four consecutive successes in eight periods, the probability of success will be somewhat lower (0.431) from Table 5.3.12.

The mission planner might also gain some useful information from the persistence of the winds aloft. From Table 5.3.7, Section 5.3.4 the probability of winds < 50 ms^{-1} on any day in January is 0.496. But if a wind speed < 50 ms^{-1} does occur, then the probability that the next observed wind 12 hours later would be < 50 ms^{-1} is 0.82, a rather dramatic change. Furthermore, if the wind continues below 50 ms^{-1} for five observations, the probability that it will remain there for one more 12-hour period is 0.92.

As the time of the operation approaches T-4 to T-1 days, the conditional probability statements assume a more significant role. At this point, as the winds will usually be monitored, the appropriate conditional probability value can be identified and used to greater advantage.

The above is intended to illustrate the type of analysis that can be accomplished to provide objective data for program decisions. This may best be accomplished by a close working relationship between the analyst and those concerned with the decision.

5.4.2 Prelaunch Wind Monitoring.

Inflight winds constitute the major atmospheric-forcing function in space vehicle and missile design and operations (Ref: 5.50). A frequency content of the wind profile near the bending mode frequencies or wind shear with the characteristics of a step input may exceed the vehicle's structural capabilities (especially on forward stations for the small scale variations of the wind profiles). Wind profiles with high speeds and shears exert high structural loads at all stations on a large space vehicle, and when the influences of bending dynamics are high, even a profile with low speeds and high shears can create large loads (Ref. 5.51).

Because of the possibility of launch into unknown winds, operational missiles systems must accept some inflight loss risk in exchange for a rapid-launch capability. But research and development missiles and space vehicles, in particular, cost so much that the overall success of a flight outweighs the consideration of launch delays caused by excessive inflight wind loads. If the exact wind profile could be known in advance, it would be a relatively simple task to decide upon the launch date and time. However, there is little hope of accurately forecasting the detailed wind profile very much into the future.

Over the years, these situations have increasingly put emphasis on prelaunch monitoring of inflight winds. Now, finally, prelaunch wind profile determination techniques essentially preclude the risk of launching a space vehicle or research and development missile into an inflight wind condition that would cause it to fail.

Recent development and operational deployment of the FPS-16 radar/Jimsphere system (Ref. 5.32) significantly minimizes vehicle failure risks when properly integrated into a flight simulation program. The Jimsphere sensor, when tracked with the FPS-16, or other radar with equal tracking capability, provides a very accurate "all weather" detailed wind profile measurement. FPS-16 radars are available at all national test ranges.

In general, the system provides a wind profile measurement from the surface to an altitude of 17 kilometers in slight less than 1 hour, a vertical spacial frequency resolution of 1 cycle per 100 meters, and an rms error of about 0.5 ms^{-1} or less for wind velocities averaged over 50-meter intervals. The resolution of this data permits calculating the structural loads associated with the first bending mode, and generally the second mode of missiles and space vehicles, during the critical, high dynamic pressure phase of flight. This provides better than an order-of-magnitude accuracy improvement over the conventional rawinsonde wind profile measuring system (Ref. 5.52).

By employing the appropriate data transmission resources, a detailed wind profile from the FPS-16 radar can be ready for input to the vehicle's flight simulation program within a few minutes after tracking of the Jimsphere. The flight simulation program provides flexibility relative to vehicle dynamics and other parameters in order to make maximum use of the detailed wind profiles.

If very critical wind conditions exist and the mission requirement dictates a maximum effort to launch with provision for last minute termination of the operation, then a contingency plan that will provide essentially real time wind profile and flight simulation data may be employed. This is done while the Jimsphere balloon is still in flight.

An example of the FPS-16 radar/Jimsphere system data appears in Figure 5.4.5 — the November 8 and 9, 1967, sequence observed during prelaunch activities for the first Apollo/Saturn-V test flight, AS-501. The persistence over a period of 1 hour of some small scale features in the wind profile structure, as well as the rather distinct changes that developed in the profiles over a period of a few hours, is evident.

The FPS-16 radar/Jimsphere system (Fig. 5.4.6) is routinely used in the prelaunch monitoring of NASA's Apollo/Saturn-IB and -V flights. The wind profile data are transmitted to the Manned Spacecraft Center in Texas and Marshall Space Flight Center, Alabama, and the flight simulation results are sent to the launch complex at Kennedy Space Center, Florida

An FPS-16/Jimsphere operational measurement program is currently being conducted at Cape Kennedy, Florida; Wallops Island, Virginia;

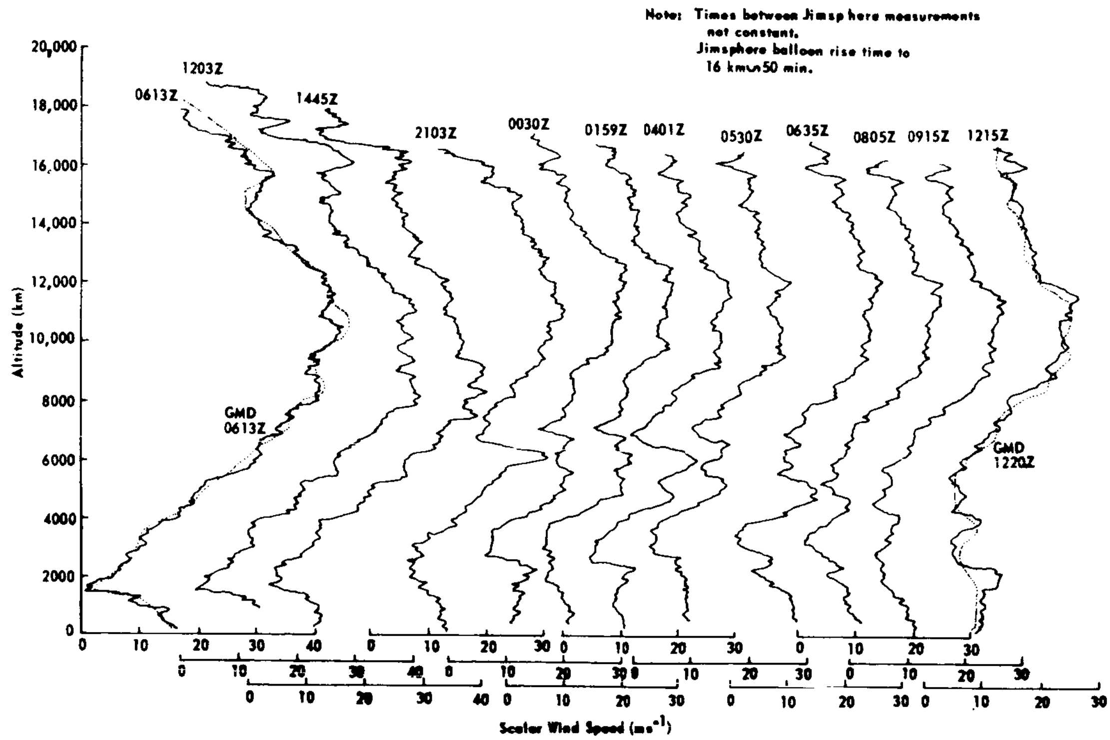


FIGURE 5.4.5 EXAMPLE OF THE FPS-16 RADAR/JIMSPHERE SYSTEM DATA — NOVEMBER 8-9, 1967

Green River, Utah; White Sands Missile Range, New Mexico; and Point Mugu, California, to obtain detailed wind profile data for use in space vehicle and missile response studies, airplane turbulence analysis, atmospheric turbulence investigations, and mesometeorological studies. Sequential measurements similar to the Saturn-V data shown here — of eight to ten Jimsphere wind profiles approximately 1 hour apart — are currently being made on at least 1 day per month for each location. Single profile measurements are also made daily at Cape Kennedy.

5.4.3 Post Flight Evaluation.

5.4.3.1 Introduction.

Because of the variable effects of the atmosphere upon a large space vehicle at launch and during flight, various meteorological parameters are measured at the time of each space vehicle launch, including wind and thermodynamic data at the earth's surface and up to an altitude of at least 50 kilometers. To make the data available, meteorological tapes are prepared, presentations are made at flight evaluation meetings, memoranda of data

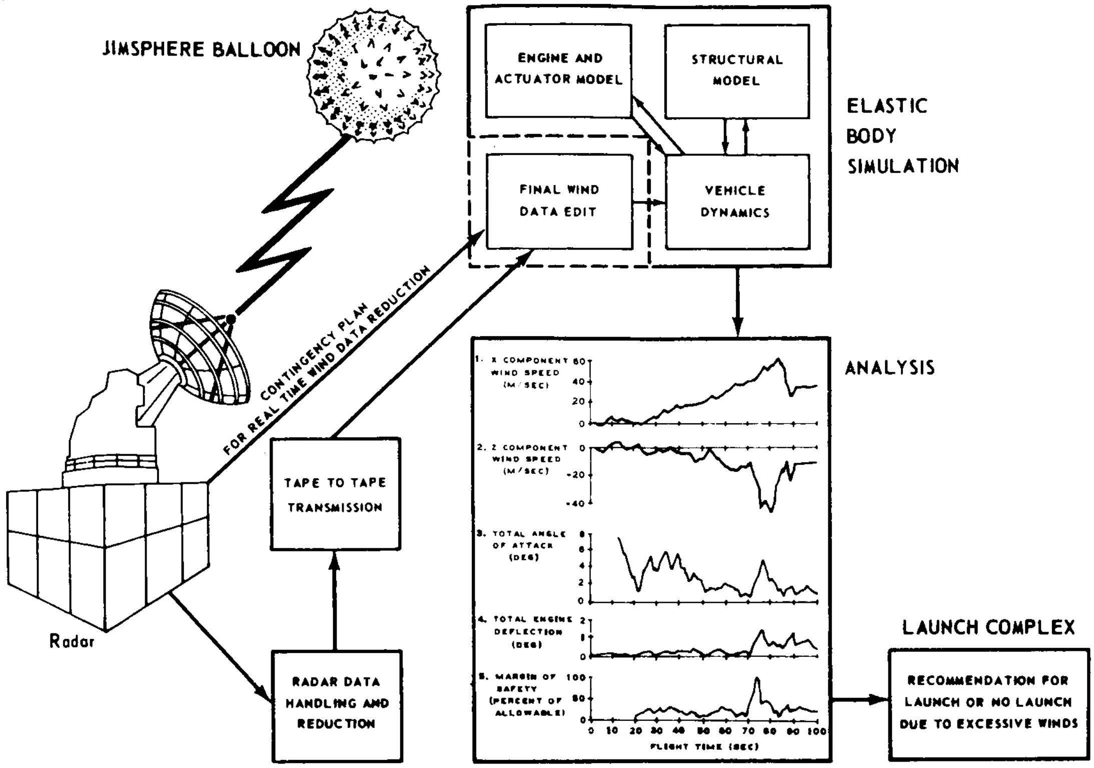


FIGURE 5.4.6 OPERATION OF THE FPS-16 RADAR/JIMSPHERE SYSTEM

tabulations are prepared and distributed, and a summary is written for the final vehicle flight evaluation report. Reference 5.53 for Apollo — Saturn-503 is an example of one of the reports with an atmospheric section.

5.4.3.2 Meteorological Tapes.

Shortly after the launch of each space vehicle, under the cognizance of the Marshall Space Flight Center, a preliminary meteorological tape is prepared by combining the FPS-16 radar/Jimsphere wind profile data and the rawinsonde wind profile and thermodynamic data (temperature, pressure, and humidity) observed as near the vehicle launch time as feasible. This is done under the supervision of the Marshall Space Flight Center's Aerospace Environment Division. The preliminary meteorological tape is normally available within 12 hours after launch time and provides data to about 35 kilometers. The final meteorological tape is prepared and available for use about 3 days after launch. Addition of rocketsonde wind and thermodynamic data extends the data to at least 50 kilometers.

In the two meteorological data tapes (preliminary and final), thermodynamic data above the measured data is given by Patrick Reference Atmosphere values (Ref. 5.54). To prevent unnatural jumps in the data when the two types are merged, the data is carefully examined to pick the best altitude for the merging.

The meteorological data tapes are made available to all government and contractor groups for their use in the space vehicle launch and flight evaluation. This provides a consistent set of data for all evaluation studies and ensures the best available information of the state-of-the-atmosphere.

Twenty-one parameters of data are included in the meteorological data tape at 25-meter increments of altitude* in Table 5.4.1.

5.4.3.3 Presentations at Flight Evaluation Working Group Meetings.

Unless the space vehicle performance was bad or the magnitude of some atmospheric parameters were near extremes at launch or during flight, only two presentations are made at the flight evaluation meetings on the atmospheric launch environment.

The first presentation is given at the "Quick Look" meeting normally held on the day following launch. At this meeting, preliminary values of the surface weather conditions (temperature, pressure, dew point or relative humidity, visibility, cloudiness, and launch pad wind speed and direction) are given, and plots of the upper wind speeds, direction, and components are shown up to the highest altitude of the available data. Any unusual features of the data are discussed in detail.

At the "First General" Flight Evaluation meeting, the final upper wind speeds and component graphs are shown for all the data used in the meteorological data tape.

Surface wind speeds and directions are measured and recorded at several locations and heights above the launch pad, starting several hours before

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* Altitude increments of 25 meters were chosen to provide for maximum engineering value and for use of the available atmospheric data and do not necessarily represent the attainable frequency response of the measurements.

TABLE 5.4.1 FORMAT OF METEOROLOGICAL TAPE

First Record: Identification			
Word	Symbol	Parameter	Units
1	Y_S	Altitude (geometric) ($0=Y_S=700,000$) H=25	m
2	T	Temperature	°K
3	P	Pressure	mb
4	W	Wind Speed	ms^{-1}
5	W_D	Wind Direction	deg
6	U/100	Relative Humidity (U is percent)	(10^{-2}) %
7	E	Water Vapor Pressure	mb
8	ρ	Density	kg m^{-3}
9	P'	Pressure	newtons cm^{-2}
10	$V_S=C_S$	Velocity of Sound	ms^{-1}
11	N_o	Optical Index of Refraction	unitless
12	N_e	Electomagnetic Index of Refraction	unitless
13	W_x	Pitch Component of Wind Velocity	ms^{-1}
14	W_x	Yaw Component of Wind Velocity	ms^{-1}
15	W_{w-e}	Zonal Component of Wind Velocity	ms^{-1}
16	W_{a-n}	Meridional Component of Wind Velocity	ms^{-1}
17	ρ	Density	kg m^{-3}
18	μ	Coefficient of Viscosity	newton s m^{-3}
19	T	Temperature	°C
20	$S_{x\,250}$	Pitch Component Wind Shear	s^{-1}
21	$S_{z\,250}$	Yaw Component Wind Shear	s^{-1}

launch time. Detailed tabulations are made from the various measuring locations and are distributed by memoranda for flight evaluation purposes.

5.4.3.4 Atmospheric Data Section for Final Vehicle Launch Report.

The results of the flight evaluation are presented in a final vehicle launch report. A section in this report gives the information on the atmospheric environment at launch time. Records are maintained on the atmospheric parameters for all space vehicle test flights conducted at Kennedy Space Center, Florida. Requests for summaries of these atmospheric data, or related questions on specific topics, should be directed to the Aerospace Environment Division, NASA-Marshall Space Flight Center, Alabama 35812.

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APPENDIX 5A
(SECTION V)

RECOMMENDED (EXAMPLE) SPACE VEHICLE WIND CRITERIA FOR PRELAUNCH, LAUNCH, AND FLIGHT

5A.1 Summary of Space Vehicle Wind Criteria

To design* a Space Vehicle, the engineer requires environmental design criteria for both vertically ascending and horizontally flying vehicles. The items described in the following paragraphs are examples for use in the design. Reference is given to specific tables, graphs, equations, and pages of Section V in parenthesis after each item.

5A.2 Ground Winds for Vertically Erect Aerospace Vehicles

During the preflight and lift-off phases, the Space Vehicle will be exposed to the ground wind environment which may be represented with:

a. Wind profiles

(1) For launch, use a one-hour exposure period peak scalar ground winds at the 10-meter level (95 percent). (Table 5.2.13 for 5% risk, page 5.49)

(2) For on pad prelaunch operations, use a thirty-day exposure period peak scalar ground winds at the 10-meter level (99 percent). (Table 5.2.16 for 30-day exposure, page 5.50)

b. Gust factors for a 10-minute averaging period. (Table 5.2.46, page 5.77)

c. Spectra associated with the 99-percentile peak ground wind profiles and associated 10-minute mean wind profiles. (Strong wind speed spectra of Section 5.2.6 on page 5.31)

5A.3 Inflight Winds for Vertically Ascending Vehicles

During the inflight portion of the mission, a Space Vehicle will be exposed to wind shears and turbulence which could result in excessive

* The Space Vehicle should not be launched when its nominal flight path will carry it through a cumulonimbus (thunderstorm) cloud formation.

loads. For design purposes, the environment may be represented with:

a. Synthetic wind profiles

(1) For inflight constant and structural response, use the windiest monthly reference period scalar wind profile (95 percent). (Table 5.3.15 for 95-percentile, page 5.172)

(2) Associated wind shears and discrete gust (99 percent). (Table 5.3.20, page 5.179; Figure 5.3.16, page 5.186; Figure 5.3.17, page 5.187; and see Section 5.3.9.2, page 5.191 for combining gust and shears)

b. Spectra of vertical wind profile details (99 percent) (Figures 5.3.18A and B, page 5.188 and Figure 5.3.18C, page 5.189)

c. Selection of Jimsphere FPS-16 detail wind profiles for analog digital simulation and design confirmation. (Page 5.198)

5A.4 Inflight Winds for Horizontally Flying Vehicles

Recoverable booster stages will experience loads resulting from atmospheric turbulence. These loads will be similar to those experienced by aircraft. Atmospheric turbulence may be represented with:

a. Longitudinal, lateral, and vertical turbulence spectra. (Section 5.3.12, page 5.199 and following pages)

b. Exceedance statistics.

The selection of the exceedance statistics will be consistent with the design ground rules for horizontal flight of the Space Vehicle based on expected operational use. (Pages 5.202 and 5.204)

SECTION VI. ABRASION

By

Glenn E. Daniels

6.1 Introduction.

Particles carried by wind will remove paint from exposed surfaces or scratch, abrade, or erode them, and pit transparent surfaces. When the wind velocities are low or moderate, damage can occur whenever the particle hardness is equal to or greater than the exposed surface. When the speed of an object with relation to atmospheric particles is high, erosion will occur even when the particles have a hardness less than the exposed surface. A space vehicle and its associated facilities should be designed to either withstand or be protected from the conditions described for the geographic area of application.

The penetration of sand and dust into moving parts (bearings, gears, etc.) can result in abnormal wear and failure. Large sand and dust particles may be suspended in the atmosphere during periods of high winds and low humidities (under 50 percent). Particles of dust less than 0.002 mm (0.000078 in.) in diameter are common at any time near or over land surfaces except shortly after precipitation. Particles larger than 0.002 mm (0.000078 in.) will settle out rapidly unless wind or other forces are present to keep the particles suspended. Small particles in the atmosphere over the sea will consist almost entirely of salt.

Particle hardness in this section is expressed according to Mohs' hardness scale, which is based on the relative hardness of representative minerals as listed in Table 6.1 (Ref. 6.2).

TABLE 6.1 MOHS' SCALE-OF-HARDNESS FOR MINERALS

Mohs' Relative Hardness	Mineral	Mohs' Relative Hardness	Mineral
1	Talc	6	Orthoclase
2	Gypsum	7	Quartz
3	Calcite	8	Topaz
4	Fluorite	9	Corundum
5	Apatite	10	Diamond

6.2 Sand and Dust at Surface.

The presence of sand and dust can be expected in all geographical areas of interest, but will occur more frequently in the areas with lower water vapor concentration. The extreme values expected are as follows:

6.2.1 Size of Particles.

a. Sand particles will be between 0.080 mm (0.0031 in.) and 1.0 mm (0.039 in.) in diameter. At least 90 percent of the particles will be between 0.080 mm (0.0031 in.) and 0.30 mm (0.012 in.) in diameter.

b. Dust particles will be between 0.0001 mm (0.0000039 in.) and 0.080 mm (0.0031 in.) in diameter. At least 90 percent of these particles will be between 0.0001 mm (0.0000039 in.) and 0.002 mm (0.000079 in.) in diameter.

6.2.2 Hardness and Shape.

More than 50 percent of the sand and dust particles will be composed of angular quartz or harder material, with a hardness of 7 to 8.

6.2.3 Number and Distribution of Particles.

a. Sand. For a wind speed of 10 m sec^{-1} (19.4 knots) at 3 m (9.9 ft) above surface and relative humidity of 30 percent or less, there will be 0.02 g cm^{-3} (1.2 lb ft^{-3}) of sand suspended in the atmosphere during a sand storm. Under these conditions, 10 percent of the sand grains will be between 0.02 m (0.079 ft) and 1.0 m (3.3 ft) above the ground surface, with the remaining 90 percent below 0.02 m (0.079 ft), unless disturbed by a vehicle moving through the storm.

When the wind speed decreases below 10 m sec^{-1} (19.4 knots), the sand grains will be distributed over a smaller distance above the ground surface; while a steady-state wind speed below 5 m sec^{-1} (9.7 knots) will not be sufficient to set the grains of sand in motion.

As the wind speed increases above 10 m sec^{-1} (19.4 knots), the sand grains will be distributed over higher and higher distances above the ground surface.

b. Dust. For a wind speed of 10 m sec^{-1} (19.4 knots) at 3 m (9.9 ft) above surface, and relative humidity of 30 percent or less, there will be 6×10^{-9} g cm^{-3} (3.7×10^{-7} lb ft^{-3}) of dust suspended in the atmosphere. Distribution will be uniform to about 200 m (656 ft) above the ground.

6.3 Sand and Dust at Altitude.

Only small particles (less than 0.002 mm [0.000079 in.]) will be in the atmosphere above 400 m (1312 ft) in the areas of interest. During actual flight, the vehicle should pass through the region of maximum dust in such a short time that little or no abrasion can be expected.

6.4 Snow and Hail at Surface.

Snow and hail can cause abrasion at Huntsville, River Transportation, New Orleans, Wallops Test Range, and White Sands Missile Range areas. Extreme values expected with reference to abrasion are as follows:

6.4.1 Snow Particles.

Snow particles will have a hardness of 2 to 4 (Ref. 6.3) and a diameter of 1.0 mm (0.039 in.) to 5.0 mm (0.20 in.). A wind speed of 10 m sec^{-1} (19 knots) at a minimum air temperature of -17.8°C (0°F) should be considered for design calculations. At New Orleans a minimum air temperature of -9.4°C (15°F) should be used.

6.4.2 Hail Particles.

Hail particles will have a hardness of 2 to 4 and a diameter of 5.0 mm (0.20 in.) or greater. A wind speed of 10 m sec^{-1} (19 knots) at an air temperature of 10.0°C (50°F) should be considered for design calculations.

6.5 Snow and Hail at Altitude.

Snow and hail particles will have higher hardness values at higher altitudes. The approximate hardness of snow and hail particles in reference to temperature is given in Table 6.2 (See paragraph 4.4.2 remarks).

TABLE 6.2 HARDNESS OF HAIL AND SNOW FOR ALL LOCATIONS

Temperature		Relative Hardness
(°C)	(°F)	(Mohs' Scale)
0	32.0	2
-20	- 4.0	3
-40	-40.0	4
-60	-76.0	5
-80	-112.0	6

Although the flight time of a vehicle through a cloud layer will be extremely short, if the cloud layer contains a large concentration of moderate sized hailstones (25 mm [1 in.] or larger) at temperatures below - 20.0°C (-4°F), considerable damage may be expected (especially to antennas and other protrusions) because of the kinetic energy of the hailstone at impact. Tests have shown a definite relationship between the damage to aluminum aircraft wing sections and the velocity of various sized hailstones. Equal dents (sufficient to require repair) of 1 mm (0.039 in.) in 75 S-T aluminum resulted from the following impacts (Ref. 6.4):

a. A 19-mm (0.75 in.) ice sphere at 190 m sec^{-1} (369 knots).

b. A 32-mm (1.25 in.) ice sphere at 130 m sec^{-1} (253 knots).

c. A 48-mm (1.88 in.) ice sphere at 90 m sec^{-1} (175 knots).

6.6 Raindrops.

With the advent of high-speed aircraft a new phenomenon has been encountered in the erosion of paint coatings, of structural plastic components, and even of metallic parts by the impingement of raindrops on surfaces. The damage may be severe enough to affect the performance of a space vehicle. Tests conducted by the British Ministry of Aviation (Ref. 6.1) have resulted in a table of rates of erosion for various materials and coatings. These materials and coatings were tested at speeds of 220 m sec^{-1} (428 knots). Sufficient data are not available to present any specific extreme values for use in design, but results of the tests indicate that materials used should be carefully considered and weather conditions evaluated prior to launch.

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SECTION VII. ATMOSPHERIC PRESSURE

7.1 Definition.

Atmospheric pressure (also called barometric pressure) is the force exerted as a consequence of gravitational attraction, by the mass of the column of air of unit cross section lying directly above the area in question. It is expressed as a force per unit area.

7.2 Pressure at Surface.

The total variation of pressure from day to day is relatively small. Rapid but slightly greater variations occur as the result of the passage of frontal systems, while the passage of a hurricane can cause somewhat larger, but still not significant changes for pressure environment design of space vehicles. Surface pressure extremes for various locations and their extreme ranges are given in Table 7.1 These data use the results of a study of pressure extremes (Ref. 7.1 and Section XV).

7.3 Pressure Change.

a. A gradual rise or fall in pressure of 3 mb (0.04 lb in.$^{-2}$) and then a return to original pressure can be expected over a 24-hour period.

b. A maximum pressure change (frontal passage change) of 6 mb (0.09 lb in.$^{-2}$) (rise or fall) can be expected within a 1-hour period at all localities.

7.4 Data on pressure distribution with altitude are given in Section XIV.

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TABLE 7.1 SURFACE PRESSURE EXTREMES

Area	Pressure				Elevation (from mean sea level) of Equivalent Station with Standard Atmospheric Conditions			
	Units	Maximum **	Mean	Minimum **	Units	Maximum **	Mean	Minimum **
Huntsville	newton m^{-2}	102500	98800	96000	m	- 92	202	432
	mb	1025	988	960				
	lb $in.^{-2}$	14.9	14.3	13.9	ft	- 302	663	1417
River Transportation	newton m^{-2}	104400	100000	95000*	m	-238	106	516
	mb	1044	1000	950*				
	lb $in.^{-2}$	15.1	14.5	13.8*	ft	-781	348	1693
New Orleans, Gulf Transportation, Panama Canal Transportation, and Wallops Test Range	newton m^{-2}	105000	101325	90000*	m	-285	0	948
	mb	1050	1013.25	900*				
	lb $in.^{-2}$	15.2	14.7	13.1*	ft	-935	0	3110
Eastern Test Range	newton m^{-2}	103550	101750	99250	m	-185	-40	166
	mb	1035.5	1017.5	992.5				
	lb $in.^{-2}$	15.0	14.8	14.4	ft	-606	-133	544
West Coast Transportation, Western Test Range, and Sacramento	newton m^{-2}	104800	101325	93800	m	-265	0	617
	mb	1048	1013.25	938				
	lb $in.^{-2}$	15.2	14.7	13.6	ft	-882	0	2024
White Sands Missile Range	newton m^{-2}	90700	88000	82800	m	886	1216	1614
	mb	907	880	828				
	lb $in.^{-2}$	13.2	12.8	12.0	ft	2907	3989	5295

* During hurricane conditions

** Based on period of available records.

SECTION VIII. ATMOSPHERIC DENSITY

8.1 Definition.

Density is the ratio of the mass of a substance to its volume. (It also is defined as the reciprocal of specific volume.) Density is usually expressed in grams or kilograms per cubic centimeter or cubic meter.

8.2 Atmospheric Density at Surface.

The variation of the density of the atmosphere at the surface from the average for any one station, and between the areas of interest, is small and should have no important effect on preflight operations. Table 8.1 gives the median density at the surface for the four test ranges.

TABLE 8.1 MEDIAN SURFACE* DENSITIES

Area	Surface Altitude	Source of Data	Density	
	m		kg m^{-3}	lb ft^{-3}
Eastern Test Range	5	(Ref. 8.1)	1.1835	7.388×10^{-2}
Western Test Range	61	(Ref. 8.2)	1.2267	7.658×10^{-2}
White Sands Missile Range	1219	(Ref. 8.3)	1.049	6.549×10^{-2}
Wallops Test Range	2	(Ref. 8.4)	1.2320	7.691×10^{-2}

8.3 Data on density distribution with altitude are given in Section XIV.

* At station elevation above mean sea level.

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8.1 Smith, O. E.; and Weidner, Don K.: "A Reference Atmosphere for Patrick AFB, Florida, Annual (1963 Revision)". NASA TM X-53139, 1964. NASA-Marshall Space Flight Center, Huntsville, Alabama.

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8.3 "White Sands Missile Range Reference Atmosphere (Part I)," 1964. IRIG Document No. 104-63, Secretariat, Range Commander's Council, White Sands Missile Range, New Mexico.

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SECTION IX. ATMOSPHERIC ELECTRICITY

By

Glenn E. Daniels

9.1 Thunderstorm Electricity.

Space vehicles not adequately protected can be damaged by (1) direct lightning stroke, (2) current induced in the vehicle from a nearby object struck by lightning, (3) charge induced by nearby charged clouds, or (4) a large buildup of the atmospheric potential gradient. The vehicle is protected in several ways: (1) by ensuring that all metallic sections are connected electrically (bonded) so that the current flow from a lightning stroke is conducted over the skin without any gaps where sparking would occur or current would be carried inside (MIL-B-5087B(ASG)), 15 October 1964, and later amendments (Ref. 9.1) give requirements for electrical bonding); (2) by protecting objects on the ground, such as buildings, by a system of lightning rods and wires over the outside to carry the lightning stroke to the ground; (3) by a cone of protection as shown in Reference 9.2 for the lightning protection plan for Saturn Launch Complex 39; or (4) by surge protection devices in critical circuits (Ref. 9.3).

If lightning should strike a space vehicle ready for test or flight, or a large metallic object nearby such as the test stand or gantry, a complete checkout will be required of all electronic components and moving parts in the vehicle. Potential gradient recorders which will give warning of dangerous conditions in the local area are currently being produced commercially. If potential gradient is a critical item, the use of a unit to monitor potential gradient conditions during test periods should be considered.

9.1.1 Frequency of Occurrence of Thunderstorms.

The frequency of occurrence of "thunderstorm days" (number of days per year on which thunder is heard) is an approximate guide to the probability of lightning strokes to earth in a given area. The number of thunderstorm days per year is called the "isokeraunic level." A direct lightning strike is possible at all locations of interest, but the frequency of such an occurence varies between the locations, as given in Table 9.1 (Refs. 9.2, 9.3, and 9.4).

TABLE 9.1 FREQUENCY-OF-OCCURRENCE OF "THUNDERSTORM DAYS" (ISOKERAUNIC LEVEL)

Location	Mean Number of Days Per Year for Thunderstorms		Monthly Distribution (percent of annual)											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Huntsville	70	%	1	3	6	8	11	19	22	18	9	1	1	1
		No. Days	0.70	2.10	4.20	5.60	7.70	13.30	15.40	12.60	6.30	0.70	0.70	0.70
River Transportation and New Orleans	75	%	3	3	5	5	8	16	21	20	10	3	3	3
		No. Days	2.25	2.25	3.75	3.75	6.0	12.0	15.75	15.0	7.5	2.25	2.25	2.25
Gulf Transportation	90	%	1	1	4	2	9	18	24	23	12	4	1	1
		No. Days	0.90	0.90	3.60	1.80	8.10	16.20	21.60	20.70	10.80	3.60	0.90	0.90
Eastern Test Range	75	%	1	2	5	5	9	19	18	20	14	5	1	1
		No. Days	0.75	1.50	3.75	3.75	6.75	14.25	13.50	15.00	10.50	3.75	0.75	0.75
Panama Canal Transportation	100	%	1	1	4	2	9	18	24	23	12	4	1	1
		No. Days	1.0	1.0	4.0	2.0	9.0	18.0	24.0	23.0	12.0	4.0	1.0	1.0
Western Test Range and West Coast Transportation	6	%	9	11	19	13	7	4	3	7	8	8	3	8
		No. Days	0.54	0.66	1.14	0.78	0.42	0.24	0.18	0.42	0.48	0.48	0.24	0.48
Sacramento	4	%	6	16	12	15	9	6	3	3	10	12	5	3
		No. Days	0.24	0.64	0.48	0.60	0.54	0.24	0.12	0.12	0.40	0.48	0.20	0.12
Wallops Test Range	41	%	1	2	5	7	13	19	24	18	7	2	1	1
		No. Days	0.41	0.82	2.05	2.87	5.33	7.79	9.84	7.38	2.87	0.82	0.41	0.41
White Sands Missile Range	35	%	1	1	3	6	14	19	24	18	9	3	1	1
		No. Days	0.35	0.35	1.05	2.10	4.90	6.65	8.40	6.30	3.15	1.05	0.35	0.35

9.1.2 Frequency of Lightning Strokes to Earth.

If the isokeraunic level is multiplied by 0.23 (Ref. 9.2), a good estimate of the stroke frequency to the earth per square mile can be obtained. For the 0.2 square mile launch area of Saturn Launch Complex 39, this gives four strokes per year or nearly one stroke for the month of August. The probable number of strokes per year to buildings of different heights will increase with height as shown in Table 9.2.

TABLE 9.2 ESTIMATE OF THE NUMBER OF LIGHTNING STROKES PER YEAR FOR VARIOUS HEIGHTS (EASTERN TEST RANGE) (Ref. 9.2)

Height (m)	Height (feet)	Number of Lightning Strokes (per year)
30.5	100	0.4
61.0	200	1.1
91.4	300	2.3
121.9	400	3.5
152.4	500	4.4
182.9	600	5.3
213.4	700	5.8

9.1.3 Characteristics of Lightning Strokes.

Lightning strokes have the following characteristics at all the areas covered by this document (Refs. 9.5, 9.6, and 9.7):

a. An average peak current of 10,000 amperes can be expected. The peak current flow is reached 6 microseconds after start of stroke, with a fall to one-half the peak value in 24 microseconds. A total stroke charge of 25 coulombs is transmitted to the earth with 90 percent of the current flow, after the initiation of the first stroke, at less than 1000 amperes.

b. The maximum peak current will not be greater than 100,000 amperes 90 percent of the time. This peak current flow is reached in 10 microseconds after start of the stroke, and the current then falls to one-half the peak value in 20 microseconds. A total stroke charge of 100 coulombs is transmitted to the earth, with 95 percent of the current flow, after the initiation of the first stroke, at less than 5000 amperes.

9.1.4 Induced Charge from Atmospheric Potential Gradient.

In many cases, current may be induced in equipment from the atmospheric potential gradient. Normally on a clear day the potential gradient of the atmosphere at the earth's surface averages about 300 volts m^{-1}. Even this potential on a 100-meter-high vehicle could amount to a 30,000 volt potential between the ground and top, if the vehicle is not grounded. With the development of cumulus clouds the potential gradient will increase. If it reaches as high as 3×10^6 volts m^{-1} (the average breakdown voltage of air), then a lightning flash may occur.

Because of the potential gradient, on days when scattered clouds occur, severe shocks can result from the charge induced along a metal cable on a captive balloon. Similarly induced charges on home television antennas have exploded fine wire coils in television sets. Such equipment damage can be prevented by installing lightning arresters with air gaps small enough to discharge the current before it discharges within the equipment.

9.1.5 Radio Interference.

Whenever an electrical charge produces a spark between two points, electromagnetic radiation is emitted. This discharge is not limited to a narrow band of frequencies, but covers most of the electromagnetic radiation spectrum with various intensities. Most static heard in radio reception is related to electrical discharges, with lightning strokes contributing a large percentage of the interference. This interference from lightning strokes is propagated through the atmosphere in accordance with laws valid for ordinary radio transmission and may travel for great distances. With the transmission of interference from lightning strokes over great distances, certain frequencies remain prominent, with 30 kc being the major frequency. Interference to telemetering and guidance needs to be considered only when thunderstorms are occurring within 100 km (60 miles) of the space vehicle site. Prediction of such weather can be obtained from the local weather forecast personnel.

9.1.6 Coronal Discharge.

As the atmospheric potential gradient increases, the air surrounding exposed sharp points is increasingly ionized. If the ionization is sufficient, coronal discharges may occur. The induced charge from a nearby lightning stroke may aid such a discharge. Such a discharge may be severe when lightning storms or cumulus development are within about 16 km (10 miles) of the launch pad.

9.1.7 Ground Current.

When lightning strikes an object, the current will flow through a path to the true earth ground. The voltage drop along this path may be great enough over short distances to be dangerous to personnel and equipment (Ref. 9.3). Cattle and humans have been electrocuted from the current flow through the ground and the voltage potential between their feet while standing under a tree struck by lightning.

9.2 Static Electricity.

A static electric charge can result from motion of an object through air containing dust or snow particles, or by wind-borne dust (often too small to be visible) or snow particles striking the object. This charge builds up until a potential is reached sufficiently high to bridge an air gap and so permit the charge to be carried to the ground. A discharge of potential will then occur, and may cause the ignition of explosive gases or interference in radio communications. This type of discharge, which occurs more frequently during periods of low humidities, is best prevented by grounding all metallic parts.

Static electric discharges can be expected at all geographical areas of concern.

9.3 Breakdown Voltage.

The breakdown voltage (voltage required for a spark to jump a gap) is a function of the atmospheric pressure. The breakdown voltage decreases to a minimum of 327 volts mm^{-1} at an atmospheric pressure of 760 newtons m^{-2} (7.6 mb) representing an altitude of 33.3 km. Above and below this altitude, the breakdown voltage increases rapidly, reaching several thousand volts per millimeter at normal atmospheric pressure as shown in Figure 9.1 (Ref. 9.8).

9.4 Inflight Triggered Lightning.

The launch vehicle should be capable of withstanding an electrical discharge from triggered lightning while inflight. The characteristics of such a discharge is the same as given in Par. 9.1.3, except that the average current flow will remain at a value of at least 185 Amperes for at least 175 milliseconds before falling to zero. This is similar to a long-continuing-current-discharge. Reference is made to MIL-B-5087B(ASG), 15 October 1964 (Ref. 9.1); MIL-STD-461A, 1 August 1968 (Ref. 9.9); MIL-STD-462, 31 July 1967 (Ref. 9.10); and "Analysis of Apollo 12 Lightning Incident," report dated February 1970 (Ref. 9.11)

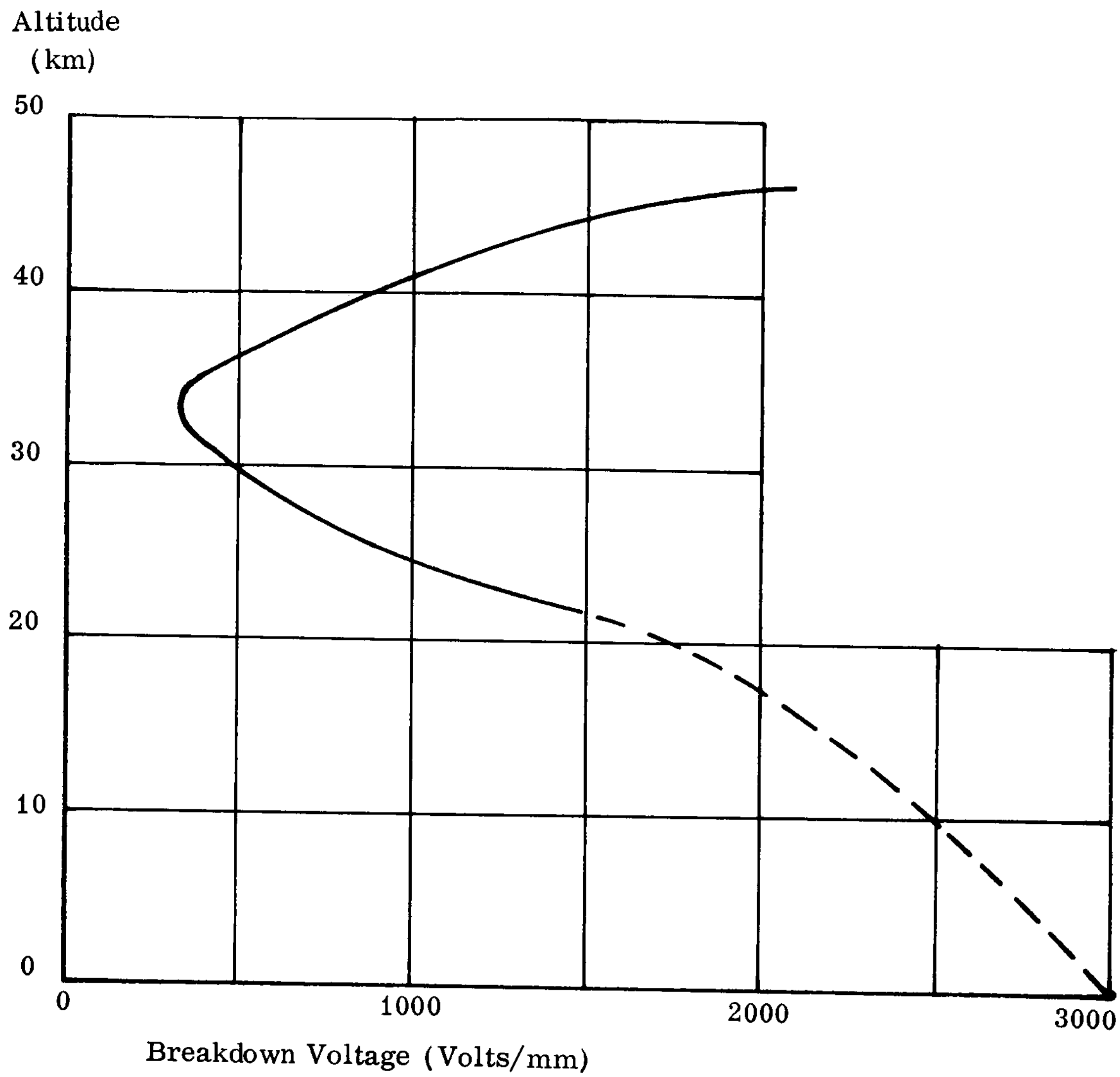

FIGURE 9.1. BREAKDOWN VOLTAGE VS ALTITUDE

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9.3 "Lightning Protection Guideline for STADAN Ground Equipment," prepared by High Voltage Laboratory, General Electric Company, Pittsfield, Mass. N68-24516 NASA CR 94682, Goddard Space Flight Center, Greenbelt, Maryland, November 1967.

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SECTION X. ATMOSPHERIC CORROSION

By

Glenn E. Daniels

10.1 Introduction.

The atmosphere near the ocean will cause corrosion of exposed metals. Wind moving over breaking sea waves will pick up small droplets of salt water. These droplets are small enough to remain suspended in the air. Some will evaporate and leave tiny particles of salt in the air. When these droplets and particles accumulate on surfaces and dry, a film of salt remains on the surface. The efficiency of an optical surface coated with this salt film will be considerably reduced over periods of time. When the relative humidity is near saturation, or when light rain or drizzle occurs, the salt on the surface will absorb water and form a highly conductive solution. Corrosion by electrolytic action can result when two dissimilar metals are involved, and corrosion of a single metal can occur when the solution can react chemically. This solution can provide a conductive electrical path and short electrical equipment.

10.2 Corrosion.

The amount of corrosion is a function of several factors. Among the most important factors are (Ref. 10.1):

a. The distance of the exposed site from the ocean.

b. The length of time the humidity is high — the longer a material is wet, the more the corrosion.

c. Air temperature.

d. The corrosion rate varies with elevation above sea level.

e. Corrosion is dependent on exposure direction, shelter around or near the material, and the direction and magnitude of the prevailing winds.

10.2.1 Laboratory Salt Spray Tests.

Methods have been devised to simulate the effects of salt spray in the laboratory. The following procedures have been taken from MIL-STD-810, Method 509 (Ref. 10.2), (Federal Test Method Standard No. 151; Method 811 has slight differences):

a. A salt solution is formed under the following conditions:

(1) Five percent sodium chloride in distilled water.

(2) pH between 6.5 and 7.2 and specific gravity from 1.027 to 1.041 when measured at a temperature between 33.3° and 36.1°C (92° and 97°F).

b. An air temperature of 35.0°C (95°F) is maintained in the test chamber.

c. The salt solution is atomized and applied so that 0.5 to 3.0 milliliters (0.015 to 0.10 fluid ounces) of solution will collect over an 80-square-centimeter (12.4 square in.) horizontal area in 1 hour.

d. The time of exposure of the test will vary with the material being evaluated.

Increasing the salt concentration will not accelerate the test.

Acceptance of the laboratory tests as an exact representation of the corrosion which will occur at a specific site may result in erroneous conclusions.

In any area where corrosion by the atmosphere can be an important factor, on-the-spot tests are needed. A test such as "Sample's wire-on-bolt test" (Ref. 10.3) should be conducted on the site, with tests made at various heights above the ground.

Protection from salt spray corrosion will be required in the following areas:

(1) New Orleans

(2) Gulf Transportation

(3) Eastern Test Range

(4) Panama Canal Transportation

(5) Western Test Range

(6) West Coast Transportation

(7) Sacramento

(8) Wallops Test Range

10.3 Obscuration of Optical Surfaces.

The accumulation of salt on exposed surfaces is greatest during onshore winds when many waves are breaking and forming white caps. Extremes expected are as follows (Ref. 10.4):

a. Particle size: Range from 0.1 to 20 microns, with 98 percent of the total mass greater than 0.8 microns.

b. Distribution is uniform above 3048 meters (10,000 ft), but below cloud levels.

c. Fallout of salt particles at Eastern Test Range:

(1) Maximum: 5.0×10^{-7} g cm^{-2} day^{-1}, to produce a coating on an exposed surface of 100 microns day^{-1}. This extreme occurs during precipitation.

(2) Minimum: 2.5×10^{-8} g cm^{-2} day^{-1}, to produce a coating on an exposed surface averaging 5 microns day^{-1}. This fallout occurs continuously during periods of no precipitation, and is independent of wind direction. This coating will not usually be of uniform thickness, but be spots of salt particles unevenly distributed over the optical surface.

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SECTION XI. FUNGI AND BACTERIA

By

Glenn E. Daniels

Fungi (including mold) and bacteria have the highest rate of growth at temperatures between 20.0° C (68° F) and 37.7° C (100° F) and relative humidities between 75 and 95 percent (Refs. 11.1 and 11.2). Fungi and bacteria secrete enzymes and acids during their growth. These secretions can destroy most organic substances and many of their derivatives. Typical materials which will support growth of fungi and bacteria and are damaged by them if not properly protected are cotton, wood, linen, leather, paper, cork, hair, felt, lens-coating material, paints, and metals. The four groups of fungi used in the fungus-resistance tests for equipment are as follows:

Group	Organism	American Type Culture Collection Number
I	Chaetomuim globosum	6205
	Myrothecium verrucaria	9095
II	Memenialla echinata	9597
	Aspergillus niger	6275
III	Aspergillus flavus	10836
	Aspergillus terreus	10690
IV	Penicillium citrinum	9849
	Penicillium ochrochloron	9112

A suspension of mixed spores made from one species of fungus from each group is sprayed on the equipment being tested in a test chamber. The equipment is then left for 28 days in the test chamber at a temperature of 30° ± 2° C (86° ± 3.6° F) and relative humidity of 95 ± 5 percent.

Equipment is usually protected from fungi and bacteria by incorporating a fungicide-bactericide in the material, by a fungicide-bactericide spray, or by reducing the relative humidity to a degree where growth will not take place. A unique method used in the Canal Zone to protect delicate, expensive bearings in equipment was to maintain a pressure (with dry air or nitrogen) slightly above the outside atmosphere (few millibars) within the working parts of the equipment, thus preventing fungi from entering equipment.

Proper fungus- and bacteria-proofing measures are required at the following areas:

(1) River Transportation

(2) New Orleans

(3) Gulf Transportation

(4) Panama Canal Transportation

(5) Eastern Test Range

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SECTION XII. ATMOSPHERIC OXIDANTS

By

Glenn E. Daniels

12.1 Introduction.

Air pollution at the earth's surface has received considerable publicity in recent years because the pollutants reduce visibility, cause damage to crops, irritate the eyes, and have an objectional odor. The ingredients which cause the air pollution are a mixture of oxides of organic matter (mostly nitrogen oxides and hydrocarbons) and ozone. In the Los Angeles area, the mixing of the organic oxides, ozone, and water droplets forms the well known smog. Ozone, although considered one of the rare atmospheric gases, needs consideration in design because of its chemical reaction (oxidation) with organic materials, especially rubber, which becomes hard and brittle under tension in a few minutes time. The presence in smog of strong oxidizing agents closely resembling ozone in their action on organic compounds leads one to believe that ozone exists in smog in greater quantities than in the normal atmosphere.

12.2 Ozone.

Ozone, in high concentrations, is explosive and poisonous. One hundred (100) parts per hundred million (phm) of ozone is toxic to man sufficient to cause death. The use of the atmosphere at high altitudes for breathing by pressurizing, requires removal of the ozone. Ozone may be formed in high concentrations by short wavelength ultraviolet light (below 2537Å), or by the arcing or discharge of electrical currents. A motor or generator with arcing brushes is an excellent source of ozone. The natural ozone concentration at the earth's surface is normally less than 3 parts per hundred million (phm), except during periods of intense smog, where it may exceed 5 phm. Ozone concentration increases with altitude, with the maximum concentration of 1100 parts per hundred million being at about 30 km (98,000 ft).

Maximum expected values of natural atmospheric ozone, for purposes of design studies, are as follows: (a) surface, at all areas, a maximum concentration of 3 phm except during smog, when the maximum will be 6 phm, and (b) maximum concentration, with altitude, is given in Table 12.1 (Ref. 12.1).

TABLE 12.1 DISTRIBUTION OF MAXIMUM DESIGN VALUES OF OZONE CONCENTRATION WITH ALTITUDE FOR ALL LOCATIONS

Geometric Altitude (km)	Geometric Altitude (ft)	Ozone (parts per hundred million)	Ozone Concentration (cm/km)
SRF*	SRF*	6	0.006
9.1	30,000	30	0.010
15.2	50,000	200	0.030
21.3	70,000	700	0.040
27.4	90,000	1100	0.024
33.5	110,000	1100	0.009
39.6	130,000	600	0.002
45.7	150,000	400	0.0005

*SRF - Surface

12.3 Atmospheric Oxidants.

At the surface, a maximum of 60 parts per hundred million of oxidants composed of nitrogen oxides, hydrocarbons, sulphur dioxide, sulphur trioxides, peroxides, and ozone can be expected for 72 hours when smog occurs. The effect of these oxidants on rubber cracking and in some chemical reactions will be equivalent to 22 parts per hundred million of ozone, but not necessarily equivalent to this concentration of ozone in other reactions (Ref. 12.2).

0

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SECTION XIII. ATMOSPHERIC COMPOSITION

By

Glenn E. Daniels

13.1 Composition.

The earth's atmosphere is made up of a number of gases in different relative amounts. Near sea level and up to about 90 km, the amount of these atmospheric gases in clean, relatively dry air is practically constant. Four of these gases, nitrogen, oxygen, argon, and carbon dioxide, make up 99.99 percent by volume of the atmosphere. Two gases, ozone and water vapor, change in relative amounts, but the total amount of these two is very small compared to the amount of the other gases.

The atmospheric composition shown in Table 13.1 can be considered valid up to 90 km geometric altitude. Above 90 km, mainly because of molecular dissociation and diffusive separation, the composition changes from that shown in Table 13.1. Reference is made to the Space Environment Criteria Guidelines document (Ref. 13.2) for additional information on composition above 90 km.

13.2 Molecular Weight.

The atmospheric composition shown in Table 13.1 gives a molecular weight of 28.9644 for dry air (Ref. 13.1). This value of molecular weight can be used as constant up to 90 km, and is equivalent to the value 28.966 on the basis of a molecular weight of 16 for oxygen.

The molecular weight of the atmosphere with relation to height is shown in Table 13.2.

TABLE 13.1 NORMAL ATMOSPHERIC COMPOSITION FOR CLEAN, DRY AIR AT ALL LOCATIONS (VALID TO 90 KILOMETERS GEOMETRIC ALTITUDE)

Gas	Percent by Volume	Percent by Weight*
Nitrogen (N_2)	78.084	75.520
Oxygen (O_2)	20.9476	23.142
Argon (Ar)	0.934	1.288
Carbon dioxide (CO_2)	0.0314	0.048
Neon (Ne)	1.818×10^{-3}	1.27×10^{-3}
Helium (He)	5.24×10^{-4}	7.24×10^{-5}
Krypton (Kr)	1.14×10^{-4}	3.30×10^{-4}
Xenon (Xe)	8.7×10^{-6}	3.9×10^{-5}
Hydrogen (H_2)	5×10^{-5}	3×10^{-6}
Methane (CH_4)	2×10^{-4}	1×10^{-4}
Nitrous Oxide (N_2O)	5×10^{-5}	8×10^{-5}
Ozone (O_3) summer	0 to 7×10^{-6}	0 to 1.1×10^{-5}
winter	0 to 2×10^{-6}	0 to 3×10^{-6}
Sulfur dioxide (SO_2)	0 to 1×10^{-4}	0 to 2×10^{-4}
Nitrogen dioxide (NO_2)	0 to 2×10^{-6}	0 to 3×10^{-6}
Ammonia (NH_3)	0 to trace	0 to trace
Carbon monoxide (CO)	0 to trace	0 to trace
Iodine (I_2)	0 to 1×10^{-6}	0 to 9×10^{-6}

*On basis of Carbon 12 isotope scale for which $C^{12} = 12.000$, as adopted by the International Union of Pure and Applied Chemistry meeting, Montreal, in 1961.

TABLE 13.2 MOLECULAR WEIGHT OF THE ATMOSPHERE FOR ALL LOCATIONS

Geometric Altitude (km)	(ft)	Molecular Weight
SRF* to 90	SRF* to 295,000	28.9644 28.9644

*SRF - Surface

REFERENCES

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SECTION XIV. INFLIGHT THERMODYNAMIC PROPERTIES

By

Orvel E. Smith
and
Dale L. Johnson

14.1 Introduction

This section presents the inflight thermodynamic parameters (temperature, pressure, and density) of the atmosphere. Mean and extreme values of the thermodynamic parameters given here can be used in application of many aerospace problems, such as: (1) research planning and engineering design of remote earth sensing systems; (2) vehicle design and development; and (3) vehicle trajectory analysis, dealing with vehicle thrust, dynamic pressure, aerodynamic drag, aerodynamic heating, vibration, structural and guidance limitations, and re-entry lifting body analysis. Atmospheric density plays a very important role in most of the above problems. The first part of this section gives median and extreme values of these thermodynamic variables with respect to altitude. In the last part of this section, an approach is presented for temperature, pressure, and density as independent variables, with a method to obtain simultaneous values of these variables at discrete altitude levels.

14.2 Temperature

14.2.1 Air Temperature at Altitude.

Extreme air temperature for the following test ranges was compiled from frequency distributions of temperature for the different ranges.

a. Eastern Test Range air temperature extreme values with altitude are given in Table 14.1 (Ref. 14.1). (Period of record was May 1950 to April 1960.)

b. Western Test Range air temperature extreme values with altitude are given in Table 14.2. (Period of record was July 1959 to June 1964.)

c. Wallops Test Range air temperature extreme values with altitude are given in Table 14.3. (Period of record was Jan. 1951 to Oct. 1960.)

d. White Sands Missile Range air temperature extreme values with altitude are given in Table 14.4. (Period of record was Nov. 1951 to Jan. 1960.)

TABLE 14.1 EASTERN TEST RANGE AIR TEMPERATURES AT VARIOUS ALTITUDES

Geometric Altitude (km)	Minimum (°C)	Minimum (°F)	Median (°C)	Median (°F)	Maximum (°C)	Maximum (°F)
SRF(0.005 MSL)	-2.2	28	23.9	75	37.2	99
1	-8.9	16	17.2	63	27.8	82
2	-10.0	14	12.2	54	21.1	70
3	-11.1	12	7.2	45	16.1	61
4	-13.9	7	2.2	36	11.1	52
5	-20.0	-4	-3.9	25	5.0	41
6	-26.1	-15	-10.0	14	-1.1	30
7	-33.9	-29	-17.2	1	-7.2	19
8	-41.1	-42	-25.0	-13	-13.9	7
9	-50.0	-58	-32.2	-26	-21.1	-6
10	-56.1	-69	-40.0	-40	-30.0	-22
16.2	-80.0	-112	-70.0	-94	-57.8	-72
20	-76.1	-105	-62.8	-81	-47.8	-54
30	-58.9	-74	-42.2	-44	-30.0	-22
40	-30.0	-22	-17.8	0	2.2	36
50	-15.0	5	-2.2	28	26.1	79
59	-37.8	-36	-20.0	-4	27.8	82
			*			

* For higher altitudes see references 14.1 and 14.3.

TABLE 14.2 WESTERN TEST RANGE AIR TEMPERATURES AT VARIOUS ALTITUDES

Geometric Altitude (km)	Minimum (°C)	Minimum (°F)	Median (°C)	Median (°F)	Maximum (°C)	Maximum (°F)
SRF(0.06 MSL)	-2.2	28.0	12.6	54.7	41.7	107.0
1	-3.6	25.5	13.5	56.3	33.4	92.1
2	-7.0	19.4	10.1	50.2	28.0	82.4
3	-15.2	4.6	4.7	40.5	17.6	63.7
4	-22.6	-8.7	-0.9	30.4	12.1	53.8
5	-29.7	-21.5	-7.2	19.0	3.3	37.9
6	-35.6	-32.1	-14.4	6.1	-2.7	27.1
7	-43.3	-45.9	-21.9	-7.4	-9.9	14.2
8	-47.4	-53.3	-29.8	-21.6	-15.9	3.4
9	-51.3	-60.3	-36.9	-34.4	-26.8	-16.2
10	-57.0	-70.6	-44.6	-48.3	-31.2	-24.2
16.3	-76.0	-104.8	-64.1	-83.4	-51.0	-59.8
20	-74.9	-102.8	-59.5	-75.1	-49.0	-56.2
30	-63.7	-82.7	-42.5	-44.5	-29.4	-20.9
			**			

** For higher altitudes see references 14.2, 14.3, and 14.4.

TABLE 14.3 WALLOPS TEST RANGE AIR TEMPERATURES AT VARIOUS ALTITUDES.

Geometric Altitude (km)	Minimum (°C)	Minimum (°F)	Median (°C)	Median (°F)	Maximum (°C)	Maximum (°F)
SRF(0.002 MSL)	-11.7	11	12.8	55	39.4	103
1	-21.1	- 6	10.0	50	31.1	88
2	-26.1	- 15	5.0	41	22.8	73
3	-30.0	- 22	1.1	34	15.0	59
4	-33.9	- 29	- 3.9	25	7.8	46
5	-40.0	- 40	-10.0	14	2.8	37
6	-43.9	- 47	-17.2	1	- 1.1	30
7	-47.8	- 54	-23.9	-11	- 7.8	18
8	-50.6	- 59	-32.2	-26	-15.0	5
9	-56.1	- 69	-38.9	-38	-21.1	- 6
10	-61.1	- 78	-45.0	-49	-27.2	-17
16.5	-77.8	-108	-62.2	-80	-47.2	-53
20	-71.1	- 96	-57.2	-71	-46.1	-51
30	-65.0	- 85	-43.9	-47	-27.2	-17
40*	-36.1	- 33	-12.2	10	6.1	43
44*	-20.0	- 4	0.0	32	17.2	63
50*	-22.2	- 8	-10.0	14	5.0	41
56*	-22.2	- 8	-11.1	12	5.0	41
			**			

* Values based on less than 10 observations.
** For higher altitudes see references 14.2, 14.3, and 14.4.

TABLE 14.4 WHITE SANDS MISSILE RANGE AIR TEMPERATURES AT VARIOUS ALTITUDES

Geometric Altitude (km)	Minimum (°C)	Minimum (°F)	Median (°C)	Median (°F)	Maximum (°C)	Maximum (°F)
SRF(1.2 MSL)	-11.7	11	16.1	61	42.8	109
2	-11.7	11	12.8	55	31.1	88
3	-18.9	- 2	6.1	43	22.2	72
4	-23.9	- 11	0.0	32	12.8	55
5	-31.1	- 24	- 7.2	19	6.1	43
6	-36.1	- 33	-13.9	7	0.0	32
7	-42.2	- 44	-20.0	- 4	- 7.2	19
8	-48.9	- 56	-30.0	-22	-13.9	7
9	-55.0	- 67	-37.2	-35	-21.1	- 6
10	-60.0	- 76	-42.8	-45	-27.2	-17
16.5	-80.0	-112	-67.2	-89	-47.8	-54
20	-77.8	-108	-60.0	-76	-52.2	-62
30	-58.9	- 74	-42.8	-45	-26.1	-15
40	-40.0	- 40	-13.9	7	20.0	68
50	-22.8	- 9	6.1	43	17.8	64
60	- 5.0	23	7.2	45	25.0	77
65	- 5.0	23	8.9	48	17.8	64
			*			

* For higher altitudes see references 14.2, 14.3, and 14.4.

14.2.2 Compartment Extreme Cold Temperature.

Extreme cold temperatures during aircraft flight, when compartments are not heated, are given in Table 14.5

TABLE 14.5 COMPARTMENT DESIGN COLD TEMPERATURE EXTREMES FOR ALL LOCATIONS

Maximum Flight Altitude (Geometric) Of Aircraft Used For Transport		Compartment Cold Temperature Extreme	
(m)	(ft)	(°C)	(°F)
4,550	15,000	-35.0	-31
6,100	20,000	-45.0	-49
7,600	25,000	-53.3	-64
9,150	30,000	-65.0	-85
15,200	50,000	-86.1	-123

14.3 Atmospheric Pressure

14.3.1 Definition.

Atmospheric pressure (also called barometric pressure) is the force exerted, as a consequence of gravitational attraction, by the mass of the column of air of unit cross section lying directly above the area in question. It is expressed as force per unit area.

14.3.2 Pressure at Altitude.

Atmospheric pressure extremes for all locations are given in Table 14.6. These data were taken from the pressure frequency distributions for the four test ranges.

14.4 Atmospheric Density.

14.4.1 Definition.

Density (ρ) is the ratio of the mass of a substance to its volume. (It is also defined as the reciprocal of specific volume.) Density is usually expressed in grams or kilograms per cubic centimeter or cubic meter.

TABLE 14.6 ATMOSPHERIC PRESSURE-HEIGHT EXTREMES FOR ALL LOCATIONS

Geometric Altitude (above mean sea level)		Pressure					
		Maximum		Median		Minimum	
(km)	(ft)	(mb)	(lb in.$^{-2}$)	(mb)	(lb in.$^{-2}$)	(mb)	(lb in.$^{-2}$)
0	0	(Use values in Table 7.1 for surface pressure for each station)					
3	9,800	730	10.6	714	10.4	680	9.86
6	19,700	510	7.40	490	7.11	460	6.67
10	32,800	295	4.28	283	4.10	255	3.70
15	49,200	135	1.96	129	1.87	118	1.71
20	65,600	60	8.7×10^{-1}	56	8.1×10^{-1}	51	7.4×10^{-1}
25	82,000	30	4.4×10^{-1}	28	4.1×10^{-1}	22	3.2×10^{-1}
30	98,400	12.5	1.8×10^{-1}	11.7	1.7×10^{-1}	11.2	1.6×10^{-1}
40	131,000	2.9	4.2×10^{-2}	2.7	3.9×10^{-2}	2.5	3.6×10^{-2}
50*	164,000	1.2	1.7×10^{-2}	8.5×10^{-1}	1.2×10^{-2}	1.5×10^{-1}	2.2×10^{-3}
75*	246,000	7.5×10^{-2}	1.1×10^{-3}	2.5×10^{-2}	3.6×10^{-4}	2.5×10^{-4}	3.6×10^{-6}

* Median values from reference 14.2, maximum and minimum values estimated.

14.4.2 Atmospheric Density at Altitude.

14.4.2.1 The density of the atmosphere decreases rapidly with height, decreasing to one-half that of the surface at 7-km altitude. Density is also variable at a fixed altitude, with the greatest relative variability occurring at about 70-km altitude in the high northern latitudes (60°N) for altitude ranges up to 90 km. Other altitudes of maximum density variability occur around 16 km and at 0 km. Altitudes of minimum variability (isopycnic levels) occur around 8, 24, and 90-km altitude.

14.4.2.2 Density varies with latitude in the northern hemisphere, with the mean annual density near the surface increasing to the north. In the region around 8 km, the density variation with latitude and season is small (isopycnic level). Above 8 km to about 28 km, the mean annual density decreases toward the north. Mean-monthly densities between 30 km and 90 km increase toward the north in July and toward the south in January.

14.4.2.3 Considerable data are now available on the mean density and its variability below 30 km at the various test ranges from the data collected for preparation of the IRIG Range Reference Atmospheres (Ref. 14.5). Additional information on the seasonal variability of density below 30 km is presented in an article by J. W. Smith (Ref. 14.6).

14.4.2.4 Above 30 km, the data are less plentiful and the accuracy of the temperature measurements (used to compute densities) becomes poorer with altitude.

14.4.2.5 The median density and extreme minimum and maximum values for the Eastern Test Range are given in Table 14.7. These extreme density values do approach the $\pm 3\sigma$ (corresponding to the normal distribution) density values.

14.4.2.6 The maximum, minimum and median densities for 3 km and above, given in Table 14.7, can be used for all locations given in par 1.5 with an adjustment of the surface median density using the values given in Table 8.1, Section VIII, reduced to sea level.

TABLE 14.7 DENSITY HEIGHT MAXIMUM ($\approx$ +3 SIGMA), MINIMUMS ($\approx$ -3 SIGMA) AND MEDIANS FOR EASTERN TEST RANGE

Altitude **		Density							
		Maximum			Median*		Minimum		
(km)	(ft)	(kg m^{-3})	(lb ft^{-3})	(% Deviation)	(kg m^{-3})	(lb ft^{-3})	(% Deviation)	(kg m^{-3})	(lb ft^{-3})
0	0	1.326	8.278×10^{-2}	12.0	1.1835	7.388×10^{-2}	-3.6	1.141	7.123×10^{-2}
2	6,600	1.047	6.536×10^{-2}	6.1	9.7903×10^{-1}	6.112×10^{-2}	-3.0	9.497×10^{-1}	5.929×10^{-2}
4	13,100	8.287×10^{-1}	5.174×10^{-2}	3.7	7.9916×10^{-1}	4.989×10^{-2}	-2.1	7.824×10^{-1}	4.885×10^{-2}
6	19,700	6.706×10^{-1}	4.187×10^{-2}	3.2	6.4983×10^{-1}	4.057×10^{-2}	-2.2	6.355×10^{-1}	3.967×10^{-2}
8	26,200	5.428×10^{-1}	3.389×10^{-2}	3.1	5.2652×10^{-1}	3.287×10^{-2}	-4.0	5.055×10^{-1}	3.156×10^{-2}
10	32,800	4.352×10^{-1}	2.717×10^{-2}	3.0	4.2255×10^{-1}	2.638×10^{-2}	-6.8	3.938×10^{-1}	2.458×10^{-2}
15	49,200	2.345×10^{-1}	1.464×10^{-2}	7.0	2.1920×10^{-1}	1.368×10^{-2}	-9.7	1.979×10^{-1}	1.235×10^{-2}
20	65,600	1.002×10^{-1}	6.255×10^{-3}	7.5	9.3194×10^{-2}	5.818×10^{-3}	-6.1	8.751×10^{-2}	5.463×10^{-3}
25	82,000	4.274×10^{-2}	2.668×10^{-3}	5.9	4.0358×10^{-2}	2.520×10^{-3}	-6.1	3.790×10^{-2}	2.366×10^{-3}
30	98,400	1.976×10^{-2}	1.234×10^{-3}	7.8	1.8334×10^{-2}	1.145×10^{-3}	-7.3	1.700×10^{-2}	1.061×10^{-3}
35	115,000	9.427×10^{-3}	5.885×10^{-4}	10.3	8.5464×10^{-3}	5.336×10^{-4}	-10.6	7.640×10^{-3}	4.770×10^{-4}
40	131,200	4.637×10^{-3}	2.895×10^{-4}	12.5	4.1220×10^{-3}	2.573×10^{-4}	-14.8	3.512×10^{-3}	2.193×10^{-4}
50	164,000	1.275×10^{-3}	7.960×10^{-5}	16.3	1.0966×10^{-3}	6.846×10^{-5}	-21.3	8.630×10^{-4}	5.388×10^{-5}
60	196,800	3.946×10^{-4}	2.463×10^{-5}	19.4	3.3049×10^{-4}	2.063×10^{-5}	-25.4	2.465×10^{-4}	1.539×10^{-5}
70	229,700	1.100×10^{-4}	6.867×10^{-6}	23.6	8.8998×10^{-5}	5.556×10^{-6}	-25.1	6.666×10^{-5}	4.162×10^{-6}
80	262,500	2.342×10^{-5}	1.462×10^{-6}	19.0	1.9677×10^{-5}	1.228×10^{-6}	-18.9	1.596×10^{-5}	9.964×10^{-7}
90	295.000	3.684×10^{-6}	2.300×10^{-7}	10.9	3.3216×10^{-6}	2.074×10^{-7}	-11.8	2.930×10^{-6}	1.829×10^{-7}

* Median Values from NASA TM X-53139 (Ref. 14.1)

** Geometric Altitude above mean sea level

14.4.2.7 The units for density (kg m-3) are consistent units with those given in the Patrick Reference Atmosphere (1963 Revision) included in Table 14.10 of this document. Density deviations were found as follows:

$$\% \text{ Deviation } \Delta\rho = \frac{\rho_{\text{max or min}} - \rho_{\text{PRA 63}}}{\rho_{\text{PRA 63}}} \times 100$$

where

$\Delta\rho$ = Deviation of density from the Patrick Reference Atmosphere 1963

$\rho_{\text{PRA 63}}$ = Patrick Reference Atmosphere 1963 density = median density

$\rho_{\text{max or min}}$ = Given maximum or minimum densities.

14.5 Simultaneous Values of Temperature, Pressure, and Density at Discrete Altitude Levels.

14.5.1 Introduction

In the previous publication (Ref. 14.10), there were certain typographical errors in the equations presented. These errors have been corrected, and additional material has been added to this section. This section presents simultaneous values for temperature, pressure, and density as guidelines for aerospace vehicle design considerations. The necessary assumptions and the lack of sufficient statistical data sample restrict the precision by which these data can presently be presented. Therefore, the analysis is limited to the Eastern Test Range (Cape Kennedy, Florida).

14.5.2 Method of Determing Simultaneous Value

An aerospace vehicle design problem that often arises in considering natural environmental data is stated by way of the following question: "How should the extremes (maxima and minima) of temperature, pressure, and density be combined (a) at discrete altitude levels? (b) versus altitude?" It would seem simple to work with only three variables with respect to altitude that are connected by two physical equations, which are (1) the equation of state and (2) the hydrostatic equation. However, it is these facts that make rigorous statistical treatment of sample data impossible, and the only recourse is to make empirical comparisons of results derived by independent methods. The following discussion will be addressed to the first question. "How should extremes of three variables be combined?" Or stated in another way: Given an extreme density, what values of temperature and pressure should be used simultaneously with the extreme density?

The differentiation of the equation of state yields:

$$\frac{d\rho}{\rho} = \frac{dP}{P} - \frac{dT}{T} \tag{14.1}$$

Equation (14.1) holds only if the departures $d\rho$, dP, and dT are small relative to their respective quantities. There is also a problem of how to treat the $\pm$ deviations. What is needed is the correlation coefficients between these variables. From basic statistical principles (Ref. 14.7) a satisfactory set of three equations can be derived to relate these three variables to each other. These equations are:

$$\left(\frac{\sigma_T}{\overline{T}}\right) = \left(\frac{\sigma_P}{\overline{P}}\right) r(PT) - \left(\frac{\sigma_\rho}{\overline{\rho}}\right) r(\rho T) \tag{14.2}$$

$$\left(\frac{\sigma_P}{\overline{P}}\right) = \left(\frac{\sigma_\rho}{\overline{\rho}}\right) r(P\rho) + \left(\frac{\sigma_T}{\overline{T}}\right) r(PT) \tag{14.3}$$

$$\left(\frac{\sigma_\rho}{\overline{\rho}}\right) = \left(\frac{\sigma_P}{\overline{P}}\right) r(P\rho) - \left(\frac{\sigma_T}{\overline{T}}\right) r(\rho T) \tag{14.4}$$

where

r( ) are correlation coefficients between thermodynamic quantities denoted in parenthesis

σ is the standard deviation of the thermodynamic quantity denoted by subscript.

As written, equations (14.2), (14.3), and (14.4) represent population parameters, and the underlying assumption is that the sample distribution is normal (Gaussian). From private communications with Dr. Buell, * it was

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* Dr. C. Eugene Buell, Kaman Sciences Corporation, Colorado Springs, Colorado.

learned that in deriving these equations, second and higher order terms have been neglected. An application of these equations was made to derive the correlation coefficients using the available statistics for Cape Kennedy. In the development of the pole-to-pole cross sections for NASA TN D-1641 (Ref. 14.8), the means and standard deviations of temperature, pressure, and density were computed for several stations, including Cape Kennedy. From these statistics the sample estimates for

$$\frac{\sigma_T}{\overline{T}}, \quad \frac{\sigma_P}{\overline{P}}, \quad \frac{\sigma_\rho}{\overline{\rho}}$$

were computed. These parameters are called coefficients of variation (CV). Using the sample coefficients of variations as known quantities, a simultaneous solution of equations (14.2), (14.3), and (14.4) can be obtained to yield the desired correlation coefficients, namely,

$$r(P\rho) = \frac{\left(\frac{\sigma_\rho}{\overline{\rho}}\right)^2 - \left(\frac{\sigma_T}{\overline{T}}\right) + \left(\frac{\sigma_P}{\overline{P}}\right)^2}{2\left[\left(\frac{\sigma_\rho}{\overline{\rho}}\right)\left(\frac{\sigma_P}{\overline{P}}\right)\right]} \tag{14.5a}$$

$$r(PT) = \frac{\left(\frac{\sigma_T}{\overline{T}}\right)^2 + \left(\frac{\sigma_P}{\overline{P}}\right)^2 - \left(\frac{\sigma_\rho}{\overline{\rho}}\right)^2}{2\left[\left(\frac{\sigma_T}{\overline{T}}\right)\left(\frac{\sigma_P}{\overline{P}}\right)\right]} \tag{14.5b}$$

$$r(\rho T) = \frac{\left(\frac{\sigma_P}{\overline{P}}\right)^2 - \left(\frac{\sigma_\rho}{\overline{\rho}}\right)^2 - \left(\frac{\sigma_T}{\overline{T}}\right)^2}{2\left[\left(\frac{\sigma_T}{\overline{T}}\right)\left(\frac{\sigma_\rho}{\overline{\rho}}\right)\right]} \tag{14.5c}$$

From equations (14.5a), (14.5b), and (14.5c), the correlation coefficients were computed for seasonal data samples at 1-km intervals from 0 to 27-km altitude for Cape Kennedy, Florida, and were compared with the correlation coefficients that were derived by the standard statistical method for Cape Kennedy. The maximum differences in the correlation coefficients for the two different methods occurred at 0-km altitude for r(PT) and r(Pρ). These differences were less than 0.08. At altitudes above 1 km, the derived correlation coefficients are almost identical to those computed by the standard statistical method.

The values for the coefficient of variations and the derived correlation coefficients $r(P\rho)$, $r(PT)$, and $r(\rho T)$, are illustrated in Figures 14.1 and 14.2, respectively, and are given in Table 14.8. The density variability is a minimum at the isopycnic levels near 8-and 90-km altitude. The correlation coefficient between pressure and density is also a minimum at the isopycnic levels. Because of the meager data sample for statistical analysis at altitudes above 30 km, the coefficients of variation had to be adjusted by making several trial computations to yield correlation coefficients that were consistent with statistical theory. That is, the correlation coefficients must lie between ± 1. Even though no claim for accuracy can be made about the resulting data, we do have for the first time deviations for temperature, pressure, and density from 0- to 120-km altitude that are consistent in terms of a statistical method and a procedure whereby departures from the mean values of these quantities can be combined. As an example, suppose it is desired to know what temperature and pressure should be used simultaneously with a maximum density at a discrete altitude. Solution: Let the mean density plus 3 standard deviations represent the maximum density. From the foregoing equations it is seen that

$$\text{maximum } \rho = (\bar{\rho} + 3\sigma_{\rho}) = \bar{\rho}\left[1 + 3\,\frac{\sigma_{\rho}}{\bar{\rho}}\right]$$

$$= \bar{\rho}\left[1 + 3\left\{\underbrace{\left(\frac{\sigma_P}{\bar{P}}\right) r(P\rho)}_{(A)} - \underbrace{\left(\frac{\sigma_T}{\bar{T}}\right) r(\rho T)}_{(B)}\right\}\right] . \qquad (14.6)$$

The associated values for pressure and temperature are the last two terms, (A) and (B), multiplied by $\bar{P}$ and $\bar{T}$, respectively, and then this result is added to $\bar{P}$ and $\bar{T}$, respectively. Obtain the appropriate values of r and CV from Table 14.8.

In general, the three extreme ρ, P, and T equations of interest are:

$$\text{Extreme } \rho = (\bar{\rho} \pm M\sigma_{\rho}) = \bar{\rho}\left[1 \pm M\left(\frac{\sigma_{\rho}}{\bar{\rho}}\right)\right]$$

$$= \bar{\rho}\left[1 \pm M\left\{\left(\frac{\sigma_P}{\bar{P}}\right) r(P\rho) - \left(\frac{\sigma_T}{\bar{T}}\right) r(\rho T)\right\}\right] \qquad (14.7a)$$

TABLE 14.8 COEFFICIENTS OF VARIATION AND DISCRETE ALTITUDE LEVEL CORRELATION COEFFICIENTS BETWEEN PRESSURE - DENSITY r(Pρ); PRESSURE - TEMPERATURE r(PT); AND DENSITY - TEMPERATURE r(ρT), EASTERN TEST RANGE (CAPE KENNEDY, FLORIDA), ANNUAL

ALTITUDE	COEFFICIENTS OF VARIATION (CV)			CORRELATION COEFFICIENTS (r)		
(km)	$\sigma(\rho)/\bar{\rho}$ (percent)	$\sigma(P)/\bar{P}$ (percent)	$\sigma(T)/\bar{T}$ (percent)	r(Pρ) (unitless)	r(PT) (unitless)	r(ρT) (unitless)
0	1.8000	.6000	1.5000	.6250	-0.3500	-0.9500
1	1.7000	.5500	1.6000	.3382	-0.0156	-0.9462
2	1.5000	.8000	1.5900	.1508	.3609	-0.8675
3	1.1800	.9800	1.5700	-0.0485	.6606	-0.7818
4	.9700	.8500	1.4000	-0.1799	.7318	-0.8021
5	.8000	.8700	1.3400	-0.2864	.8203	-0.7830
6	.7400	.8400	1.2600	-0.2690	.8246	-0.7666
7	.8800	.9800	1.4200	-0.1633	.7913	-0.7324
8	.9000	1.1300	1.4700	-0.0364	.7910	-0.6402
9	1.1800	1.4700	1.6200	.2678	.7124	-0.4854
10	1.6300	1.7500	1.7200	.4 40	.5588	-0.4553
11	1.8800	1.8000	1.7800	.5328	.4485	-0.5174
12	2.1500	1.8700	1.8500	.5841	.3320	-0.5717
13	2.3800	1.9000	1.8500	.6470	.1946	-0.6220
14	2.6200	1.9200	1.7700	.7373	-0.0066	-0.6804
15	2.7800	1.8800	1.6700	.8107	-0.2238	-0.7520
16	2.8800	1.8400	1.7100	.8262	-0.3154	-0.7953
17	2.8800	1.8000	1.7000	.8338	-0.3537	-0.8113
18	2.7500	1.7500	1.7000	.8036	-0.2706	-0.7904
19	2.5000	1.7800	1.6700	. .7449	-0.0492	-0.7031
20	2.2700	1.8500	1.6500	.6969	.1625	-0.5944
21	2.0800	1.9500	1.6200	.6786	.3325	-0.4672
22	1.9800	2.1200	1.5700	.7087	.4565	-0.3041
23	1.9200	2.3200	1.4800	.7721	.5659	-0.0870
24	1.9500	2.4000	1.4300	.8032	.5831	-0.0157
25	2.000	2.4300	1.4200	.8116	.5682	-0.0196
26	2.0800	2.5000	1.5000	.8006	.5565	-0.0523
27	2.1500	2.6000	1.5800	.7948	.5640	-0.0528
28	2.2300	2 6700	1.7500	.7591	.5584	-0.1161
29	2.3700	2.6300	1.8700	.7249	.4877	-0.2479
30	2.5200	2.6300	1.9200	.7228	.4211	-0.3224
31	2.7000	2.7000	2.000	.7257	.3704	-0.3704
32	2.8800	2.7500	2.0800	.7279	.3142	-0.4222
33	3.0700	2.7300	2.1700	.7260	.2310	-0.5014
34	3.2700	2.6800	2.2300	.7361	.1223	-0.5817
35	3.4800	2.6000	2.3200	.7454	.0027	-0.6647
36	3.7000	2.5000	2.4300	.7587	-0.1263	-0.7421
37	3.9200	2.3700	2.5500	.7793	-0.2686	-0.8129
38	4.1200	2.4600	2.6300	.7947	-0.3096	-0.8232
39	4.3300	2.6400	2.6900	.8084	-0.3199	-0.8163
40	4.5500	2.7900	2.7680	.8220	-0.3442	-0.8176
41	4.7500	2.8600	3.0200	.7958	-0.3046	-0.8192
42	4.9300	2.9200	3.2600	.7712	-0.2706	-0.8215
43	5.1300	3.0000	3.3400	.7850	-0.3075	-0.8309
44	5.3200	3.1800	3.3500	.8037	-0.3270	-0.8252
45	5.5000	3.2400	3.6000	.7797	-0.2912	-0.8261
46	5.6700	3.3200	3.8300	.7571	-0.2539	-0.8242
47	5.8300	3.4100	3.9800	.7489	-0.2402	-0.8232
48	5.9800	3.4800	4.1900	.7284	-0.2090	-0.8223
49	6.1300	3.5900	4.1400	.7572	-0.2540	-0.8241
50	6.2700	3.6900	4.1900	.7644	-0.2633	-0.8232
51	6.4200	3.8200	4.0800	.7984	-0.3201	-0.8260
52	6.5500	3.9100	4.1800	.7950	-0.3103	-0.8234
53	6.7000	4.0100	4.2700	.7953	-0.3089	-0.8222
54	6.8000	4.0700	4.3100	.7990	-0.3164	-0.8232
55	6.9200	4.1400	4.3700	.8016	-0.3220	-0.8241
56	7.0300	4.2100	4.4200	.8043	-0.3267	-0.8244
57	7.1500	4.2800	4.4700	.8081	-0.3351	-0.8258
58	7.2700	4.3600	4.5100	.8127	-0.3434	-0.8263
59	7.3700	4.4200	4.5400	.8172	-0.3530	-0.8277
60	7.4700	4.4800	4.5900	.8188	-0.3565	-0.8283

TABLE 14.8 (Concluded)

ALTITUDE	COEFFICIENTS OF VARIATION (CV)			CORRELATION COEFFICIENTS (r)		
(km)	$\sigma(\rho)/\bar{\rho}$ (percent)	$\sigma(P)/\bar{P}$ (percent)	$\sigma(T)/\bar{T}$ (percent)	$r(P\rho)$ (unitless)	$r(PT)$ (unitless)	$r(\rho T)$ (unitless)
61	7.5700	4.5400	4.6300	.8217	-0.3629	-0.8293
62	7.6500	4.7000	4.8600	.7926	-0.2805	-0.8076
63	7.7500	4.9000	5.0000	.7778	-0.2256	-0.7878
64	7.8300	5.1500	5.1500	.7602	-0.1558	-0.7602
65	7.9000	5.3800	5.3800	.7342	-0.0781	-0.7342
66	7.9800	5.5700	5.4400	.7324	-0.0505	-0.7170
67	8.0300	5.6600	5.4700	.7326	-0.0408	-0.7099
68	8.0700	5.7700	5.4000	.7437	-0.0429	-0.6998
69	8.1000	5.8200	5.5100	.7331	-0.0215	-0.6957
70	8.1200	5.8700	5.4900	.7369	-0.0208	-0.6911
71	8.1200	5.8900	5.4700	.7392	-0.0205	-0.6885
72	8.0700	5.7900	5.3800	.7459	-0.0426	-0.6973
73	8.1200	5.6500	5.2900	.7615	-0.1008	-0.7216
74	8.0700	5.5000	5.1700	.7733	-0.1432	-0.7383
75	7.9000	5.2900	5.4100	.7313	-0.0901	-0.7452
76	7.6800	4.9900	5.6500	.6779	-0.0383	-0.7606
77	7.3800	5.0100	6.1600	.5628	.1390	-0.7403
78	7.0500	5.0400	6.5200	.4587	.2771	-0.7267
79	6.6800	5.1100	6.8400	.3508	.4045	-0.7145
80	6.3200	5.2700	6.7800	.3265	.4730	-0.6784
81	5.9500	5.3600	6.7200	.2975	.5342	-0.6482
82	5.5800	5.5200	6.6600	.2800	.5942	-0.6057
83	5.2500	5.1300	6.6100	.1891	.6259	-0.6475
84	4.9200	4.7800	6.5600	.0855	.6645	-0.6877
85	4.6300	4.4700	6.5100	-0.0232	.7032	-0.7272
86	4.4000	4.1900	6.4500	-0.1271	.7363	-0.7647
87	4.2000	3.9600	6.4000	-0.2296	.7694	-0.7983
88	4.0200	4.0500	6.3400	-0.2344	.7874	-0.7838
89	3.8800	4.1400	6.2800	-0.2255	.7986	-0.7665
90	3.7800	4.0400	5.9600	-0.1608	.7798	-0.7432

$$\text{Extreme } P = (\bar{P} \pm M\sigma_P) = \bar{P}\left[1 \pm M\left(\frac{\sigma_P}{\bar{P}}\right)\right]$$

$$= \bar{P}\left[1 \pm M\left\{\left(\frac{\sigma_\rho}{\bar{\rho}}\right) r(P\rho) + \left(\frac{\sigma_T}{\bar{T}}\right) r(PT)\right\}\right] \qquad (14.7b)$$

$$\text{Extreme } T = (\bar{T} \pm M\sigma_T) = \bar{T}\left[1 \pm M\left(\frac{\sigma_T}{\bar{T}}\right)\right]$$

$$= \bar{T}\left[1 \pm M\left\{\left(\frac{\sigma_P}{\bar{P}}\right) r(PT) - \left(\frac{\sigma_\rho}{\bar{\rho}}\right) r(\rho T)\right\}\right] \qquad (14.7c)$$

where the "M" denotes the multiplication factor to give the desired deviation.

The values of M for the normal distribution and the associated percentile levels are as follows:

	M		Percentile
mean	-3	standard deviations	0.135
mean	-2	standard deviations	2.275
mean	-1	standard deviations	15.866
mean	±0	standard deviations = median	50.000
mean	+1	standard deviations	84.134
mean	+2	standard deviations	97.725
mean	+3	standard deviations	99.865

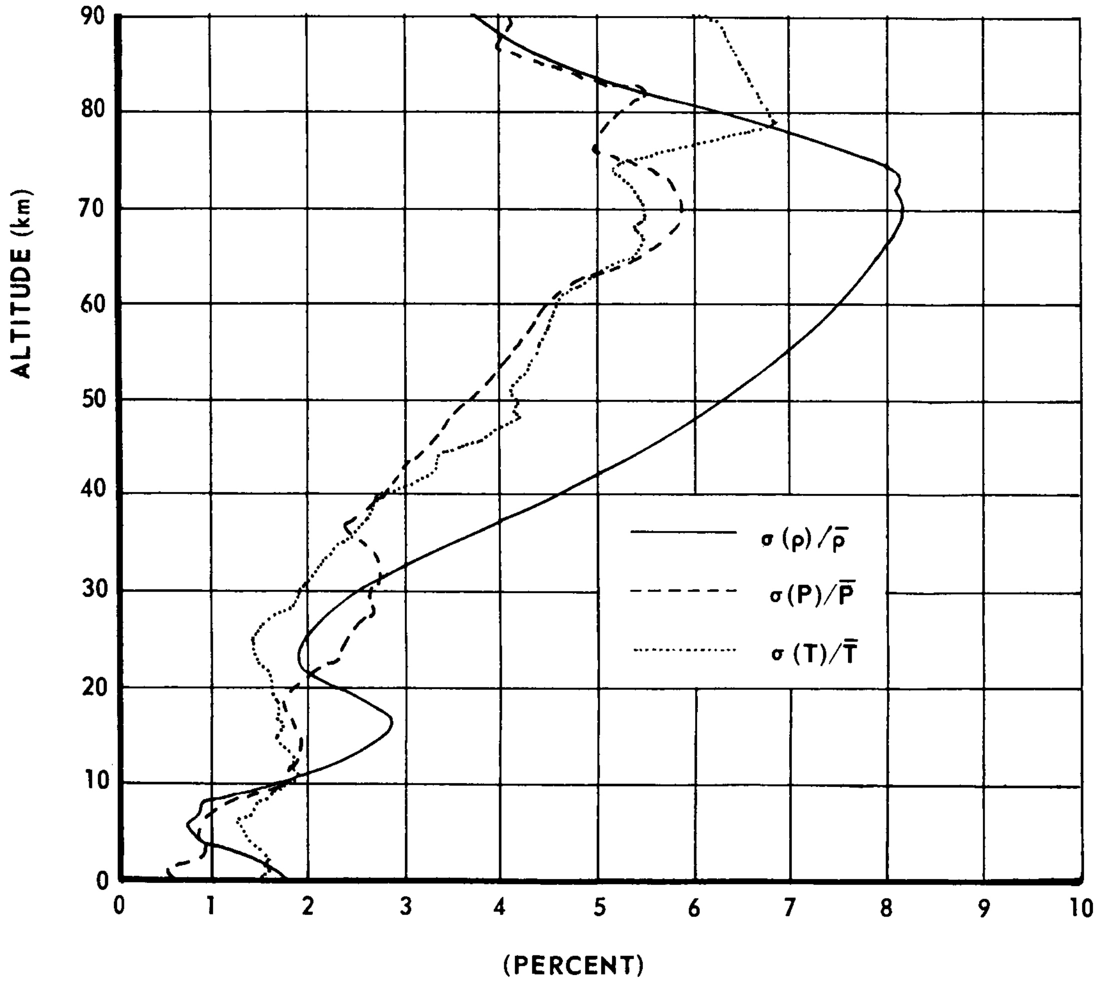

FIGURE 14.1 COEFFICIENT OF VARIATION OF DENSITY, PRESSURE, AND TEMPERATURE AT EASTERN TEST RANGE (CAPE KENNEDY, FLORIDA), ANNUAL.

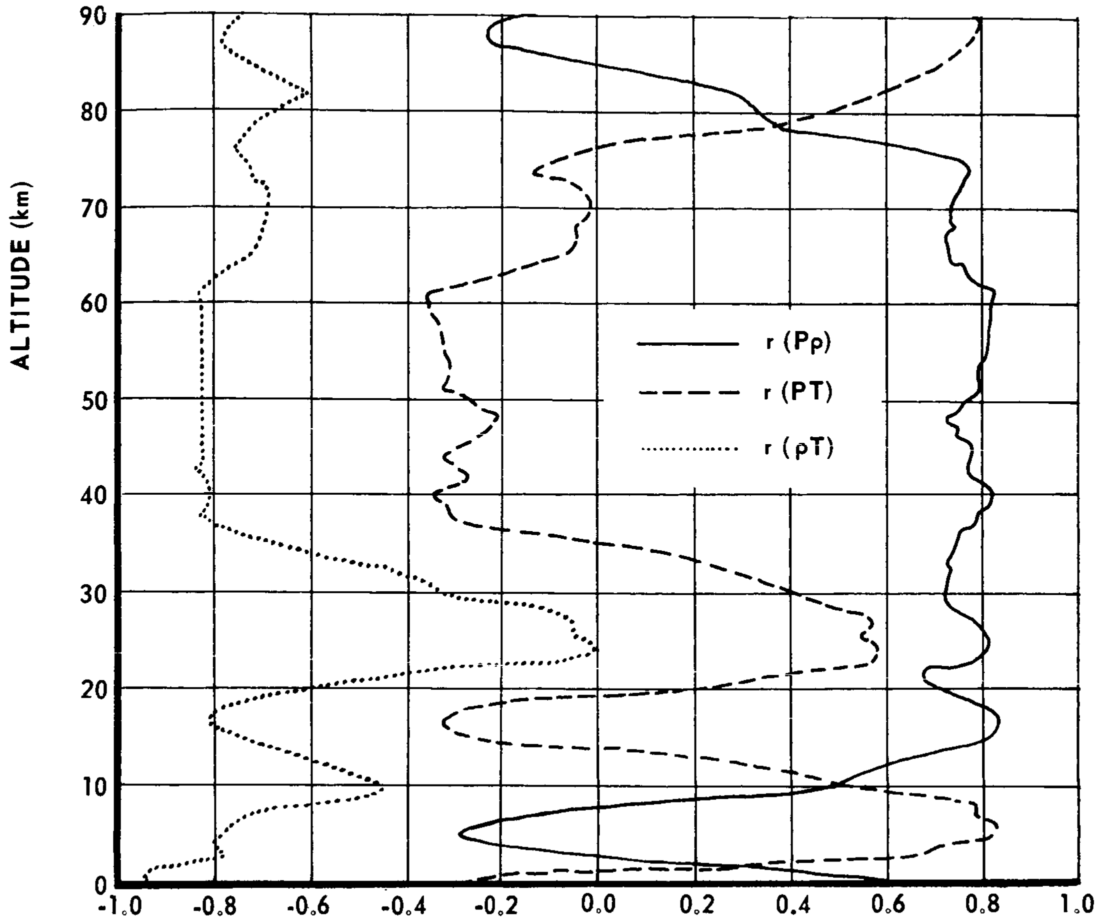

FIGURE 14.2 DISCRETE ALTITUDE LEVEL CORRELATION COEFFICIENTS BETWEEN PRESSURE-DENSITY, r(Pρ); PRESSURE-TEMPERATURE, r(PT); AND DENSITY-TEMPERATURE, r(ρT) AT EASTERN TEST RANGE (CAPE KENNEDY, FLORIDA), ANNUAL.

The two associated atmospheric parameters that deal with a third extreme parameter are listed, in more detail, in the following chart.

	For Extreme Density	For Extreme Temperature	For Extreme Pressure
$P_{assoc.}$ =	$\bar{P}\left[1 \pm \left\{M\left(\frac{\sigma_P}{\bar{P}}\right) r(P\rho)\right\}\right]$	$\bar{P}\left[1 \pm \left\{M\left(\frac{\sigma_P}{\bar{P}}\right) r(PT)\right\}\right]$	
$T_{assoc.}$ =	$\bar{T}\left[1 \pm \left\{M\left(\frac{\sigma_T}{\bar{T}}\right) r(\rho T)\right\}\right]$		$\bar{T}\left[1 \pm \left\{M\left(\frac{\sigma_T}{\bar{T}}\right) r(PT)\right\}\right]$
$\rho_{assoc.}$ =		$\bar{\rho}\left[1 \pm \left\{M\left(\frac{\sigma_\rho}{\bar{\rho}}\right) r(\rho T)\right\}\right]$	$\bar{\rho}\left[1 \pm \left\{M\left(\frac{\sigma_\rho}{\bar{\rho}}\right) r(P\rho)\right\}\right]$

Use + sign when extreme parameter is maximum.
Use - sign when extreme parameter is minimum.

It must be emphasized that this procedure is to be used at discrete altitudes only. Whenever extreme profiles of pressure, temperature, and density are required for engineering application, the use of these correlated variables at discrete altitudes is not satisfactory. See section 14.6, which deals directly with this problem, since a profile of extreme pressure, or temperature, or density from 0- to 90-km altitude is unrealistic in the real atmosphere.

14.6 Extreme Density Profiles for Cape Kennedy, Florida

The envelopes of deviations of density given in Table 14.7 imply that a typical individual extreme density profile may be represented by a similarly shaped profile, that is, deviations of density either all negative or all positive from sea level to 90-km altitude. However, examination of many individual density profiles shows that when large positive deviations of density occur at the surface, correspondingly large negative deviations will occur near 15-km altitude and above. Such a situation occurs during the winter season (cold atmosphere). The reverse is also true — that density profiles with large negative deviations at lower levels will have correspondingly large positive deviations at higher levels. This situation occurs in the summer season (hot atmosphere). See figure 14.3.

The two extreme density profiles of figure 14.3 are shown as percent deviations from the Patrick Reference Atmosphere 1963 (Cape Kennedy Reference Atmosphere) density profile. The two profiles obey the hydrostatic equation and the ideal gas law. The extreme density profiles shown here to 30-km altitude were derived from a study of actual extreme density profiles that were observed in the atmosphere. The results shown above 30-km altitude should be taken as somewhat speculative because of the limited data from this region of the atmosphere. Isopycnic levels (levels of minimum density variation) are noted at approximately 8 and 86 km. Another level of minimum density variability is seen at 24 km, and levels of maximum variability occur at 0,- 15,-and 68-km altitude.

Figure 14.4 compares the temperature* profiles of the hot-and-cold atmospheres with the Patrick Reference Atmosphere 1963 (PRA-63)

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* Temperatures below 10-km altitude are virtual temperature, that is, temperature corrected for atmospheric moisture.

$$T_V = T\,(1 + 0.61\,w)$$

where

T_V = Virtual Temperature (°K)

T = Kinetic Temperature (°K)

w = Mixing Ratio (g/Kg)

temperature profile. The extreme temperature envelope data to 59 km were taken from Table 14.1. Data above 59 km came from unpublished data.

Figures 14.5 and 14.6 show the relative deviations (%) of temperatures* and pressures, respectively, that are associated with the two extreme density profiles of figure 14.3. Table 14.9 gives the numerical data used to prepare figures 14.3 through 14.6.

The envelopes given in figures 14.5 and 14.6 are ±3 standard deviation limits from the mean (with the ±3 standard deviation being derived from 1/6 of the range). Since atmospheric parameters are not normally distributed, any profile that goes outside such a theoretical envelope does not necessarily mean the profile is in error (see figure 14.6).

Density profiles similar to the two shown in this section indicate that summer (hot) density profiles will produce more aerodynamic heating on a launch vehicle than will typical winter (cold) density profiles. A study is in progress to produce extreme density profiles that will give the maximum aerodynamic heating for given trajectories.

14.7 Reference Atmospheres

In design and preflight analysis of space vehicles, special atmospheres are used to represent the mean or median thermodynamic conditions with respect to altitude. For general world wide design, the U.S. Standard Atmosphere, 1962 (Ref. 14.2), is used, but more specific atmospheres are needed at each launch area. A group of Range Reference Atmospheres (Ref. 14.5) have been prepared to represent the thermodynamic medians in the first 30 km at various launch areas.

A more extensive reference atmosphere presenting data to 700 km has been published for the Eastern Test Range as NASA TM X-53139, "A Reference Atmosphere for Patrick AFB, Florida, Annual (1963 Revision)," (Ref. 14.1). Because of the utility of this atmosphere, the table from the referenced report is included in this section as Table 14.10. The computer subroutine used to prepare the tables in this section is available in the subroutine files of the George C. Marshall Space Flight Center Computation Laboratory, Huntsville, Alabama, as Computer Subroutine PRA-63. For all orbital studies, see NASA TM X-53957 (Ref. 14.4).

* See footnote on page 14.16

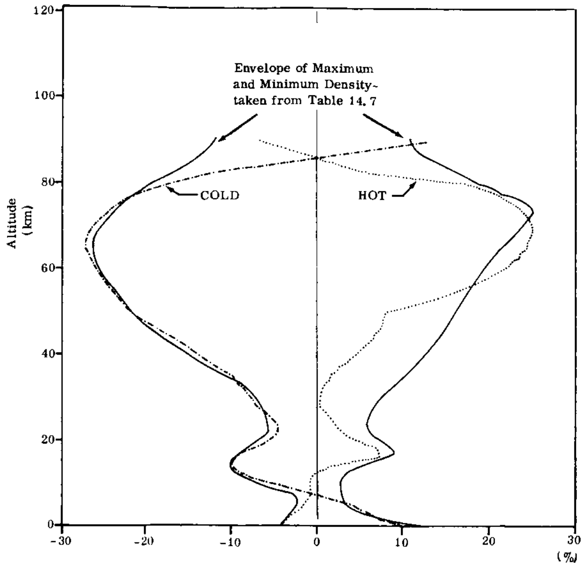

Figure 14.3 Relative Deviations (%) of Extreme Density Profiles With Respect to the Patrick Reference Atmosphere 1963, Cape Kennedy, Florida

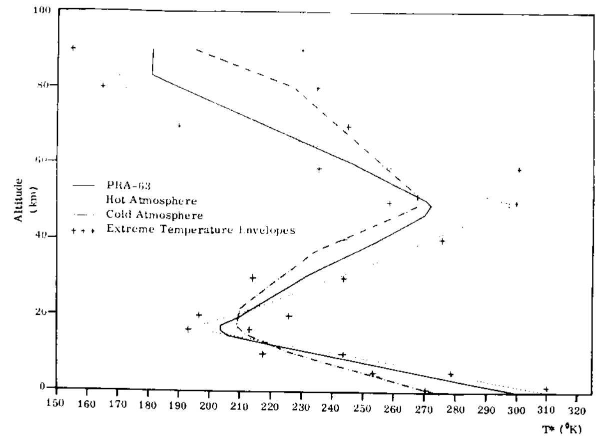

Figure 14.4 Virtual Temperature Profiles of the Hot, Cold, and the Patrick Reference Atmosphere 1963, Cape Kennedy, Florida

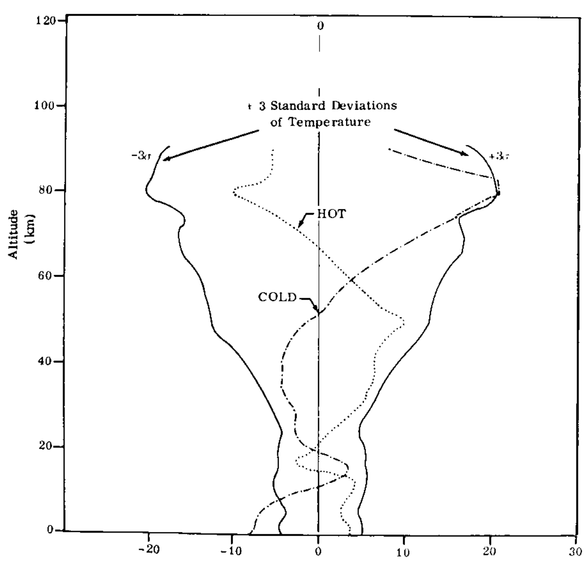

Figure 14.5 Relative Deviations (%) of Temperature, Associated With Extreme Density, With Respect to the Patrick Reference Atmosphere 1963, Cape Kennedy, Florida

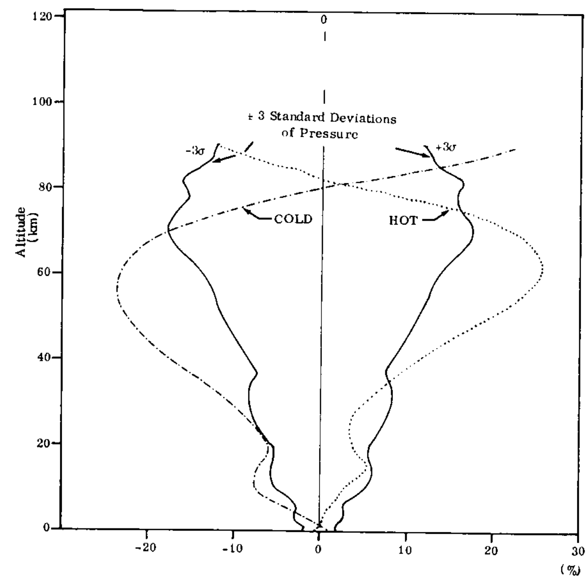

Figure 14.6 Relative Deviations (%) of Pressure, Associated With Extreme Density, With Respect to the Patrick Reference Atmosphere 1963, Cape Kennedy, Florida

TABLE 14.9 THERMODYNAMIC QUANTITIES ASSOCIATED WITH EXTREME DENSITY — CAPE KENNEDY, FLORIDA.

Geometric Altitude	Geopotential Altitude	Extreme Winter (Cold) Density Profile						Extreme Summer (Hot) Density Profile					
		Virtual Temperature	Pressure	Density	Rel. Dev. (T*) with Respect to PRA-63	Rel. Dev. (P) with Respect to PRA-63	Rel. Dev. (D) with Respect to PRA-63	Virtual Temperature	Pressure	Density	Rel. Dev. (T*) with Respect to PRA-63	Rel. Dev. (P) with Respect to PRA-63	Rel. Dev. (D) with Respect to PRA-63
Z(m)	H(m)	T*(°K)	P(mb)	D(g/m³)	RD(T*) %	RD(P) %	RD(D) %	T*(°K)	P(mb)	D(g/m³)	RD(T*) %	RD(P) %	RD(D) %
0	0	2.75000000E 02	1.02700000E 03	1.30099479E 03	-8.14	.98	9.92	3.09900000E 02	1.01000000E 03	1.13537050E 03	3.52	-0.69	-4.07
1000	998.5	2.70000000E 02	9.05981124E 02	1.16894262E 03	-7.67	-0.01	8.30	3.03136364E 02	9.03467679E 02	1.03827498E 03	3.66	-0.28	-3.81
2000	1996.6	2.65000000E 02	7.97351867E 02	1.04819467E 03	-7.51	-0.98	7.06	2.96372727E 02	8.06141882E 02	9.47569459E 02	3.43	.12	-3.21
3000	2994.5	2.60000000E 02	7.00042268E 02	9.37969511E 02	-7.46	-1.95	5.95	2.89609091E 02	7.17410164E 02	8.62964919E 02	3.07	.48	-2.52
4000	3992.0	2.55000000E 02	6.13057001E 02	8.37526355E 02	-7.38	-2.92	4.80	2.82845455E 02	6.36688087E 02	7.84179214E 02	2.74	.82	-1.87
5000	4989.2	2.50000000E 02	5.35471446E 02	7.46163696E 02	-7.16	-3.89	3.51	2.76081818E 02	5.63418548E 02	7.10937038E 02	2.53	1.13	-1.37
6000	5986.1	2.45250000E 02	4.66460635E 02	6.62588341E 02	-6.66	-4.82	1.96	2.69318182E 02	4.97071109E 02	6.42969917E 02	2.50	1.42	-1.06
7000	6982.7	2.40300000E 02	4.05225130E 02	5.87462848E 02	-6.03	-5.69	.36	2.62554545E 02	4.37141324E 02	5.80016206E 02	2.67	1.74	-0.91
8000	7979.0	2.36000000E 02	3.51068004E 02	5.18223441E 02	-4.97	-6.46	-1.58	2.55790909E 02	3.83150076E 02	5.21821077E 02	3.00	2.09	-0.89
9000	8975.0	2.31750000E 02	3.03352258E 02	4.56000476E 02	-3.73	-7.09	-3.49	2.49027273E 02	3.34642905E 02	4.68136511E 02	3.44	2.49	-0.92
10000	9970.6	2.27500000E 02	2.61414033E 02	4.00299736E 02	-2.42	-7.55	-5.27	2.42263636E 02	2.91189335E 02	4.18721286E 02	3.91	2.98	-0.91
11000	10965.9	2.24000000E 02	2.24699418E 02	3.49455385E 02	-0.74	-7.81	-7.15	2.35500000E 02	2.52382222E 02	3.73340973E 02	4.35	3.55	-0.81
12000	11961.0	2.20500000E 02	1.92681441E 02	3.04417138E 02	.77	-7.85	-8.59	2.28200000E 02	2.17799610E 02	3.32490518E 02	4.29	4.16	-0.16
13000	12955.7	2.17500000E 02	1.64849412E 02	2.64037704E 02	2.16	-7.70	-9.68	2.20900000E 02	1.87057194E 02	2.94996258E 02	3.76	4.73	.91
14000	13950.1	2.14300000E 02	1.40721972E 02	2.28758662E 02	2.95	-7.41	-10.05	2.13600000E 02	1.59834610E 02	2.60679802E 02	2.61	5.16	2.50
15000	14944.2	2.11500000E 02	1.19858344E 02	1.97422073E 02	3.26	-7.04	-9.94	2.06300000E 02	1.35828791E 02	2.29366725E 02	.72	5.35	4.64
16000	15937.9	2.09500000E 02	1.01901485E 02	1.69447159E 02	3.18	-6.61	-9.47	1.99000000E 02	1.14753584E 02	2.00886610E 02	-1.99	5.16	7.32
17000	16931.4	2.08500000E 02	8.65340950E 01	1.44583590E 02	2.78	-6.20	-8.75	1.98000000E 02	9.66090199E 01	1.69977052E 02	-2.39	4.72	7.27
18000	17924.5	2.08250000E 02	7.34482055E 01	1.22866641E 02	1.44	-5.95	-7.19	2.00000000E 02	8.13685235E 01	1.41730802E 02	-2.58	4.19	7.05
19000	18917.4	2.08500000E 02	6.23411950E 01	1.04161415E 02	.34	-5.91	-6.13	2.04166667E 02	6.87117249E 01	1.17242162E 02	-1.74	3.70	5.66
20000	19909.9	2.09000000E 02	5.29293969E 01	8.82243497E 01	-0.64	-6.01	-5.33	2.08333333E 02	5.82222137E 01	9.73571289E 01	-0.96	3.39	4.47
21000	20902.1	2.09900000E 02	4.49630996E 01	7.46245303E 01	-1.41	-6.23	-4.87	2.12500000E 02	4.94961327E 01	8.11428280E 01	-0.19	3.23	3.44
22000	21894.0	2.10800000E 02	3.82224604E 01	6.31663582E 01	-2.12	-6.54	-4.57	2.15666667E 02	4.21951555E 01	6.81580838E 01	.14	3.17	2.97
23000	22885.6	2.12200000E 02	3.25210399E 01	5.33896226E 01	-2.52	-6.95	-4.65	2.18833333E 02	3.60548925E 01	5.73969131E 01	.53	3.16	2.51
24000	23876.9	2.13600000E 02	2.76994749E 01	4.51760333E 01	-2.83	-7.42	-4.85	2.22000000E 02	3.08778517E 01	4.84542538E 01	1.00	3.21	2.05
25000	24867.8	2.15200000E 02	2.36192533E 01	3.82350539E 01	-2.94	-7.94	-5.26	2.25166667E 02	2.65022905E 01	4.10031402E 01	1.55	3.29	1.60
26000	25858.5	2.16800000E 02	2.01638490E 01	3.24005188E 01	-2.97	-8.50	-5.76	2.28333333E 02	2.27953662E 01	3.47788376E 01	2.19	3.44	1.15
27000	26848.8	2.18500000E 02	1.72340087E 01	2.74781691E 01	-2.88	-9.09	-6.38	2.31500000E 02	1.96476690E 01	2.95663588E 01	2.69	3.64	.73
28000	27838.9	2.20000000E 02	1.47477916E 01	2.33529698E 01	-2.84	-9.67	-7.03	2.34666667E 02	1.69688456E 01	2.51906109E 01	3.63	3.93	.28
29000	28828.6	2.21650000E 02	1.26338345E 01	1.98566167E 01	-3.04	-10.22	-7.40	2.37833333E 02	1.46840841E 01	2.15085903E 01	4.04	4.35	.30
30000	29818.0	2.23500000E 02	1.08360649E 01	1.68900866E 01	-3.16	-10.79	-7.88	2.41000000E 02	1.27312825E 01	1.84031819E 01	4.42	4.82	.38
31000	30807.1	2.24750000E 02	9.30399033E 00	1.44213978E 01	-3.55	-11.39	-8.13	2.44166667E 02	1.10587613E 01	1.57782166E 01	4.78	5.32	.52
32000	31795.9	2.26400000E 02	7.99635989E 00	1.23042095E 01	-3.79	-12.04	-8.57	2.47333333E 02	9.62341016E 00	1.35545203E 01	5.11	5.86	.72
33000	32784.4	2.28000000E 02	6.87995963E 00	1.05120847E 01	-4.07	-12.71	-9.01	2.50500000E 02	8.38918248E 00	1.16667453E 01	5.40	6.44	.99
34000	33772.6	2.29700000E 02	5.92584483E 00	8.98725546E 00	-4.32	-13.40	-9.49	2.53666667E 02	7.32586847E 00	1.00608233E 01	5.67	7.06	1.32
35000	34760.4	2.31250000E 02	5.10942287E 00	7.69711388E 00	-4.65	-14.13	-9.94	2.56833333E 02	6.40809356E 00	8.69191983E 00	5.90	7.70	1.70
36000	35748.0	2.33839286E 02	4.41129365E 00	6.57182967E 00	-4.57	-14.85	-10.77	2.60000000E 02	5.61449790E 00	7.52272839E 00	6.11	8.37	2.14
37000	36735.2	2.36428571E 02	3.81472057E 00	5.62083168E 00	-4.51	-15.56	-11.57	2.62884615E 02	4.92671736E 00	6.52875338E 00	6.18	9.06	2.71
38000	37722.1	2.39017857E 02	3.30405167E 00	4.81564305E 00	-4.45	-16.24	-12.34	2.65769231E 02	4.32935997E 00	5.67488159E 00	6.24	9.75	3.30
39000	38708.8	2.41607143E 02	2.86617994E 00	4.13267724E 00	-4.41	-16.91	-13.08	2.68653846E 02	3.80974368E 00	4.94015416E 00	6.30	10.44	3.90
40000	39695.1	2.44196429E 02	2.49010843E 00	3.55235825E 00	-4.35	-17.57	-13.82	2.71538462E 02	3.35707362E 00	4.30692509E 00	6.36	11.13	4.49
41000	40681.1	2.46785714E 02	2.16659315E 00	3.05840613E 00	-4.28	-18.22	-14.55	2.74423077E 02	2.96214618E 00	3.76031012E 00	6.43	11.82	5.06
42000	41666.8	2.49375000E 02	1.88784930E 00	2.63725556E 00	-4.19	-18.85	-15.30	2.77307692E 02	2.61710098E 00	3.28773171E 00	6.54	12.50	5.60
43000	42652.2	2.51964286E 02	1.64730910E 00	2.27758145E 00	-4.06	-19.46	-16.05	2.80192308E 02	2.31521370E 00	2.87854274E 00	6.69	13.20	6.10
44000	43637.3	2.54553571E 02	1.43942173E 00	1.96991128E 00	-3.88	-20.06	-16.83	2.83076923E 02	2.05072248E 00	2.52371456E 00	6.89	13.90	6.56
45000	44622.0	2.57142857E 02	1.25948775E 00	1.70630746E 00	-3.63	-20.62	-17.63	2.85961538E 02	1.81868235E 00	2.21557795E 00	7.17	14.63	6.96
46000	45606.5	2.59732143E 02	1.10352174E 00	1.48010662E 00	-3.30	-21.15	-18.46	2.88846154E 02	1.61484276E 00	1.94760759E 00	7.54	15.39	7.30
47000	46590.7	2.62321429E 02	9.68138219E-01	1.28570521E 00	-2.87	-21.63	-19.32	2.91730769E 02	1.43554449E 00	1.71424237E 00	8.02	16.21	7.57
48000	47574.5	2.64910714E 02	8.50456632E-01	1.11838274E 00	-2.31	-22.06	-20.21	2.94615385E 02	1.27763264E 00	1.51073532E 00	8.64	17.10	7.79
49000	48558.0	2.67500000E 02	7.48022144E-01	9.74155921E-01	-1.61	-22.38	-21.11	2.97500000E 02	1.13838318E 00	1.33302811E 00	9.42	18.13	7.96
50000	49541.3	2.67500000E 02	6.58334980E-01	8.57355526E-01	-1.15	-22.71	-21.81	2.97500000E 02	1.01487911E 00	1.18840686E 00	9.94	19.14	8.38
51000	50524.2	2.67500000E 02	5.79401224E-01	7.54559391E-01	-0.59	-22.99	-22.53	2.93250000E 02	9.04025086E-01	1.07394062E 00	8.98	20.16	10.26
52000	51506.8	2.67500000E 02	5.09931553E-01	6.64088417E-01	.07	-23.20	-23.25	2.89000000E 02	8.03920836E-01	9.69065759E-01	8.12	21.08	12.00
53000	52489.1	2.66071429E 02	4.48637656E-01	5.87401820E-01	.28	-23.36	-23.57	2.84750000E 02	7.13659400E-01	8.73102164E-01	7.32	21.92	13.60
54000	53471.1	2.64642857E 02	3.94439268E-01	5.19227605E-01	.58	-23.49	-23.93	2.80500000E 02	6.32398584E-01	7.85408921E-01	6.60	22.67	15.07
55000	54452.8	2.63214286E 02	3.46546813E-01	4.58659358E-01	.94	-23.59	-24.30	2.76250000E 02	5.59357194E-01	7.05382608E-01	5.94	23.33	16.42
56000	55434.2	2.61785714E 02	3.04254999E-01	4.04883040E-01	1.37	-23.65	-24.68	2.72000000E 02	4.93811445E-01	6.32455617E-01	5.32	23.91	17.65
57000	56415.3	2.60357143E 02	2.66934210E-01	3.57168003E-01	1.65	-23.68	-25.06	2.67750000E 02	4.35091531E-01	5.66094528E-01	4.75	24.41	18.77
58000	57396.1	2.58928571E 02	2.34022733E-01	3.14858831E-01	2.40	-23.65	-25.44	2.63500000E 02	3.82578344E-01	5.05798538E-01	4.21	24.82	19.78
59000	58376.6	2.57500000E 02	2.05019748E-01	2.77367945E-01	2.99	-23.57	-25.79	2.59250000E 02	3.35700354E-01	4.51097937E-01	3.69	25.14	20.69
60000	59356.7	2.56071429E 02	1.79479009E-01	2.44168899E-01	3.63	-23.44	-26.12	2.55000000E 02	2.93930633E-01	4.01552631E-01	3.20	25.39	21.50
61000	60336.6	2.54642857E 02	1.57003152E-01	2.14790308E-01	4.31	-23.24	-26.41	2.50750000E 02	2.56784018E-01	3.56750718E-01	2.71	25.54	22.22
62000	61316.1	2.53214286E 02	1.37238571E-01	1.88810346E-01	5.02	-22.98	-26.66	2.46500000E 02	2.23814418E-01	3.16307101E-01	2.24	25.61	22.86
63000	62295.4	2.51785714E 02	1.19870801E-01	1.65851776E-01	5.76	-22.65	-26.86	2.42250000E 02	1.94612246E-01	2.79862163E-01	1.76	25.58	23.41
64000	63274.3	2.50357143E 02	1.04620375E-01	1.45577444E-01	6.53	-22.24	-27.01	2.38000000E 02	1.68801990E-01	2.47080466E-01	1.28	25.46	23.88
65000	64253.0	2.48928571E 02	9.12390915E-02	1.27686215E-01	7.32	-21.75	-27.09	2.33750000E 02	1.46039898E-01	2.17649516E-01	.78	25.25	24.28
66000	65231.3	2.47500000E 02	7.95066688E-02	1.11909295E-01	8.13	-21.18	-27.11	2.29500000E 02	1.26011788E-01	1.91278558E-01	.27	24.93	24.59
67000	66209.3	2.46071429E 02	6.92277358E-02	9.80069205E-02	8.95	-20.52	-27.05	2.25250000E 02	1.08430976E-01	1.67697418E-01	-0.27	24.50	24.83
68000	67187.0	2.44642857E 02	6.02291357E-02	8.57653566E-02	9.79	-19.76	-26.91	2.21000000E 02	9.30363115E-02	1.46655386E-01	-0.82	23.95	24.98
69000	68164.5	2.43214286E 02	5.23575082E-02	7.49942032E-02	10.62	-18.90	-26.69	2.16750000E 02	7.95903180E-02	1.27920144E-01	-1.41	23.28	25.05
70000	69141.6	2.41785714E 02	4.54771216E-02	6.55239602E-02	11.47	-17.93	-26.38	2.12500000E 02	6.78774452E-02	1.11276731E-01	-2.03	22.49	25.03
71000	70118.4	2.40357143E 02	3.94679330E-02	5.72038363E-02	12.31	-16.85	-25.97	2.08250000E 02	5.77024138E-02	9.65265485E-02	-2.69	21.56	24.92
72000	71094.9	2.38928571E 02	3.42238518E-02	4.98997772E-02	13.16	-15.65	-25.47	2.04000000E 02	4.88886578E-02	8.34864037E-02	-3.38	20.49	24.70
73000	72071.1	2.37500000E 02	2.96511868E-02	4.34926905E-02	14.01	-14.33	-24.86	1.99750000E 02	4.12768593E-02	7.19875948E-02	-4.11	19.26	24.37
74000	73047.0	2.36071429E 02	2.56672586E-02	3.78768509E-02	14.87	-12.87	-24.15	1.95500000E 02	3.47235708E-02	6.18750302E-02	-4.87	17.87	23.91
75000	74022.6	2.34642857E 02	2.21991599E-02	3.29584674E-02	15.73	-11.27	-23.33	1.91250000E 02	2.90999218E-02	5.30063848E-02	-5.67	16.31	23.31
76000	74997.9	2.33214286E 02	1.91826497E-02	2.86543956E-02	16.59	-9.52	-22.40	1.87000000E 02	2.42904072E-02	4.52512932E-02	-6.51	14.58	22.55
77000	75972.8	2.31785714E 02	1.65611665E-02	2.48909839E-02	17.48	-7.60	-21.35	1.82750000E 02	2.01917519E-02	3.84905770E-02	-7.38	12.65	21.62
78000	76947.5	2.30357143E 02	1.42849493E-02	2.16030378E-02	18.38	-5.52	-20.19	1.78500000E 02	1.67118507E-02	3.26155069E-02	-8.27	10.53	20.50
79000	77921.9	2.28928571E 02	1.23102543E-02	1.87328922E-02	19.30	-3.26	-18.91	1.74250000E 02	1.37687780E-02	2.75270972E-02	-9.19	8.20	19.16
80000	78896.0	2.27500000E 02	1.05986583E-02	1.62295805E-02	20.27	-0.80	-17.52	1.70000000E 02	1.12898658E-02	2.31354346E-02	-10.13	5.67	17.57
81000	79869.7	2.24250000E 02	9.11088356E-03	1.41535652E-02	20.31	1.60	-15.39	1.70000000E 02	9.23440672E-03	1.89233440E-02	-8.79	3.18	13.12
82000	80843.2	2.21000000E 02	7.81467794E-03	1.23184657E-02	20.39	4.48	-13.22	1.70000000E 02	7.55316931E-03	1.54781163E-02	-7.39	.99	9.04
83000	81816.4	2.17750000E 02	6.68766082E-03	1.06992634E-02	20.53	7.25	-11.02	1.70000000E 02	6.17802186E-03	1.26601347E-02	-5.90	-0.92	5.29
84000	82789.2	2.14500000E 02	5.70979163E-03	9.27322440E-03	18.74	10.06	-7.31	1.70000000E 02	5.05323693E-03	1.03552013E-02	-5.90	-2.59	3.51
85000	83761.8	2.11250000E 02	4.86315472E-03	8.01971945E-03	16.94	12.67	-3.65	1.70000000E 02	4.13323295E-03	8.46990945E-03	-5.90	-4.24	1.76
86000	84734.0	2.08000000E 02	4.13176125E-03	6.92005729E-03	15.14	15.04	-0.08	1.70000000E 02	3.38072701E-03	6.92785818E-03	-5.90	-5.87	.03
87000	85706.0	2.04750000E 02	3.50136683E-03	5.95732796E-03	13.34	17.16	3.37	1.70000000E 02	2.76522404E-03	5.66655632E-03	-5.90	-7.47	-1.67
88000	86677.6	2.01500000E 02	2.95930411E-03	5.11625702E-03	11.54	19.00	6.68	1.70000000E 02	2.26178097E-03	4.63488999E-03	-5.90	-9.05	-3.35
89000	87649.0	1.98250000E 02	2.49432912E-03	4.38306961E-03	9.74	20.52	9.82	1.70000000E 02	1.84999590E-03	3.79105121E-03	-5.90	-10.61	-5.01
90000	88620.0	1.95000000E 02	2.09648048E-03	3.74536389E-03	7.94	21.72	12.76	1.70000000E 02	1.51318138E-03	3.10084367E-03	-5.90	-12.15	-6.65

TABLE 14.9 THERMODYNAMIC QUANTITIES ASSOCIATED WITH EXTREME DENSITY - CAPE KENNEDY, FLORIDA

In Table 14.10, the tabular values are given in standard computer printout where the two-digit numbers that are at the end of the tabular value (number preceded by E) indicate the power of 10 by which the respective principal value must be multiplied. For example, a tabular value indicated as

2.9937265E 02 is 299.37265

or

1.5464054E-05 is 0.000015464054.

14.8 Reentry (90 km to surface)

The atmospheric models to be used for all reentry analyses are the U. S. Standard Atmosphere, 1962 (Ref. 14.2) and the U. S. Standard Atmosphere Supplements, 1966 (Ref. 14.3), as expanded in the following paragraphs. Primary consideration is given to atmospheric density since it is the most significant parameter in reentry analyses.

For all analyses, use the supplemental atmospheres according to the latitude ranges shown in Figure 14.7.

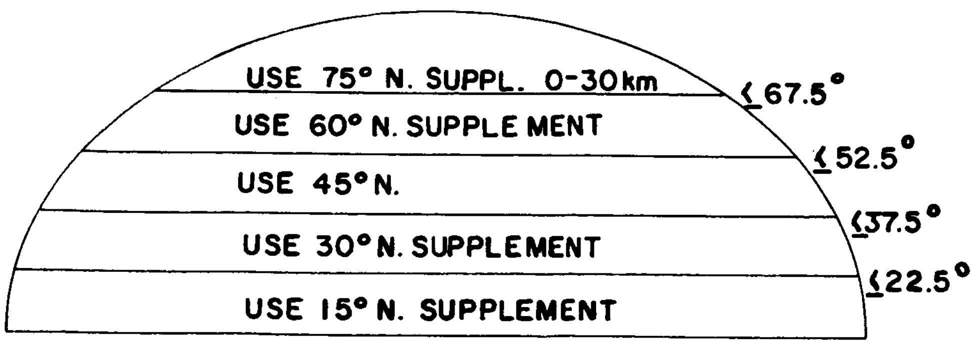

Figure 14.7. Latitude range of supplemental atmospheres (applicable to both N and S hemispheres).

Even though only mean values are tabulated in the U. S. Standard Supplements, 1966, extreme density values suitable for use in vehicle design calculations can be obtained from the document. To insure uniformity for space shuttle designers, those extreme densities are listed in Table 14.11. For all computations, these tabulated maximum and minimum values may be used with the appropriate mean values of temperature and pressure.

14.8.1 Reentry Heating

Since atmospheric parameters are seldom constant over large areas, it is unrealistic to expect minimum, maximum, or mean values of density to exist over the entire reentry trajectory. However, if one is concerned only with instantaneous vehicle heating computations (not considering accumulated heat), the density value producing the most severe heating may be used at every point of the trajectory. For example, use the July maximum values from Table 14.11 for 60 degree north latitude from 90 to 70 km, and then use the July maximum values for 45 degree north latitude from 65 to 30 km.

In some design problems, it may be useful to consider density changes along the trajectory -- changes that may occur in the atmosphere. For example, when making accumulated heat calculations, realistic results can be obtained by allowing the density to change in a somewhat regular manner over the vehicle trajectory. Extreme density changes by latitude and altitude are given in Tables 14.12 and 14.13. Of course, lesser rates of change may exist. Undoubtedly, several simulations will be required to determine the gradient and trajectory location (latitude and altitude) that produce the most severe heating rates. In applying these maximum gradients, care must be exercised to insure that the maximum or minimum density values for each latitude and altitude are not exceeded. Figure 14.8 illustrates an application of the density gradients near 70-km altitude and 60 degrees N (or S) latitude. In this case, mean values from the 60 degrees N January supplemental atmosphere are being used in the reentry heating calculations when a perturbation is begun. The density first decreases at a rate ≤ 4 percent/ 60 n. mi. to -56 percent (Table 14.11). At this point, the extreme horizontal density gradient

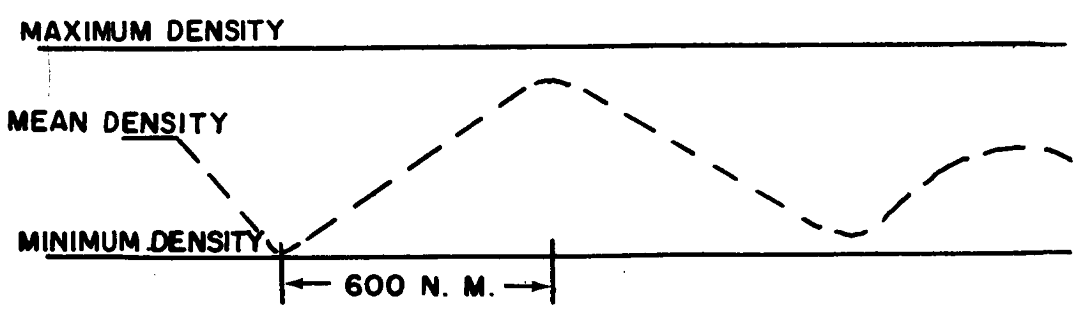

Figure 14.8 Density Gradients

from Table 14.12 of +4 percent/ 60 n. mi. is applied for a distance of 600 n. mi. (resulting in a horizontal density increase of +40 percent). A check is made to insure that the density (-56 percent + 40 percent = -16 percent) does not exceed the maximum (-6 percent) from Table 14.11. The perturbation then begins to decrease and the density eventually returns to a near mean value. Although this illustration assumed horizontal flight, the vertical density gradients from Table 14.12 can easily be included. If while traversing 600 n. m., the vehicle also descends 10 km, the combined horizontal and vertical gradients indicate a total possible increase of +55 percent (40 percent horizontal + 15 percent vertical). Since this increase would result in a higher density value than the 60-km maximum (-3 percent, Table 14.11), the total gradient may not be used. The perturbation must be discontinued or reversed when the maximum density value is reached. During this process, use mean values of pressure and temperature from the appropriate supplemental atmosphere.

TABLE 14.11 95-PERCENT RANGE OF OBSERVED ATMOSPHERIC DENSITY

Altitude (km)	Density as Percent Change from the U. S. 1962 Standard Atmosphere (Ref. 16.2)													
	60-degree North Latitude				45-degree North Latitude				30-degree North Latitude				15-degree North Latitude	
	January		July		January		July		January		July		Annual	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
90	- 3	13	2	13	- 2	13	0	13	- 3	13	0	13	- 1	12
85	-22	11	9	40	-18	12	2	30	-14	16	- 5	19	- 6	14
80	-44	6	10	48	-36	10	4	33	-20	17	-10	20	-10	16
75	-56	- 6	10	45	-42	6	6	37	-24	16	- 5	21	-12	17
70	-56	- 6	10	42	-42	6	6	40	-20	14	0	23	-11	18
65	-54	- 6	9	39	-40	6	4	40	-17	13	0	24	-10	18
60	-51	- 3	8	36	-36	5	2	38	-17	15	0	25	- 8	18
55	-47	2	6	36	-32	4	2	37	-17	18	- 4	27	- 3	18
50	-41	8	4	36	-30	2	2	34	-16	17	- 6	28	- 6	16
45	-36	15	6	27	-28	2	2	31	-15	16	- 4	25	- 6	14
40	-36	[illegible]	6	20	-25	5	0	28	-13	10	- 1	19	- 8	12
35	-36	10	4	16	-21	8	- 2	22	-11	5	- 1	14	- 8	8
30	-28	6	2	13	-14	6	- 1	18	- 9	3	- 2	10	- 6	6

a. Use with 60-deg N cold supplemental atmosphere.

b. Use with 60-deg N warm supplemental atmosphere.

TABLE 14.10 CAPE KENNEDY REFERENCE ATMOSPHERE VERSUS GEOMETRIC ALTITUDE (ANNUAL)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	VIRTUAL TEMPERATURE	DENSITY	KINEMATIC VISCOSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	m^2 sec^{-1}	newton-sec m^{-2}	m sec^{-1}
0.	1.0170147E 01	2.9667877E 02	2.9937265E 02	1.1835467E 00	1.5464054E-05	1.8302431E-05	3.4685752E 02
250.	9.8829373E 00	2.9503576E 02	2.9749989E 02	1.1573534E 00	1.5746406E-05	1.8224157E-05	3.4577071E 02
500.	9.6022651E 00	2.9348321E 02	2.9573026E 02	1.1312645E 00	1.6044844E-05	1.8149999E-05	3.4474100E 02
750.	9.3280864E 00	2.9200674E 02	2.9404920E 02	1.1051739E 00	1.6358708E-05	1.8079299E-05	3.4375977E 02
1000.	9.0603418E 00	2.9059301E 02	2.9244316E 02	1.0793462E 00	1.6687362E-05	1.8011441E-05	3.4281972E 02
1250.	8.7989596E 00	2.8922965E 02	2.9089953E 02	1.0537666E 00	1.7030194E-05	1.7945850E-05	3.4191375E 02
1500.	8.5438573E 00	2.8790525E 02	2.8940665E 02	1.0284922E 00	1.7386608E-05	1.7881991E-05	3.4103527E 02
1750.	8.2949430E 00	2.8660932E 02	2.8795373E 02	1.0035670E 00	1.7756031E-05	1.7819367E-05	3.4017814E 02
2000.	8.0521168E 00	2.8533228E 02	2.8653088E 02	9.7902801E-01	1.8137912E-05	1.7757524E-05	3.3933664E 02
2250.	7.8152728E 00	2.8406543E 02	2.8512905E 02	9.5490568E-01	1.8531717E-05	1.7696042E-05	3.3850555E 02
2500.	7.5843002E 00	2.8280087E 02	2.8374002E 02	9.3122447E-01	1.8936939E-05	1.7634541E-05	3.3768001E 02
2750.	7.3590840E 00	2.8153156E 02	2.8235634E 02	9.0800345E-01	1.9353094E-05	1.7572676E-05	3.3685564E 02
3000.	7.1395065E 00	2.8025121E 02	2.8097134E 02	8.8525681E-01	1.9779728E-05	1.7510139E-05	3.3602946E 02
3250.	6.9254477E 00	2.7895429E 02	2.7957909E 02	8.6299447E-01	2.0216413E-05	1.7446653E-05	3.3519489E 02
3500.	6.7167869E 00	2.7763601E 02	2.7817435E 02	8.4122243E-01	2.0662760E-05	1.7381977E-05	3.3435175E 02
3750.	6.5134029E 00	2.7629224E 02	2.7675260E 02	8.1994327E-01	2.1118413E-05	1.7315901E-05	3.3349622E 02
4000.	6.3151745E 00	2.7491954E 02	2.7530995E 02	7.9715662E-01	2.1583059E-05	1.7248245E-05	3.3262585E 02
4250.	6.1219816E 00	2.7351511E 02	2.7384314E 02	7.7885945E-01	2.2056429E-05	1.7178858E-05	3.3173858E 02
4500.	5.9337050E 00	2.7207674E 02	2.7234951E 02	7.5904647E-01	2.2538305E-05	1.7107621E-05	3.3083264E 02
4750.	5.7502279E 00	2.7060280E 02	2.7082700E 02	7.3971052E-01	2.3028518E-05	1.7034437E-05	3.2990662E 02
5000.	5.5714348E 00	2.6909222E 02	2.6927405E 02	7.2084275E-01	2.3526960E-05	1.6959239E-05	3.2895940E 02
5250.	5.3972132E 00	2.6754444E 02	2.6768968E 02	7.0243297E-01	2.4033585E-05	1.6881983E-05	3.2799020E 02
5500.	5.2274531E 00	2.6595939E 02	2.6607333E 02	6.8446986E-01	2.4548412E-05	1.6802648E-05	3.2699847E 02
5750.	5.0620471E 00	2.6433747E 02	2.6442497E 02	6.6694129E-01	2.5071532E-05	1.6721240E-05	3.2598400E 02
6000.	4.9008912E 00	2.6267950E 02	2.6274496E 02	6.4983435E-01	2.5603110E-05	1.6637781E-05	3.2494679E 02
6250.	4.7438843E 00	2.6098670E 02	2.6103412E 02	6.3313566E-01	2.6143393E-05	1.6552315E-05	3.2388713E 02
6500.	4.5909286E 00	2.5926069E 02	2.5929361E 02	6.1683158E-01	2.6692708E-05	1.6464906E-05	3.2280552E 02
6750.	4.4419296E 00	2.5750339E 02	2.5752496E 02	6.0090817E-01	2.7251477E-05	1.6375635E-05	3.2170270E 02
7000.	4.2967959E 00	2.5571708E 02	2.5573002E 02	5.8535153E-01	2.7820208E-05	1.6284601E-05	3.2057962E 02
7250.	4.1554397E 00	2.5390429E 02	2.5391096E 02	5.7014776E-01	2.8399511E-05	1.6191918E-05	3.1943741E 02
7500.	4.0177761E 00	2.5206783E 02	2.5207021E 02	5.5528319E-01	2.8990096E-05	1.6097713E-05	3.1827741E 02
7750.	3.8837237E 00	2.5021074E 02	2.5021046E 02	5.4074435E-01	2.9592781E-05	1.6002129E-05	3.1710112E 02
8000.	3.7532040E 00	2.4833622E 02	2.4833459E 02	5.2651817E-01	3.0208491E-05	1.5905319E-05	3.1591021E 02
8250.	3.6261415E 00	2.4644770E 02	2.4644571E 02	5.1259196E-01	3.0838268E-05	1.5807448E-05	3.1470648E 02
8500.	3.5024639E 00	2.4454868E 02	2.4454707E 02	4.9895351E-01	3.1483272E-05	1.5708689E-05	3.1349187E 02
8750.	3.3821013E 00	2.4264284E 02	2.4264207E 02	4.8559116E-01	3.2144787E-05	1.5609225E-05	3.1226845E 02
9000.	3.2649869E 00	2.4073389E 02	2.4073420E 02	4.7249382E-01	3.2824226E-05	1.5509244E-05	3.1103836E 02
9250.	3.1510561E 00	2.3882562E 02	2.3882706E 02	4.5965099E-01	3.3523131E-05	1.5408941E-05	3.0980386E 02
9500.	3.0402469E 00	2.3692182E 02	2.3692429E 02	4.4705284E-01	3.4243187E-05	1.5308514E-05	3.0856726E 02
9750.	2.9324993E 00	2.3502631E 02	2.3502955E 02	4.3469020E-01	3.4986216E-05	1.5208165E-05	3.0733094E 02
10000.	2.8277555E 00	2.3314283E 02	2.3314652E 02	4.2255460E-01	3.5754185E-05	1.5108096E-05	3.0609732E 02
10250.	2.7259597E 00	2.3127509E 02	2.3127885E 02	4.1063824E-01	3.6549218E-05	1.5008507E-05	3.0486882E 02
10500.	2.6270579E 00	2.2942670E 02	2.2943012E 02	3.9893405E-01	3.7373593E-05	1.4907599E-05	3.0364789E 02
10750.	2.5309974E 00	2.2760114E 02	2.2760385E 02	3.8743564E-01	3.8229747E-05	1.4811567E-05	3.0243695E 02
11000.	2.4373144E 00	2.2567654E 02	2.2567654E 02	3.7638429E-01	3.9076662E-05	1.4707842E-05	3.0115374E 02
11250.	2.3466644E 00	2.2389290E 02	2.2389290E 02	3.6528888E-01	3.9999485E-05	1.4611367E-05	2.9996129E 02
11500.	2.2587459E 00	2.2215274E 02	2.2215274E 02	3.5436502E-01	4.0966008E-05	1.4516921E-05	2.9879332E 02
11750.	2.1735153E 00	2.2046105E 02	2.2046105E 02	3.4360979E-01	4.1980165E-05	1.4424796E-05	2.9765349E 02
12000.	2.0909281E 00	2.1882266E 02	2.1882266E 02	3.3302120E-01	4.3046155E-05	1.4335282E-05	2.9654540E 02
12250.	2.0109393E 00	2.1724226E 02	2.1724226E 02	3.2259810E-01	4.4168460E-05	1.4248661E-05	2.9547260E 02
12500.	1.9335036E 00	2.1572436E 02	2.1572436E 02	3.1234019E-01	4.5351869E-05	1.4165211E-05	2.9443853E 02
12750.	1.8585748E 00	2.1427329E 02	2.1427329E 02	3.0224786E-01	4.6601486E-05	1.4085200E-05	2.9344659E 02
13000.	1.7861068E 00	2.1289318E 02	2.1289318E 02	2.9232218E-01	4.7922760E-05	1.4008886E-05	2.9250004E 02
13250.	1.7160527E 00	2.1158795E 02	2.1158795E 02	2.8256482E-01	4.9321493E-05	1.3936519E-05	2.9160202E 02
13500.	1.6483655E 00	2.1036130E 02	2.1036130E 02	2.7297794E-01	5.0803867E-05	1.3868335E-05	2.9075553E 02
13750.	1.5829980E 00	2.0921670E 02	2.0921670E 02	2.6356414E-01	5.2376472E-05	1.3804560E-05	2.8996343E 02
14000.	1.5199026E 00	2.0815732E 02	2.0815732E 02	2.5432637E-01	5.4046313E-05	1.3745403E-05	2.8922838E 02
14250.	1.4590316E 00	2.0718613E 02	2.0718613E 02	2.4526789E-01	5.5820832E-05	1.3691058E-05	2.8855287E 02
14500.	1.4003371E 00	2.0630579E 02	2.0630579E 02	2.3639213E-01	5.7707945E-05	1.3641704E-05	2.8793917E 02
14750.	1.3437711E 00	2.0551865E 02	2.0551865E 02	2.2770271E-01	5.9716027E-05	1.3597501E-05	2.8738935E 02
15000.	1.2892856E 00	2.0482679E 02	2.0482679E 02	2.1920326E-01	6.1853961E-05	1.3558590E-05	2.8690521E 02
15250.	1.2368322E 00	2.0423197E 02	2.0423197E 02	2.1089744E-01	6.4131138E-05	1.3525093E-05	2.8648832E 02
15500.	1.1863629E 00	2.0373557E 02	2.0373557E 02	2.0278882E-01	6.6557450E-05	1.3497107E-05	2.8613994E 02
15750.	1.1378295E 00	2.0333869E 02	2.0333869E 02	1.9488087E-01	6.9143324E-05	1.3474711E-05	2.8586110E 02
16000.	1.0911841E 00	2.0304201E 02	2.0304201E 02	1.8717685E-01	7.1899693E-05	1.3457958E-05	2.8565248E 02
16250.	1.0463788E 00	2.0284589E 02	2.0284589E 02	1.7967978E-01	7.4838014E-05	1.3446878E-05	2.8551449E 02
16500.	1.0033656E 00	2.0275027E 02	2.0275027E 02	1.7239240E-01	7.7970223E-05	1.3441474E-05	2.8544719E 02
16750.	9.6209732E-01	2.0275470E 02	2.0275470E 02	1.6531714E-01	8.1308715E-05	1.3441724E-05	2.8545030E 02
17000.	9.2252642E-01	2.0285831E 02	2.0285831E 02	1.5845601E-01	8.4866322E-05	1.3447579E-05	2.8552323E 02
17250.	8.8460605E-01	2.0305981E 02	2.0305981E 02	1.5181071E-01	8.8656214E-05	1.3458963E-05	2.8566500E 02
17500.	8.4828967E-01	2.0335748E 02	2.0335748E 02	1.4538244E-01	9.2691882E-05	1.3475772E-05	2.8587431E 02
17750.	8.1353120E-01	2.0374913E 02	2.0374913E 02	1.3917203E-01	9.6986954E-05	1.3497672E-05	2.8614946E 02

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
-0.	9.9999996E-01	9.9999995E-01	1.0000000E 00	2.8964400E 01	2.3841858E-07
250.	9.7175951E-01	9.7786878E-01	9.9572337E-01		2.8720987E-01
500.	9.4416186E-01	9.5577506E-01	9.9167156E-01	MOLECULAR WEIGHT CONSTANT TO 90,000 METERS	5.6788206E-01
750.	9.1720269E-01	9.3378559E-01	9.8780868E-01		8.4206080E-01
1000.	8.9087617E-01	9.1195906E-01	9.8410108E-01		1.1098053E 00
1250.	8.6517525E-01	8.9034644E-01	9.8051734E-01		1.3711876E 00
1500.	8.4009180E-01	8.6899160E-01	9.7702823E-01		1.6262898E 00
1750.	8.1561680E-01	8.4793186E-01	9.7360662E-01		1.8752042E 00
2000.	7.9174043E-01	8.2719843E-01	9.7022765E-01		2.1180304E 00
2250.	7.6845227E-01	8.0681703E-01	9.6686846E-01		2.3548744E 00
2500.	7.4574143E-01	7.8680835E-01	9.6350816E-01		2.5858470E 00
2750.	7.2359660E-01	7.6718850E-01	9.6012805E-01		2.8110632E 00
3000.	7.0200620E-01	7.4796946E-01	9.5671116E-01		3.0306407E 00
3250.	6.8095845E-01	7.2915960E-01	9.5324244E-01		3.2446995E 00
3500.	6.6044146E-01	7.1076401E-01	9.4970870E-01		3.4533603E 00
3750.	6.4044333E-01	6.9278488E-01	9.4609845E-01		3.6567443E 00
4000.	6.2095212E-01	6.7522185E-01	9.4240189E-01		3.8549727E 00
4250.	6.0195604E-01	6.5807240E-01	9.3861079E-01		4.0481656E 00
4500.	5.8344336E-01	6.4133206E-01	9.3471855E-01		4.2364422E 00
4750.	5.6540262E-01	6.2499476E-01	9.3071997E-01		4.4199193E 00
5000.	5.4782243E-01	6.0905305E-01	9.2661133E-01		4.5987124E 00
5250.	5.3069175E-01	5.9349830E-01	9.2239023E-01		4.7729340E 00
5500.	5.1399974E-01	5.7832093E-01	9.1805561E-01		4.9426941E 00
5750.	4.9773586E-01	5.6351072E-01	9.1360767E-01		5.1081001E 00
6000.	4.8188989E-01	5.4905677E-01	9.0904764E-01		5.2692560E 00
6250.	4.6645187E-01	5.3494775E-01	9.0437800E-01		5.4262629E 00
6500.	4.5141221E-01	5.2117212E-01	8.9960216E-01		5.5792186E 00
6750.	4.3676159E-01	5.0771816E-01	8.9472464E-01		5.7282175E 00
7000.	4.2249102E-01	4.9457407E-01	8.8975078E-01		5.8733513E 00
7250.	4.0859190E-01	4.8172814E-01	8.8468679E-01		6.0147074E 00
7500.	3.9505585E-01	4.6916878E-01	8.7953967E-01		6.1523710E 00
7750.	3.8187487E-01	4.5688466E-01	8.7431720E-01		6.2864235E 00
8000.	3.6904126E-01	4.4486470E-01	8.6902775E-01		6.4169432E 00
8250.	3.5654760E-01	4.3309820E-01	8.6368030E-01		6.5440056E 00
8500.	3.4438674E-01	4.2157483E-01	8.5828435E-01		6.6676832E 00
8750.	3.3255185E-01	4.1028473E-01	8.5284985E-01		6.7880459E 00
9000.	3.2103635E-01	3.9921856E-01	8.4738715E-01		6.9051602E 00
9250.	3.0983387E-01	3.8836742E-01	8.4190682E-01		7.0190911E 00
9500.	2.9893833E-01	3.7772301E-01	8.3641976E-01		7.1299003E 00
9750.	2.8834383E-01	3.6727760E-01	8.3093694E-01		7.2376479E 00
10000.	2.7804469E-01	3.5702401E-01	8.2546939E-01		7.3423917E 00
10250.	2.6803542E-01	3.4695566E-01	8.2002810E-01		7.4441875E 00
10500.	2.5831070E-01	3.3706658E-01	8.1462401E-01		7.5430893E 00
10750.	2.4886536E-01	3.2735136E-01	8.0926777E-01		7.6391498E 00
11000.	2.3965380E-01	3.1801388E-01	8.0360048E-01		7.7328327E 00
11250.	2.3074045E-01	3.0863917E-01	7.9832937E-01		7.8234828E 00
11500.	2.2209570E-01	2.9940940E-01	7.9316903E-01		7.9114012E 00
11750.	2.1371522E-01	2.9032211E-01	7.8813556E-01		7.9966319E 00
12000.	2.0559467E-01	2.8137562E-01	7.8324474E-01		8.0792190E 00
12250.	1.9772962E-01	2.7256896E-01	7.7851201E-01		8.1592078E 00
12500.	1.9011559E-01	2.6390186E-01	7.7395250E-01		8.2366436E 00
12750.	1.8274807E-01	2.5537467E-01	7.6958085E-01		8.3115723E 00
13000.	1.7562250E-01	2.4698829E-01	7.6541126E-01		8.3840404E 00
13250.	1.6873430E-01	2.3874412E-01	7.6145730E-01		8.4540944E 00
13500.	1.6207882E-01	2.3064399E-01	7.5773191E-01		8.5217816E 00
13750.	1.5565143E-01	2.2269010E-01	7.5424739E-01		8.5871491E 00
14000.	1.4944745E-01	2.1488494E-01	7.5101517E-01		8.6502445E 00
14250.	1.4346219E-01	2.0723127E-01	7.4804591E-01		8.7111155E 00
14500.	1.3769094E-01	1.9973198E-01	7.4534935E-01		8.7698100E 00
14750.	1.3212898E-01	1.9239013E-01	7.4293422E-01		8.8263760E 00
15000.	1.2677157E-01	1.8520879E-01	7.4080821E-01		8.8808615E 00
15250.	1.2161397E-01	1.7819105E-01	7.3897798E-01		8.9333149E 00
15500.	1.1665149E-01	1.7133994E-01	7.3744892E-01		8.9837842E 00
15750.	1.1187936E-01	1.6465836E-01	7.3622527E-01		9.0323176E 00
16000.	1.0729285E-01	1.5814910E-01	7.3530992E-01		9.0789630E 00
16250.	1.0288728E-01	1.5181469E-01	7.3470452E-01		9.1237683E 00
16500.	9.8657924E-02	1.4565745E-01	7.3440926E-01		9.1667815E 00
16750.	9.4600136E-02	1.3967943E-01	7.3442291E-01		9.2080498E 00
17000.	9.0709249E-02	1.3388234E-01	7.3474283E-01		9.2476207E 00
17250.	8.6980654E-02	1.2826761E-01	7.3536484E-01		9.2855411E 00
17500.	8.3409772E-02	1.2283625E-01	7.3628323E-01		9.3218575E 00
17750.	7.9992077E-02	1.1758896E-01	7.3749069E-01	2.8964400E 01	9.3566159E 00

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	VIRTUAL TEMPERATURE	DENSITY	KINEMATIC VISCOSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	m^2 sec^{-1}	newton-sec m^{-2}	m sec^{-1}
18000.	7.8097365E-01	2.0530313E 02	2.0530313E 02	1.3239218E-01	1.0261471E-04	1.3585386E-05	2.8723862E 02
18250.	7.4940996E-01	2.0591008E 02	2.0591008E 02	1.2665197E-01	1.0753477E-04	1.3619491E-05	2.8766290E 02
18500.	7.1920003E-01	2.0652754E 02	2.0652754E 02	1.2117497E-01	1.1268123E-04	1.3654144E-05	2.8809388E 02
18750.	6.9028297E-01	2.0715365E 02	2.0715365E 02	1.1594809E-01	1.1806259E-04	1.3689238E-05	2.8853025E 02
19000.	6.6260092E-01	2.0778667E 02	2.0778667E 02	1.1096236E-01	1.2366766E-04	1.3724675E-05	2.8897076E 02
19250.	6.3609866E-01	2.0842488E 02	2.0842488E 02	1.0620395E-01	1.2956538E-04	1.3760356E-05	2.8941420E 02
19500.	6.1072356E-01	2.0906669E 02	2.0906669E 02	1.0166309E-01	1.3570500E-04	1.3796191E-05	2.8985945E 02
19750.	5.8642544E-01	2.0971051E 02	2.0971051E 02	9.7329618E-02	1.4211596E-04	1.3832092E-05	2.9030542E 02
20000.	5.6315652E-01	2.1035486E 02	2.1035486E 02	9.3193799E-02	1.4880793E-04	1.3867977E-05	2.9075108E 02
20250.	5.4087104E-01	2.1099834E 02	2.1099834E 02	8.9246359E-02	1.5579085E-04	1.3903766E-05	2.9119544E 02
20500.	5.1952558E-01	2.1163959E 02	2.1163959E 02	8.5478435E-02	1.6307487E-04	1.3939385E-05	2.9163759E 02
20750.	4.9907848E-01	2.1227735E 02	2.1227735E 02	8.1881557E-02	1.7067049E-04	1.3974765E-05	2.9207668E 02
21000.	4.7949015E-01	2.1291042E 02	2.1291042E 02	7.8447674E-02	1.7858834E-04	1.4009840E-05	2.9251188E 02
21250.	4.6072266E-01	2.1353768E 02	2.1353768E 02	7.5169075E-02	1.8683947E-04	1.4044550E-05	2.9294246E 02
21500.	4.4273989E-01	2.1415808E 02	2.1415808E 02	7.2038414E-02	1.9543514E-04	1.4078838E-05	2.9336769E 02
21750.	4.2550730E-01	2.1477067E 02	2.1477067E 02	6.9048639E-02	2.0438693E-04	1.4112651E-05	2.9378698E 02
22000.	4.0899191E-01	2.1537455E 02	2.1537455E 02	6.6193250E-02	2.1370675E-04	1.4145944E-05	2.9419972E 02
22250.	3.9316222E-01	2.1596891E 02	2.1596891E 02	6.3465692E-02	2.2340689E-04	1.4178673E-05	2.9460538E 02
22500.	3.7798811E-01	2.1655302E 02	2.1655302E 02	6.0859976E-02	2.3349993E-04	1.4210800E-05	2.9500350E 02
22750.	3.6344091E-01	2.1712624E 02	2.1712624E 02	5.8370312E-02	2.4399890E-04	1.4242292E-05	2.9539368E 02
23000.	3.4949304E-01	2.1768800E 02	2.1768800E 02	5.5991186E-02	2.5491726E-04	1.4273120E-05	2.9577557E 02
23250.	3.3611832E-01	2.1823781E 02	2.1823781E 02	5.3717368E-02	2.6626877E-04	1.4303258E-05	2.9614885E 02
23500.	3.2329168E-01	2.1877527E 02	2.1877527E 02	5.1543851E-02	2.7806785E-04	1.4332688E-05	2.9651329E 02
23750.	3.1098904E-01	2.1930008E 02	2.1930008E 02	4.9465870E-02	2.9032938E-04	1.4361396E-05	2.9686872E 02
24000.	2.9918759E-01	2.1981200E 02	2.1981200E 02	4.7478898E-02	3.0306874E-04	1.4389370E-05	2.9721502E 02
24250.	2.8786539E-01	2.2031091E 02	2.2031091E 02	4.5578615E-02	3.1630195E-04	1.4416605E-05	2.9755212E 02
24500.	2.7700151E-01	2.2079671E 02	2.2079671E 02	4.3760915E-02	3.3004564E-04	1.4443099E-05	2.9788000E 02
24750.	2.6657591E-01	2.2126948E 02	2.2126948E 02	4.2021891E-02	3.4431725E-04	1.4468859E-05	2.9819874E 02
25000.	2.5656950E-01	2.2172934E 02	2.2172934E 02	4.0357794E-02	3.5913489E-04	1.4493892E-05	2.9850846E 02
25250.	2.4696393E-01	2.2217648E 02	2.2217648E 02	3.8765104E-02	3.7451754E-04	1.4518211E-05	2.9880929E 02
25500.	2.3774181E-01	2.2261124E 02	2.2261124E 02	3.7240437E-02	3.9048512E-04	1.4541836E-05	2.9910150E 02
25750.	2.2888635E-01	2.2303400E 02	2.2303400E 02	3.5780583E-02	4.0705849E-04	1.4564795E-05	2.9938538E 02
26000.	2.2038159E-01	2.2344526E 02	2.2344526E 02	3.4382489E-02	4.2425962E-04	1.4587102E-05	2.9966127E 02
26250.	2.1221229E-01	2.2384560E 02	2.2384560E 02	3.3043241E-02	4.4211172E-04	1.4608804E-05	2.9992961E 02
26500.	2.0436382E-01	2.2423573E 02	2.2423573E 02	3.1760075E-02	4.6063921E-04	1.4629936E-05	3.0019086E 02
26750.	1.9682221E-01	2.2461640E 02	2.2461640E 02	3.0530360E-02	4.7986792E-04	1.4650541E-05	3.0044556E 02
27000.	1.8957414E-01	2.2498853E 02	2.2498853E 02	2.9351587E-02	4.9982535E-04	1.4670667E-05	3.0069433E 02
27250.	1.8260686E-01	2.2535303E 02	2.2535303E 02	2.8221373E-02	5.2054052E-04	1.4690368E-05	3.0093780E 02
27500.	1.7590816E-01	2.2571105E 02	2.2571105E 02	2.7137454E-02	5.4204438E-04	1.4709705E-05	3.0117677E 02
27750.	1.6946640E-01	2.2606372E 02	2.2606372E 02	2.6097671E-02	5.6436988E-04	1.4728740E-05	3.0141197E 02
28000.	1.6327363E-01	2.2643885E 02	2.2643885E 02	2.5119029E-02	5.8716331E-04	1.4748972E-05	3.0166194E 02
28250.	1.5729220E-01	2.2697720E 02	2.2697720E 02	2.4141415E-02	6.1214233E-04	1.4777982E-05	3.0202032E 02
28500.	1.5154519E-01	2.2751673E 02	2.2751673E 02	2.3204199E-02	6.3811838E-04	1.4807026E-05	3.0237907E 02
28750.	1.4602270E-01	2.2805774E 02	2.2805774E 02	2.2305569E-02	6.6513066E-04	1.4836119E-05	3.0273836E 02
29000.	1.4071528E-01	2.2860044E 02	2.2860044E 02	2.1443810E-02	6.9321970E-04	1.4865272E-05	3.0309836E 02
29250.	1.3561394E-01	2.2914508E 02	2.2914508E 02	2.0617288E-02	7.2242759E-04	1.4894498E-05	3.0345920E 02
29500.	1.3071014E-01	2.2969187E 02	2.2969187E 02	1.9824461E-02	7.5279778E-04	1.4923810E-05	3.0382105E 02
29750.	1.2599566E-01	2.3024104E 02	2.3024104E 02	1.9063850E-02	7.8437554E-04	1.4953217E-05	3.0418403E 02
30000.	1.2146273E-01	2.3079274E 02	2.3079274E 02	1.8334060E-02	8.1720744E-04	1.4982730E-05	3.0454826E 02
30250.	1.1710385E-01	2.3134718E 02	2.3134718E 02	1.7633751E-02	8.5134225E-04	1.5012357E-05	3.0491385E 02
30500.	1.1291193E-01	2.3190450E 02	2.3190450E 02	1.6961662E-02	8.8682977E-04	1.5042107E-05	3.0528090E 02
30750.	1.0888012E-01	2.3246485E 02	2.3246485E 02	1.6316577E-02	9.2372233E-04	1.5071986E-05	3.0564950E 02
31000.	1.0500195E-01	2.3302838E 02	2.3302838E 02	1.5697349E-02	9.6207348E-04	1.5102004E-05	3.0601975E 02
31250.	1.0127118E-01	2.3359519E 02	2.3359519E 02	1.5102878E-02	1.0019389E-03	1.5132162E-05	3.0639170E 02
31500.	9.7681869E-02	2.3416537E 02	2.3416537E 02	1.4532122E-02	1.0433760E-03	1.5162468E-05	3.0676541E 02
31750.	9.4228337E-02	2.3473904E 02	2.3473904E 02	1.3984082E-02	1.0864443E-03	1.5192926E-05	3.0714094E 02
32000.	9.0905080E-02	2.3531626E 02	2.3531626E 02	1.3457797E-02	1.1312058E-03	1.5223539E-05	3.0751834E 02
32250.	8.7706975E-02	2.3589708E 02	2.3589708E 02	1.2952372E-02	1.1777232E-03	1.5254309E-05	3.0789762E 02
32500.	8.4628981E-02	2.3648155E 02	2.3648155E 02	1.2466932E-02	1.2260625E-03	1.5285238E-05	3.0827881E 02
32750.	8.1666349E-02	2.3706971E 02	2.3706971E 02	1.2000652E-02	1.2762913E-03	1.5316328E-05	3.0866194E 02
33000.	7.8814489E-02	2.3766155E 02	2.3766155E 02	1.1552737E-02	1.3284798E-03	1.5347578E-05	3.0904698E 02
33250.	7.6068993E-02	2.3825710E 02	2.3825710E 02	1.1122427E-02	1.3827008E-03	1.5378989E-05	3.0943396E 02
33500.	7.3425727E-02	2.3885632E 02	2.3885632E 02	1.0709009E-02	1.4390274E-03	1.5410557E-05	3.0982283E 02
33750.	7.0880660E-02	2.3945918E 02	2.3945918E 02	1.0311789E-02	1.4975367E-03	1.5442282E-05	3.1021357E 02
34000.	6.8429914E-02	2.4006563E 02	2.4006563E 02	9.9301028E-03	1.5583081E-03	1.5474160E-05	3.1060615E 02
34250.	6.6069812E-02	2.4067563E 02	2.4067563E 02	9.5633199E-03	1.6214230E-03	1.5506187E-05	3.1100052E 02
34500.	6.3796784E-02	2.4128910E 02	2.4128910E 02	9.2108314E-03	1.6869660E-03	1.5538359E-05	3.1139663E 02
34750.	6.1607495E-02	2.4190593E 02	2.4190593E 02	8.8720665E-03	1.7550219E-03	1.5570671E-05	3.1179440E 02
35000.	5.9498639E-02	2.4252600E 02	2.4252600E 02	8.5464640E-03	1.8256808E-03	1.5603116E-05	3.1219375E 02
35250.	5.7467108E-02	2.4314924E 02	2.4314924E 02	8.2334940E-03	1.8990343E-03	1.5635687E-05	3.1259463E 02
35500.	5.5509918E-02	2.4377545E 02	2.4377545E 02	7.9326513E-03	1.9751753E-03	1.5668377E-05	3.1299690E 02
35750.	5.3624192E-02	2.4440454E 02	2.4440454E 02	7.6434468E-03	2.0542013E-03	1.5701179E-05	3.1340050E 02

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
18000.	7.6790792E-02	1.1186054E-01	7.4227225E-01	2.8964400E 01	9.3891735E 00
18250.	7.3687228E-02	1.0701054E-01	7.4413570E-01		9.4207371E 00
18500.	7.0716777E-02	1.0238292E-01	7.4602904E-01		9.4509470E 00
18750.	6.7873449E-02	9.7967392E-02	7.4794650E-01		9.4798641E 00
19000.	6.5151556E-02	9.3754101E-02	7.4988266E-01		9.5075462E 00
19250.	6.2545671E-02	8.9733634E-02	7.5183217E-01		9.5340484E 00
19500.	6.0050611E-02	8.5896982E-02	7.5379012E-01		9.5594236E 00
19750.	5.7661451E-02	8.2235550E-02	7.5575168E-01		9.5837216E 00
20000.	5.5373487E-02	7.8741122E-02	7.5771233E-01		9.6069906E 00
20250.	5.3182223E-02	7.5405859E-02	7.5966776E-01		9.6292760E 00
20500.	5.1083388E-02	7.2222272E-02	7.6161389E-01		9.6506215E 00
20750.	4.9072887E-02	6.9183205E-02	7.6354699E-01		9.6710687E 00
21000.	4.7146826E-02	6.6281855E-02	7.6546340E-01		9.6906570E 00
21250.	4.5301473E-02	6.3511708E-02	7.6735986E-01		9.7094245E 00
21500.	4.3533282E-02	6.0866556E-02	7.6923324E-01		9.7274072E 00
21750.	4.1838853E-02	5.8340492E-02	7.7108074E-01		9.7446399E 00
22000.	4.0214945E-02	5.5927871E-02	7.7289979E-01		9.7611552E 00
22250.	3.8658459E-02	5.3623306E-02	7.7468801E-01		9.7769849E 00
22500.	3.7166434E-02	5.1421692E-02	7.7644337E-01		9.7921590E 00
22750.	3.5736052E-02	4.9318130E-02	7.7816400E-01		9.8067062E 00
23000.	3.4364600E-02	4.7307963E-02	7.7984835E-01		9.8206540E 00
23250.	3.3049504E-02	4.5386774E-02	7.8149503E-01		9.8340288E 00
23500.	3.1788299E-02	4.3550330E-02	7.8310302E-01		9.8468554E 00
23750.	3.0578617E-02	4.1794606E-02	7.8467152E-01		9.8591580E 00
24000.	2.9418216E-02	4.0115778E-02	7.8619990E-01		9.8709595E 00
24250.	2.8304938E-02	3.8510194E-02	7.8768802E-01		9.8822818E 00
24500.	2.7236725E-02	3.6974387E-02	7.8913562E-01		9.8931456E 00
24750.	2.6211607E-02	3.5505046E-02	7.9054306E-01		9.9035712E 00
25000.	2.5227707E-02	3.4099028E-02	7.9191080E-01		9.9135777E 00
25250.	2.4283220E-02	3.2753335E-02	7.9323955E-01		9.9231832E 00
25500.	2.3376438E-02	3.1465117E-02	7.9453037E-01		9.9324054E 00
25750.	2.2505707E-02	3.0231660E-02	7.9578452E-01		9.9412608E 00
26000.	2.1669459E-02	2.9050386E-02	7.9700357E-01		9.9497656E 00
26250.	2.0866196E-02	2.7918830E-02	7.9818932E-01		9.9579349E 00
26500.	2.0094487E-02	2.6834661E-02	7.9934393E-01		9.9657834E 00
26750.	1.9352936E-02	2.5795652E-02	8.0046970E-01	MOLECULAR WEIGHT CONSTANT TO 90,000 METERS	9.9733249E 00
27000.	1.8640255E-02	2.4799686E-02	8.0156938E-01		9.9805729E 00
27250.	1.7955183E-02	2.3844747E-02	8.0264578E-01		9.9875402E 00
27500.	1.7296520E-02	2.2928925E-02	8.0370228E-01		9.9942390E 00
27750.	1.6663121E-02	2.2050393E-02	8.0474230E-01		1.0000681E 01
28000.	1.6054205E-02	2.1223521E-02	8.0584776E-01		1.0006873E 01
28250.	1.5466069E-02	2.0397517E-02	8.0743278E-01		1.0012855E 01
28500.	1.4900983E-02	1.9605646E-02	8.0901966E-01		1.0018602E 01
28750.	1.4357973E-02	1.8846378E-02	8.1060922E-01		1.0024124E 01
29000.	1.3836110E-02	1.8118262E-02	8.1220207E-01		1.0029432E 01
29250.	1.3334511E-02	1.7419919E-02	8.1379894E-01		1.0034533E 01
29500.	1.2852335E-02	1.6750045E-02	8.1540048E-01		1.0039437E 01
29750.	1.2388774E-02	1.6107391E-02	8.1700722E-01		1.0044151E 01
30000.	1.1943065E-02	1.5490778E-02	8.1861973E-01		1.0048684E 01
30250.	1.1514467E-02	1.4899074E-02	8.2023848E-01		1.0053043E 01
30500.	1.1102290E-02	1.4331214E-02	8.2186393E-01		1.0057235E 01
30750.	1.0705855E-02	1.3786170E-02	8.2349647E-01		1.0061267E 01
31000.	1.0324527E-02	1.3262973E-02	8.2513652E-01		1.0065145E 01
31250.	9.9576907E-03	1.2760694E-02	8.2678432E-01		1.0068876E 01
31500.	9.6047645E-03	1.2278452E-02	8.2844017E-01		1.0072465E 01
31750.	9.2651891E-03	1.1815403E-02	8.3010430E-01		1.0075919E 01
32000.	8.9384232E-03	1.1370735E-02	8.3177692E-01		1.0079242E 01
32250.	8.6239631E-03	1.0943693E-02	8.3345811E-01		1.0082440E 01
32500.	8.3213134E-03	1.0533536E-02	8.3514802E-01		1.0085518E 01
32750.	8.0300065E-03	1.0139567E-02	8.3684671E-01		1.0088481E 01
33000.	7.7495918E-03	9.7611161E-03	8.3855411E-01		1.0091332E 01
33250.	7.4796354E-03	9.3975394E-03	8.4027032E-01		1.0094078E 01
33500.	7.2197310E-03	9.0482346E-03	8.4199516E-01		1.0096721E 01
33750.	6.9694821E-03	8.7126163E-03	8.4372852E-01		1.0099266E 01
34000.	6.7285077E-03	8.3901230E-03	8.4547024E-01		1.0101717E 01
34250.	6.4964459E-03	8.0802215E-03	8.4722012E-01		1.0104077E 01
34500.	6.2729465E-03	7.7823977E-03	8.4897795E-01		1.0106350E 01
34750.	6.0576797E-03	7.4961690E-03	8.5074338E-01		1.0108539E 01
35000.	5.8503222E-03	7.2210616E-03	8.5251606E-01		1.0110648E 01
35250.	5.6505679E-03	6.9566277E-03	8.5429571E-01		1.0112680E 01
35500.	5.4581233E-03	6.7024403E-03	8.5608178E-01		1.0114637E 01
35750.	5.2727056E-03	6.4580862E-03	8.5787399E-01	2.8964400E 01	1.0116523E 01

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	VIRTUAL TEMPERATURE	DENSITY	KINEMATIC VISCOSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	m^2 sec^{-1}	newton-sec m^{-2}	m sec^{-1}
36000.	5.1807184E-02	2.4503628E 02	2.4503628E 02	7.3654170E-03	2.1362103E-03	1.5734080E-05	3.1380529E 02
36250.	5.0056203E-02	2.4567052E 02	2.4567052E 02	7.0991081E-03	2.2213063E-03	1.5767073E-05	3.1421114E 02
36500.	4.8368751E-02	2.4630706E 02	2.4630706E 02	6.8410974E-03	2.3095922E-03	1.5800146E-05	3.1461794E 02
36750.	4.6742370E-02	2.4694566E 02	2.4694566E 02	6.5939717E-03	2.4011762E-03	1.5833288E-05	3.1502553E 02
37000.	4.5174757E-02	2.4758610E 02	2.4758610E 02	6.3563430E-03	2.4961657E-03	1.5866486E-05	3.1543376E 02
37250.	4.3663611E-02	2.4822817E 02	2.4822817E 02	6.1278247E-03	2.5946774E-03	1.5899729E-05	3.1584251E 02
37500.	4.2206814E-02	2.4887154E 02	2.4887154E 02	5.9080626E-03	2.6968231E-03	1.5933000E-05	3.1625156E 02
37750.	4.0802266E-02	2.4951598E 02	2.4951598E 02	5.6967042E-03	2.8027235E-03	1.5966287E-05	3.1666075E 02
38000.	3.9447995E-02	2.5016116E 02	2.5016116E 02	5.4934199E-03	2.9124978E-03	1.5999574E-05	3.1706989E 02
38250.	3.8142081E-02	2.5080680E 02	2.5080680E 02	5.2978887E-03	3.0262704E-03	1.6032844E-05	3.1747878E 02
38500.	3.6882693E-02	2.5145256E 02	2.5145256E 02	5.1098048E-03	3.1441673E-03	1.6066081E-05	3.1788723E 02
38750.	3.5668057E-02	2.5209809E 02	2.5209809E 02	4.9288731E-03	3.2663182E-03	1.6099268E-05	3.1829501E 02
39000.	3.4496486E-02	2.5274305E 02	2.5274305E 02	4.7548124E-03	3.3928543E-03	1.6132386E-05	3.1870190E 02
39250.	3.3366343E-02	2.5338705E 02	2.5338705E 02	4.5873508E-03	3.5239111E-03	1.6165417E-05	3.1910768E 02
39500.	3.2276080E-02	2.5402967E 02	2.5402967E 02	4.4262311E-03	3.6596231E-03	1.6198338E-05	3.1951207E 02
39750.	3.1224165E-02	2.5467056E 02	2.5467056E 02	4.2711993E-03	3.8001346E-03	1.6231132E-05	3.1991487E 02
40000.	3.0209180E-02	2.5530928E 02	2.5530928E 02	4.1220200E-03	3.9455843E-03	1.6263778E-05	3.2031579E 02
40250.	2.9223723E-02	2.5594537E 02	2.5594537E 02	3.9784617E-03	4.0961187E-03	1.6296252E-05	3.2071457E 02
40500.	2.8284457E-02	2.5657837E 02	2.5657837E 02	3.8403036E-03	4.2518854E-03	1.6328531E-05	3.2111092E 02
40750.	2.7372115E-02	2.5720782E 02	2.5720782E 02	3.7073359E-03	4.4130322E-03	1.6360593E-05	3.2150456E 02
41000.	2.6491424E-02	2.5783324E 02	2.5783324E 02	3.5793500E-03	4.5797177E-03	1.6392412E-05	3.2189520E 02
41250.	2.5641234E-02	2.5845410E 02	2.5845410E 02	3.4561553E-03	4.7520915E-03	1.6423966E-05	3.2228253E 02
41500.	2.4820392E-02	2.5906989E 02	2.5906989E 02	3.3375628E-03	4.9303122E-03	1.6455227E-05	3.2266623E 02
41750.	2.4027806E-02	2.5968005E 02	2.5968005E 02	3.2233931E-03	5.1145384E-03	1.6486168E-05	3.2304598E 02
42000.	2.3262411E-02	2.6028407E 02	2.6028407E 02	3.1134715E-03	5.3049350E-03	1.6516764E-05	3.2342147E 02
42250.	2.2523202E-02	2.6088134E 02	2.6088134E 02	3.0076332E-03	5.5016637E-03	1.6546987E-05	3.2379233E 02
42500.	2.1809203E-02	2.6147127E 02	2.6147127E 02	2.9057187E-03	5.7048901E-03	1.6576806E-05	3.2415822E 02
42750.	2.1119469E-02	2.6205329E 02	2.6205329E 02	2.8075735E-03	5.9147853E-03	1.6606195E-05	3.2451880E 02
43000.	2.0453115E-02	2.6262673E 02	2.6262673E 02	2.7130530E-03	6.1315131E-03	1.6635121E-05	3.2487367E 02
43250.	1.9809245E-02	2.6319098E 02	2.6319098E 02	2.6220120E-03	6.3552547E-03	1.6663554E-05	3.2522247E 02
43500.	1.9187063E-02	2.6374536E 02	2.6374536E 02	2.5343198E-03	6.5861708E-03	1.6691463E-05	3.2556482E 02
43750.	1.8585732E-02	2.6428923E 02	2.6428923E 02	2.4498413E-03	6.8244486E-03	1.6718816E-05	3.2590032E 02
44000.	1.8004513E-02	2.6482185E 02	2.6482185E 02	2.3684559E-03	7.0702506E-03	1.6745577E-05	3.2622854E 02
44250.	1.7442635E-02	2.6534256E 02	2.6534256E 02	2.2900392E-03	7.3237678E-03	1.6771716E-05	3.2654911E 02
44500.	1.6899401E-02	2.6585060E 02	2.6585060E 02	2.2144782E-03	7.5851708E-03	1.6797196E-05	3.2686158E 02
44750.	1.6374120E-02	2.6634524E 02	2.6634524E 02	2.1416613E-03	7.8546414E-03	1.6821981E-05	3.2716551E 02
45000.	1.5866134E-02	2.6682574E 02	2.6682574E 02	2.0714819E-03	8.1323606E-03	1.6846038E-05	3.2746049E 02
45250.	1.5374807E-02	2.6729129E 02	2.6729129E 02	2.0038380E-03	8.4185084E-03	1.6869327E-05	3.2774604E 02
45500.	1.4899529E-02	2.6774109E 02	2.6774109E 02	1.9386315E-03	8.7132648E-03	1.6891810E-05	3.2802169E 02
45750.	1.4439711E-02	2.6817436E 02	2.6817436E 02	1.8757674E-03	9.0168161E-03	1.6913450E-05	3.2828699E 02
46000.	1.3994781E-02	2.6859025E 02	2.6859025E 02	1.8151546E-03	9.3293467E-03	1.6934206E-05	3.2854145E 02
46250.	1.3564215E-02	2.6898792E 02	2.6898792E 02	1.7567082E-03	9.6510271E-03	1.6954039E-05	3.2878458E 02
46500.	1.3147466E-02	2.6936653E 02	2.6936653E 02	1.7003416E-03	9.9820579E-03	1.6972909E-05	3.2901589E 02
46750.	1.2744066E-02	2.6972512E 02	2.6972512E 02	1.6459792E-03	1.0322590E-02	1.6990770E-05	3.2923481E 02
47000.	1.2353487E-02	2.7006288E 02	2.7006288E 02	1.5935380E-03	1.0672843E-02	1.7007582E-05	3.2944089E 02
47250.	1.1975290E-02	2.7037884E 02	2.7037884E 02	1.5429473E-03	1.1032976E-02	1.7023301E-05	3.2963355E 02
47500.	1.1609022E-02	2.7067210E 02	2.7067210E 02	1.4941352E-03	1.1403173E-02	1.7037882E-05	3.2981226E 02
47750.	1.1254254E-02	2.7094166E 02	2.7094166E 02	1.4470338E-03	1.1783607E-02	1.7051279E-05	3.2997645E 02
48000.	1.0910568E-02	2.7118660E 02	2.7118660E 02	1.4015768E-03	1.2174463E-02	1.7063446E-05	3.3012557E 02
48250.	1.0577570E-02	2.7140590E 02	2.7140590E 02	1.3577018E-03	1.2575910E-02	1.7074335E-05	3.3025902E 02
48500.	1.0254871E-02	2.7159857E 02	2.7159857E 02	1.3153475E-03	1.2988126E-02	1.7083899E-05	3.3037623E 02
48750.	9.9421220E-03	2.7176355E 02	2.7176355E 02	1.2744583E-03	1.3411255E-02	1.7092086E-05	3.3047655E 02
49000.	9.6365027E-03	2.7187674E 02	2.7187674E 02	1.2347674E-03	1.3846901E-02	1.7097701E-05	3.3054537E 02
49250.	9.3444532E-03	2.7158682E 02	2.7158682E 02	1.1986240E-03	1.4252440E-02	1.7083316E-05	3.3036908E 02
49500.	9.0608503E-03	2.7127908E 02	2.7127908E 02	1.1635643E-03	1.4668753E-02	1.7068039E-05	3.3018185E 02
49750.	8.7854533E-03	2.7095394E 02	2.7095394E 02	1.1295526E-03	1.5096144E-02	1.7051889E-05	3.2998393E 02
50000.	8.5180215E-03	2.7061178E 02	2.7061178E 02	1.0965534E-03	1.5534932E-02	1.7034883E-05	3.2977550E 02
50250.	8.2583286E-03	2.7025298E 02	2.7025298E 02	1.0645337E-03	1.5985440E-02	1.7017040E-05	3.2955681E 02
50500.	8.0061513E-03	2.6987793E 02	2.6987793E 02	1.0334612E-03	1.6448006E-02	1.6998377E-05	3.2932805E 02
50750.	7.7612761E-03	2.6948699E 02	2.6948699E 02	1.0033052E-03	1.6922975E-02	1.6978910E-05	3.2908944E 02
51000.	7.5234920E-03	2.6908057E 02	2.6908057E 02	9.7403572E-04	1.7410715E-02	1.6958658E-05	3.2884119E 02
51250.	7.2925984E-03	2.6865905E 02	2.6865905E 02	9.4562420E-04	1.7911596E-02	1.6937638E-05	3.2858353E 02
51500.	7.0683973E-03	2.6822277E 02	2.6822277E 02	9.1804309E-04	1.8426005E-02	1.6915866E-05	3.2831662E 02
51750.	6.8506990E-03	2.6777211E 02	2.6777211E 02	8.9126593E-04	1.8954342E-02	1.6893359E-05	3.2804069E 02
52000.	6.6393197E-03	2.6730745E 02	2.6730745E 02	8.6526723E-04	1.9497023E-02	1.6870136E-05	3.2775595E 02
52250.	6.4340792E-03	2.6682914E 02	2.6682914E 02	8.4002243E-04	2.0054474E-02	1.6846209E-05	3.2746258E 02
52500.	6.2348041E-03	2.6633759E 02	2.6633759E 02	8.1550777E-04	2.0627146E-02	1.6821598E-05	3.2716081E 02
52750.	6.0413253E-03	2.6583313E 02	2.6583313E 02	7.9170040E-04	2.1215500E-02	1.6796320E-05	3.2685084E 02
53000.	5.8534791E-03	2.6531610E 02	2.6531610E 02	7.6857846E-04	2.1820008E-02	1.6770388E-05	3.2653283E 02
53250.	5.6711066E-03	2.6478688E 02	2.6478688E 02	7.4612072E-04	2.2441168E-02	1.6743821E-05	3.2620700E 02
53500.	5.4940539E-03	2.6424584E 02	2.6424584E 02	7.2430671E-04	2.3079496E-02	1.6716634E-05	3.2587356E 02
53750.	5.3221716E-03	2.6369328E 02	2.6369328E 02	7.0311693E-04	2.3735514E-02	1.6688842E-05	3.2553267E 02

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
36000.	5.0940446E-03	6.2231737E-03	8.5967164E-01	2.8964400E 01	1.0118340E 01
36250.	4.9218759E-03	5.9973196E-03	8.6147428E-01		1.0120091E 01
36500.	4.7559539E-03	5.7801666E-03	8.6328131E-01		1.0121778E 01
36750.	4.5960367E-03	5.5713656E-03	8.6509210E-01		1.0123405E 01
37000.	4.4418980E-03	5.3705889E-03	8.6690596E-01		1.0124972E 01
37250.	4.2933116E-03	5.1775097E-03	8.6872227E-01		1.0126483E 01
37500.	4.1500691E-03	4.9918287E-03	8.7054015E-01		1.0127940E 01
37750.	4.0119641E-03	4.8132482E-03	8.7235887E-01		1.0129345E 01
38000.	3.8788028E-03	4.6414896E-03	8.7417755E-01		1.0130699E 01
38250.	3.7503962E-03	4.4762817E-03	8.7599536E-01		1.0132005E 01
38500.	3.6265643E-03	4.3173663E-03	8.7781137E-01		1.0133264E 01
38750.	3.5071328E-03	4.1644938E-03	8.7962462E-01		1.0134479E 01
39000.	3.3919357E-03	4.0174268E-03	8.8143409E-01		1.0135650E 01
39250.	3.2808122E-03	3.8759355E-03	8.8323880E-01		1.0136781E 01
39500.	3.1736099E-03	3.7398026E-03	8.8503755E-01		1.0137871E 01
39750.	3.0701783E-03	3.6088134E-03	8.8682938E-01		1.0138923E 01
40000.	2.9703779E-03	3.4827691E-03	8.8861302E-01		1.0139938E 01
40250.	2.8740708E-03	3.3614740E-03	8.9038732E-01		1.0140917E 01
40500.	2.7811256E-03	3.2447418E-03	8.9215099E-01		1.0141862E 01
40750.	2.6914178E-03	3.1323950E-03	8.9390275E-01		1.0142775E 01
41000.	2.6048221E-03	3.0242574E-03	8.9564131E-01		1.0143656E 01
41250.	2.5212255E-03	2.9201680E-03	8.9736534E-01		1.0144506E 01
41500.	2.4405145E-03	2.8199670E-03	8.9907334E-01		1.0145327E 01
41750.	2.3625819E-03	2.7235030E-03	9.0076388E-01		1.0146119E 01
42000.	2.2873230E-03	2.6306283E-03	9.0243558E-01		1.0146885E 01
42250.	2.2146388E-03	2.5412036E-03	9.0408666E-01		1.0147624E 01
42500.	2.1444333E-03	2.4550942E-03	9.0571612E-01		1.0148338E 01
42750.	2.0766138E-03	2.3721695E-03	9.0732185E-01		1.0149028E 01
43000.	2.0110933E-03	2.2923075E-03	9.0890229E-01		1.0149694E 01
43250.	1.9477835E-03	2.2153852E-03	9.1045582E-01		1.0150338E 01
43500.	1.8866062E-03	2.1412925E-03	9.1198069E-01		1.0150960E 01
43750.	1.8274791E-03	2.0699151E-03	9.1347519E-01		1.0151561E 01
44000.	1.7703296E-03	2.0011512E-03	9.1493738E-01	MOLECULAR WEIGHT CONSTANT TO 90,000 METERS	1.0152142E 01
44250.	1.7150819E-03	1.9348955E-03	9.1636553E-01		1.0152704E 01
44500.	1.6616672E-03	1.8710526E-03	9.1775768E-01		1.0153248E 01
44750.	1.6100180E-03	1.8095282E-03	9.1911191E-01		1.0153773E 01
45000.	1.5600692E-03	1.7502324E-03	9.2042631E-01		1.0154281E 01
45250.	1.5117585E-03	1.6930789E-03	9.2169876E-01		1.0154772E 01
45500.	1.4650259E-03	1.6379848E-03	9.2292717E-01		1.0155247E 01
45750.	1.4198133E-03	1.5848697E-03	9.2410953E-01		1.0155707E 01
46000.	1.3760647E-03	1.5336569E-03	9.2524362E-01		1.0156152E 01
46250.	1.3337285E-03	1.4842745E-03	9.2632723E-01		1.0156583E 01
46500.	1.2927508E-03	1.4366493E-03	9.2735821E-01		1.0157000E 01
46750.	1.2530856E-03	1.3907175E-03	9.2833408E-01		1.0157403E 01
47000.	1.2146813E-03	1.3464090E-03	9.2925265E-01		1.0157793E 01
47250.	1.1774943E-03	1.3036640E-03	9.3011150E-01		1.0158172E 01
47500.	1.1414802E-03	1.2624218E-03	9.3090819E-01		1.0158538E 01
47750.	1.1065970E-03	1.2226250E-03	9.3164015E-01		1.0158893E 01
48000.	1.0728034E-03	1.1842175E-03	9.3230493E-01		1.0159236E 01
48250.	1.0400607E-03	1.1471467E-03	9.3289990E-01		1.0159569E 01
48500.	1.0083307E-03	1.1113608E-03	9.3342245E-01		1.0159892E 01
48750.	9.7757896E-04	1.0768128E-03	9.3386976E-01		1.0160205E 01
49000.	9.4752835E-04	1.0432772E-03	9.3417658E-01		1.0160511E 01
49250.	9.1881199E-04	1.0127390E-03	9.3339058E-01		1.0160803E 01
49500.	8.9092617E-04	9.8311651E-04	9.3255587E-01		1.0161086E 01
49750.	8.6384722E-04	9.5437936E-04	9.3167348E-01		1.0161362E 01
50000.	8.3755145E-04	9.2649775E-04	9.3074435E-01		1.0161629E 01
50250.	8.1201663E-04	8.9944376E-04	9.2976943E-01		1.0161889E 01
50500.	7.8722080E-04	8.7319003E-04	9.2874972E-01		1.0162141E 01
50750.	7.6314294E-04	8.4771069E-04	9.2768611E-01		1.0162386E 01
51000.	7.3976235E-04	8.2298036E-04	9.2657958E-01		1.0162624E 01
51250.	7.1705927E-04	7.9897496E-04	9.2543113E-01		1.0162854E 01
51500.	6.9501426E-04	7.7567118E-04	9.2424155E-01		1.0163079E 01
51750.	6.7360863E-04	7.5304667E-04	9.2301184E-01		1.0163296E 01
52000.	6.5282434E-04	7.3107990E-04	9.2174293E-01		1.0163508E 01
52250.	6.3264366E-04	7.0975011E-04	9.2043562E-01		1.0163713E 01
52500.	6.1304954E-04	6.8903723E-04	9.1909096E-01		1.0163912E 01
52750.	5.9402534E-04	6.6892195E-04	9.1770983E-01		1.0164106E 01
53000.	5.7555500E-04	6.4938582E-04	9.1629300E-01		1.0164293E 01
53250.	5.5762286E-04	6.3041086E-04	9.1484141E-01		1.0164476E 01
53500.	5.4021380E-04	6.1197981E-04	9.1335599E-01		1.0164653E 01
53750.	5.2331313E-04	5.9407618E-04	9.1183751E-01	2.8964400E 01	1.0164825E 01

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	VIRTUAL TEMPERATURE	DENSITY	KINEMATIC VISCOSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	m^2 sec^{-1}	newton-sec m^{-2}	m sec^{-1}
54000.	5.1553130E-03	2.6312956E 02	2.6312956E 02	6.8253221E-04	2.4409778E-02	1.6660460E-05	3.2518452E 02
54250.	4.9933376E-03	2.6255506E 02	2.6255506E 02	6.6253418E-04	2.5102866E-02	1.6631507E-05	3.2482934E 02
54500.	4.8361087E-03	2.6197010E 02	2.6197010E 02	6.4310530E-04	2.5815361E-02	1.6601996E-05	3.2446728E 02
54750.	4.6834927E-03	2.6137502E 02	2.6137502E 02	6.2422839E-04	2.6547884E-02	1.6571943E-05	3.2409855E 02
55000.	4.5353597E-03	2.6077015E 02	2.6077015E 02	6.0588697E-04	2.7301070E-02	1.6541363E-05	3.2372332E 02
55250.	4.3915860E-03	2.6015581E 02	2.6015581E 02	5.8806537E-04	2.8075569E-02	1.6510270E-05	3.2334178E 02
55500.	4.2520469E-03	2.5953237E 02	2.5953237E 02	5.7074782E-04	2.8872090E-02	1.6478682E-05	3.2295411E 02
55750.	4.1166255E-03	2.5890011E 02	2.5890011E 02	5.5391979E-04	2.9691323E-02	1.6446611E-05	3.2256049E 02
56000.	3.9852059E-03	2.5825934E 02	2.5825934E 02	5.3756684E-04	3.0534011E-02	1.6414072E-05	3.2216108E 02
56250.	3.8576765E-03	2.5761043E 02	2.5761043E 02	5.2167510E-04	3.1400924E-02	1.6381081E-05	3.2175609E 02
56500.	3.7339278E-03	2.5695369E 02	2.5695369E 02	5.0623109E-04	3.2292865E-02	1.6347652E-05	3.2134569E 02
56750.	3.6138545E-03	2.5628940E 02	2.5628940E 02	4.9122195E-04	3.3210649E-02	1.6313800E-05	3.2093004E 02
57000.	3.4973535E-03	2.5561786E 02	2.5561786E 02	4.7663518E-04	3.4155129E-02	1.6279536E-05	3.2050931E 02
57250.	3.3843247E-03	2.5493941E 02	2.5493941E 02	4.6245854E-04	3.5127209E-02	1.6244878E-05	3.2008368E 02
57500.	3.2746712E-03	2.5425435E 02	2.5425435E 02	4.4868036E-04	3.6127810E-02	1.6209839E-05	3.1965334E 02
57750.	3.1682985E-03	2.5356290E 02	2.5356290E 02	4.3528944E-04	3.7157872E-02	1.6174430E-05	3.1921839E 02
58000.	3.0651143E-03	2.5286545E 02	2.5286545E 02	4.2227457E-04	3.8218422E-02	1.6138668E-05	3.1877907E 02
58250.	2.9650293E-03	2.5216226E 02	2.5216226E 02	4.0962520E-04	3.9310484E-02	1.6102565E-05	3.1833552E 02
58500.	2.8679566E-03	2.5145360E 02	2.5145360E 02	3.9733101E-04	4.0435140E-02	1.6066135E-05	3.1788789E 02
58750.	2.7738122E-03	2.5073975E 02	2.5073975E 02	3.8538216E-04	4.1593494E-02	1.6029391E-05	3.1743634E 02
59000.	2.6825136E-03	2.5002101E 02	2.5002101E 02	3.7376892E-04	4.2786719E-02	1.5992346E-05	3.1698105E 02
59250.	2.5939802E-03	2.4929760E 02	2.4929760E 02	3.6248189E-04	4.4016023E-02	1.5955011E-05	3.1652214E 02
59500.	2.5081352E-03	2.4856981E 02	2.4856981E 02	3.5151213E-04	4.5282651E-02	1.5917401E-05	3.1605979E 02
59750.	2.4249023E-03	2.4783793E 02	2.4783793E 02	3.4085073E-04	4.6587926E-02	1.5879529E-05	3.1559415E 02
60000.	2.3442082E-03	2.4710222E 02	2.4710222E 02	3.3048920E-04	4.7933204E-02	1.5841407E-05	3.1512538E 02
60250.	2.2659808E-03	2.4636295E 02	2.4636295E 02	3.2041923E-04	4.9319911E-02	1.5803048E-05	3.1465363E 02
60500.	2.1901511E-03	2.4562030E 02	2.4562030E 02	3.1063299E-04	5.0749477E-02	1.5764462E-05	3.1417902E 02
60750.	2.1166509E-03	2.4487455E 02	2.4487455E 02	3.0112260E-04	5.2223448E-02	1.5725661E-05	3.1370170E 02
61000.	2.0454141E-03	2.4412598E 02	2.4412598E 02	2.9188045E-04	5.3743437E-02	1.5686659E-05	3.1322185E 02
61250.	1.9763771E-03	2.4337476E 02	2.4337476E 02	2.8289940E-04	5.5311054E-02	1.5647464E-05	3.1273955E 02
61500.	1.9094769E-03	2.4262118E 02	2.4262118E 02	2.7417222E-04	5.6928059E-02	1.5608093E-05	3.1225500E 02
61750.	1.8446531E-03	2.4186543E 02	2.4186543E 02	2.6569211E-04	5.8596209E-02	1.5568551E-05	3.1176829E 02
62000.	1.7818466E-03	2.4110778E 02	2.4110778E 02	2.5745233E-04	6.0317397E-02	1.5528854E-05	3.1127960E 02
62250.	1.7209993E-03	2.4034843E 02	2.4034843E 02	2.4944634E-04	6.2093563E-02	1.5489012E-05	3.1078904E 02
62500.	1.6620553E-03	2.3958754E 02	2.3958754E 02	2.4166791E-04	6.3926700E-02	1.5449032E-05	3.1029671E 02
62750.	1.6049612E-03	2.3882540E 02	2.3882540E 02	2.3411097E-04	6.5818912E-02	1.5408929E-05	3.0980278E 02
63000.	1.5496626E-03	2.3806212E 02	2.3806212E 02	2.2676949E-04	6.7772384E-02	1.5368709E-05	3.0930732E 02
63250.	1.4961084E-03	2.3729799E 02	2.3729799E 02	2.1963763E-04	6.9789435E-02	1.5328386E-05	3.0881052E 02
63500.	1.4442482E-03	2.3653317E 02	2.3653317E 02	2.1270982E-04	7.1872414E-02	1.5287968E-05	3.0831246E 02
63750.	1.3940340E-03	2.3576784E 02	2.3576784E 02	2.0598070E-04	7.4023755E-02	1.5247465E-05	3.0781327E 02
64000.	1.3454170E-03	2.3500217E 02	2.3500217E 02	1.9944483E-04	7.6246075E-02	1.5206885E-05	3.0731304E 02
64250.	1.2983516E-03	2.3423638E 02	2.3423638E 02	1.9309709E-04	7.8542044E-02	1.5166240E-05	3.0681192E 02
64500.	1.2527926E-03	2.3347064E 02	2.3347064E 02	1.8693243E-04	8.0914468E-02	1.5125538E-05	3.0631001E 02
64750.	1.2086961E-03	2.3270509E 02	2.3270509E 02	1.8094601E-04	8.3366234E-02	1.5084787E-05	3.0580740E 02
65000.	1.1660196E-03	2.3193981E 02	2.3193981E 02	1.7513312E-04	8.5900316E-02	1.5043991E-05	3.0530415E 02
65250.	1.1247208E-03	2.3117513E 02	2.3117513E 02	1.6948893E-04	8.8520038E-02	1.5003167E-05	3.0480046E 02
65500.	1.0847607E-03	2.3041111E 02	2.3041111E 02	1.6400922E-04	9.1228521E-02	1.4962319E-05	3.0429636E 02
65750.	1.0460989E-03	2.2964788E 02	2.2964788E 02	1.5868945E-04	9.4029269E-02	1.4921453E-05	3.0379196E 02
66000.	1.0086976E-03	2.2888563E 02	2.2888563E 02	1.5352539E-04	9.6925850E-02	1.4880579E-05	3.0328736E 02
66250.	9.7251890E-04	2.2812446E 02	2.2812446E 02	1.4851282E-04	9.9922040E-02	1.4839704E-05	3.0278264E 02
66500.	9.3752730E-04	2.2736447E 02	2.2736447E 02	1.4364783E-04	1.0302162E-01	1.4798833E-05	3.0227787E 02
66750.	9.0368733E-04	2.2660580E 02	2.2660580E 02	1.3892644E-04	1.0622867E-01	1.4757972E-05	3.0177313E 02
67000.	8.7096431E-04	2.2584865E 02	2.2584865E 02	1.3434472E-04	1.0954754E-01	1.4717133E-05	3.0126856E 02
67250.	8.3932542E-04	2.2509302E 02	2.2509302E 02	1.2989908E-04	1.1298245E-01	1.4676317E-05	3.0076415E 02
67500.	8.0873778E-04	2.2433905E 02	2.2433905E 02	1.2558582E-04	1.1653808E-01	1.4635530E-05	3.0026000E 02
67750.	7.7916990E-04	2.2358690E 02	2.2358690E 02	1.2140136E-04	1.2021926E-01	1.4594782E-05	2.9975623E 02
68000.	7.5059128E-04	2.2283655E 02	2.2283655E 02	1.1734236E-04	1.2403084E-01	1.4554073E-05	2.9925283E 02
68250.	7.2297136E-04	2.2208819E 02	2.2208819E 02	1.1340531E-04	1.2797823E-01	1.4513411E-05	2.9874991E 02
68500.	6.9628181E-04	2.2134183E 02	2.2134183E 02	1.0958706E-04	1.3206667E-01	1.4472799E-05	2.9824749E 02
68750.	6.7049399E-04	2.2059755E 02	2.2059755E 02	1.0588440E-04	1.3630186E-01	1.4432241E-05	2.9774563E 02
69000.	6.4558010E-04	2.1985545E 02	2.1985545E 02	1.0229411E-04	1.4068984E-01	1.4391743E-05	2.9724439E 02
69250.	6.2151386E-04	2.1911562E 02	2.1911562E 02	9.8813258E-05	1.4523667E-01	1.4351309E-05	2.9674385E 02
69500.	5.9826908E-04	2.1837805E 02	2.1837805E 02	9.5438879E-05	1.4994875E-01	1.4310941E-05	2.9624399E 02
69750.	5.7582031E-04	2.1764278E 02	2.1764278E 02	9.2168063E-05	1.5483280E-01	1.4270640E-05	2.9574485E 02
70000.	5.5414297E-04	2.1690992E 02	2.1690992E 02	8.8997983E-05	1.5989589E-01	1.4230412E-05	2.9524650E 02
70250.	5.3321321E-04	2.1617939E 02	2.1617939E 02	8.5925955E-05	1.6514514E-01	1.4190254E-05	2.9474890E 02
70500.	5.1300769E-04	2.1545138E 02	2.1545138E 02	8.2949228E-05	1.7058841E-01	1.4150177E-05	2.9425218E 02
70750.	4.9350380E-04	2.1472581E 02	2.1472581E 02	8.0065238E-05	1.7623349E-01	1.4110177E-05	2.9375629E 02
71000.	4.7467952E-04	2.1400271E 02	2.1400271E 02	7.7271433E-05	1.8208870E-01	1.4070255E-05	2.9326126E 02
71250.	4.5651352E-04	2.1328214E 02	2.1328214E 02	7.4565325E-05	1.8816272E-01	1.4030415E-05	2.9276712E 02
71500.	4.3898500E-04	2.1256401E 02	2.1256401E 02	7.1944517E-05	1.9446448E-01	1.3990653E-05	2.9227382E 02
71750.	4.2207370E-04	2.1184835E 02	2.1184835E 02	6.9406629E-05	2.0100344E-01	1.3950971E-05	2.9178139E 02

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
54000.	5.0690643E-04	5.7668378E-04	9.1028678E-01	2.8964400E 01	1.0164992E 01
54250.	4.9097988E-04	5.5978708E-04	9.0870485E-01		1.0165154E 01
54500.	4.7552003E-04	5.4337127E-04	9.0709243E-01		1.0165311E 01
54750.	4.6051375E-04	5.2742183E-04	9.0545042E-01		1.0165464E 01
55000.	4.4594829E-04	5.1192483E-04	9.0377960E-01		1.0165612E 01
55250.	4.3181145E-04	4.9686704E-04	9.0208077E-01		1.0165755E 01
55500.	4.1809098E-04	4.8223513E-04	9.0035490E-01		1.0165895E 01
55750.	4.0477541E-04	4.6801682E-04	8.9860260E-01		1.0166030E 01
56000.	3.9185332E-04	4.5419992E-04	8.9682474E-01		1.0166162E 01
56250.	3.7931373E-04	4.4077271E-04	8.9502219E-01		1.0166289E 01
56500.	3.6714590E-04	4.2772378E-04	8.9319574E-01		1.0166413E 01
56750.	3.5533945E-04	4.1504229E-04	8.9134611E-01		1.0166533E 01
57000.	3.4388426E-04	4.0271766E-04	8.8947403E-01		1.0166650E 01
57250.	3.3277048E-04	3.9073956E-04	8.8758039E-01		1.0166763E 01
57500.	3.2198857E-04	3.7909814E-04	8.8566595E-01		1.0166872E 01
57750.	3.1152927E-04	3.6778390E-04	8.8373126E-01		1.0166979E 01
58000.	3.0138347E-04	3.5678740E-04	8.8177731E-01		1.0167082E 01
58250.	2.9154242E-04	3.4609972E-04	8.7980474E-01		1.0167182E 01
58500.	2.8193755E-04	3.3571214E-04	8.7781430E-01		1.0167279E 01
58750.	2.7274061E-04	3.2561634E-04	8.7580669E-01		1.0167373E 01
59000.	2.6376350E-04	3.1580411E-04	8.7378265E-01		1.0167464E 01
59250.	2.5505827E-04	3.0626749E-04	8.7174278E-01		1.0167553E 01
59500.	2.4661739E-04	2.9699894E-04	8.6968786E-01		1.0167639E 01
59750.	2.3843330E-04	[illegible]	8.6761861E-01		1.0167722E 01
60000.	2.3049894E-04	2.7923629E-04	8.6553571E-01		1.0167803E 01
60250.	2.2280707E-04	2.7072799E-04	8.6343989E-01		1.0167881E 01
60500.	2.1535097E-04	2.6245942E-04	8.6133162E-01		1.0167957E 01
60750.	2.0812393E-04	2.5442392E-04	8.5921162E-01		1.0168030E 01
61000.	2.0111943E-04	2.4661506E-04	8.5708065E-01		1.0168101E 01
61250.	1.9433122E-04	2.3902681E-04	8.5493916E-01		1.0168171E 01
61500.	1.8775312E-04	2.3165306E-04	8.5278798E-01		1.0168238E 01
61750.	1.8137920E-04	2.2448806E-04	8.5062753E-01		1.0168302E 01
62000.	1.7520362E-04	2.1752612E-04	8.4845861E-01		1.0168365E 01
62250.	1.6922068E-04	2.1076172E-04	8.4628174E-01		1.0168426E 01
62500.	1.6342490E-04	2.0418957E-04	8.4409732E-01		1.0168485E 01
62750.	1.5781101E-04	1.9780458E-04	8.4190620E-01	MOLECULAR WEIGHT CONSTANT TO 90,000 METERS	1.0168542E 01
63000.	1.5237367E-04	1.9160163E-04	8.3970866E-01		1.0168597E 01
63250.	1.4710784E-04	1.8557580E-04	8.3750552E-01		1.0168651E 01
63500.	1.4200859E-04	1.7972236E-04	8.3529718E-01		1.0168703E 01
63750.	1.3707117E-04	1.7403681E-04	8.3308420E-01		1.0168753E 01
64000.	1.3229081E-04	1.6851453E-04	8.3086702E-01		1.0168802E 01
64250.	1.2766301E-04	1.6315121E-04	8.2864624E-01		1.0168849E 01
64500.	1.2318333E-04	1.5794259E-04	8.2642241E-01		1.0168894E 01
64750.	1.1884746E-04	1.5288455E-04	8.2419587E-01		1.0168938E 01
65000.	1.1465120E-04	1.4797314E-04	8.2196686E-01		1.0168981E 01
65250.	1.1059041E-04	1.4320426E-04	8.1973635E-01		1.0169022E 01
65500.	1.0666126E-04	1.3857435E-04	8.1750449E-01		1.0169062E 01
65750.	1.0285976E-04	1.3407958E-04	8.1527168E-01		1.0169101E 01
66000.	9.9182203E-05	1.2971638E-04	8.1303844E-01		1.0169138E 01
66250.	9.5624859E-05	1.2548116E-04	8.1080512E-01		1.0169174E 01
66500.	9.2184241E-05	1.2137064E-04	8.0857201E-01		1.0169210E 01
66750.	8.8856859E-05	1.1738146E-04	8.0633949E-01		1.0169243E 01
67000.	8.5639302E-05	1.1351028E-04	8.0410815E-01		1.0169276E 01
67250.	8.2528344E-05	1.0975408E-04	8.0187805E-01		1.0169308E 01
67500.	7.9520754E-05	1.0610972E-04	7.9964957E-01		1.0169338E 01
67750.	7.6613433E-05	1.0257420E-04	7.9742320E-01		1.0169368E 01
68000.	7.3803384E-05	9.9144681E-05	7.9519892E-01		1.0169396E 01
68250.	7.1087601E-05	9.5818192E-05	7.9297726E-01		1.0169424E 01
68500.	6.8463297E-05	9.2592089E-05	7.9075834E-01		1.0169451E 01
68750.	6.5927658E-05	8.9463636E-05	7.8854234E-01		1.0169477E 01
69000.	6.3477950E-05	8.6430142E-05	7.8632962E-01		1.0169501E 01
69250.	6.1111588E-05	8.3489105E-05	7.8412042E-01		1.0169525E 01
69500.	5.8826000E-05	8.0638031E-05	7.8191479E-01		1.0169549E 01
69750.	5.6618680E-05	7.7874460E-05	7.7971284E-01		1.0169571E 01
70000.	5.4487212E-05	7.5196002E-05	7.7751489E-01		1.0169593E 01
70250.	5.2429252E-05	7.2600390E-05	7.7532077E-01		1.0169614E 01
70500.	5.0442504E-05	7.0085300E-05	7.7313105E-01		1.0169634E 01
70750.	4.8524745E-05	6.7648565E-05	7.7094553E-01		1.0169654E 01
71000.	4.6673810E-05	6.5288028E-05	7.6876431E-01		1.0169672E 01
71250.	4.4887602E-05	6.3001588E-05	7.6658753E-01		1.0169691E 01
71500.	4.3164076E-05	6.0787221E-05	7.6441507E-01		1.0169708E 01
71750.	4.1501238E-05	5.8642914E-05	7.6224694E-01	2.8964400E 01	1.0169725E 01

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	VIRTUAL TEMPERATURE	DENSITY	KINEMATIC VISCOSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	m^2 sec^{-1}	newton-sec m^{-2}	m sec^{-1}
72000.	4.0576003E-04	2.1113518E 02	2.1113518E 02	6.6949356E-05	2.0778947E-01	1.3911371E-05	2.9128985E 02
72250.	3.9002491E-04	2.1042441E 02	2.1042441E 02	6.4570475E-05	2.1483266E-01	1.3871847E-05	2.9079913E 02
72500.	3.7484991E-04	2.0971612E 02	2.0971612E 02	6.2267774E-05	2.2214388E-01	1.3832405E-05	2.9030931E 02
72750.	3.6021682E-04	2.0901017E 02	2.0901017E 02	6.0039119E-05	2.2973417E-01	1.3793037E-05	2.8982028E 02
73000.	3.4610846E-04	2.0830656E 02	2.0830656E 02	5.7882463E-05	2.3761504E-01	1.3753744E-05	2.8933204E 02
73250.	3.3250751E-04	2.0760531E 02	2.0760531E 02	5.5795702E-05	2.4579899E-01	1.3714527E-05	2.8884462E 02
73500.	3.1939768E-04	2.0690623E 02	2.0690623E 02	5.3776921E-05	2.5429823E-01	1.3675376E-05	2.8835789E 02
73750.	3.0676280E-04	2.0620942E 02	2.0620942E 02	5.1824119E-05	2.6312645E-01	1.3636297E-05	2.8787192E 02
74000.	2.9458748E-04	2.0551462E 02	2.0551462E 02	4.9935490E-05	2.7229680E-01	1.3597275E-05	2.8738653E 02
74250.	2.8285647E-04	2.0482191E 02	2.0482191E 02	4.8109125E-05	2.8182420E-01	1.3558316E-05	2.8690179E 02
74500.	2.7155515E-04	2.0413113E 02	2.0413113E 02	4.6343256E-05	2.9172336E-01	1.3519410E-05	2.8641758E 02
74750.	2.6066926E-04	2.0344220E 02	2.0344220E 02	4.4636129E-05	3.0200992E-01	1.3480554E-05	2.8593385E 02
75000.	2.5018505E-04	2.0275499E 02	2.0275499E 02	4.2986051E-05	3.1270005E-01	1.3441740E-05	2.8545051E 02
75250.	2.4008915E-04	2.0206947E 02	2.0206947E 02	4.1391349E-05	3.2381085E-01	1.3402968E-05	2.8496755E 02
75500.	2.3036834E-04	2.0138545E 02	2.0138545E 02	3.9850378E-05	3.3536007E-01	1.3364226E-05	2.8448482E 02
75750.	2.2101015E-04	2.0070282E 02	2.0070282E 02	3.8361530E-05	3.4736598E-01	1.3325508E-05	2.8400225E 02
76000.	2.1200230E-04	2.0002147E 02	2.0002147E 02	3.6923403E-05	3.5984789E-01	1.3286809E-05	2.8351977E 02
76250.	2.0333298E-04	1.9934132E 02	1.9934132E 02	3.5534339E-05	3.7282595E-01	1.3248124E-05	2.8303733E 02
76500.	1.9499040E-04	1.9866205E 02	1.9866205E 02	3.4192910E-05	3.8632084E-01	1.3209434E-05	2.8255468E 02
76750.	1.8696371E-04	1.9798364E 02	1.9798364E 02	3.2897717E-05	4.0035419E-01	1.3170739E-05	2.8207183E 02
77000.	1.7924187E-04	1.9730592E 02	1.9730592E 02	3.1647331E-05	4.1494902E-01	1.3132029E-05	2.8158863E 02
77250.	1.7181453E-04	1.9662865E 02	1.9662865E 02	3.0440435E-05	4.3012822E-01	1.3093290E-05	2.8110492E 02
77500.	1.6467127E-04	1.9595169E 02	1.9595169E 02	2.9275652E-05	4.4591716E-01	1.3054515E-05	2.8062060E 02
77750.	1.5780237E-04	1.9527487E 02	1.9527487E 02	2.8151717E-05	4.6234101E-01	1.3015694E-05	2.8013555E 02
78000.	1.5119831E-04	1.9459798E 02	1.9459798E 02	2.7067389E-05	4.7942609E-01	1.2976813E-05	2.7964961E 02
78250.	1.4484968E-04	1.9392081E 02	1.9392081E 02	2.6021414E-05	4.9720054E-01	1.2937861E-05	2.7916261E 02
78500.	1.3874757E-04	1.9324316E 02	1.9324316E 02	2.5012613E-05	5.1569290E-01	1.2898827E-05	2.7867443E 02
78750.	1.3288332E-04	1.9256477E 02	1.9256477E 02	2.4039828E-05	5.3493286E-01	1.2859694E-05	2.7818485E 02
79000.	1.2724843E-04	1.9188547E 02	1.9188547E 02	2.3101922E-05	5.5495180E-01	1.2820453E-05	2.7769374E 02
79250.	1.2183471E-04	1.9120492E 02	1.9120492E 02	2.2197789E-05	5.7578186E-01	1.2781084E-05	2.7720087E 02
79500.	1.1663428E-04	1.9052299E 02	1.9052299E 02	2.1326351E-05	5.9745705E-01	1.2741579E-05	2.7670611E 02
79750.	1.1163954E-04	1.8983932E 02	1.8983932E 02	2.0486587E-05	6.2001130E-01	1.2701915E-05	2.7620920E 02
80000.	1.0684305E-04	1.8915372E 02	1.8915372E 02	1.9677466E-05	6.4348133E-01	1.2662082E-05	2.7570998E 02
80250.	1.0223758E-04	1.8846591E 02	1.8846591E 02	1.8897985E-05	6.6790522E-01	1.2622063E-05	2.7520826E 02
80500.	9.7816271E-05	1.8777551E 02	1.8777551E 02	1.8147211E-05	6.9332055E-01	1.2581835E-05	2.7470371E 02
80750.	9.3572375E-05	1.8708234E 02	1.8708234E 02	1.7424191E-05	7.1976859E-01	1.2541385E-05	2.7419621E 02
81000.	8.9499401E-05	1.8638606E 02	1.8638606E 02	1.6728017E-05	7.4729094E-01	1.2500695E-05	2.7368549E 02
81250.	8.5591011E-05	1.8568642E 02	1.8568642E 02	1.6057790E-05	7.7593164E-01	1.2459747E-05	2.7317133E 02
81500.	8.1841182E-05	1.8498297E 02	1.8498297E 02	1.5412671E-05	8.0573418E-01	1.2418516E-05	2.7265341E 02
81750.	7.8244016E-05	1.8427542E 02	1.8427542E 02	1.4791815E-05	8.3674524E-01	1.2376981E-05	2.7213146E 02
82000.	7.4793850E-05	1.8356358E 02	1.8356358E 02	1.4194402E-05	8.6901376E-01	1.2335131E-05	2.7160535E 02
82250.	7.1485156E-05	1.8284694E 02	1.8284694E 02	1.3619650E-05	9.0258818E-01	1.2292935E-05	2.7107464E 02
82500.	6.8312650E-05	1.8212515E 02	1.8212515E 02	1.3066791E-05	9.3751932E-01	1.2250370E-05	2.7053908E 02
82750.	6.5271214E-05	1.8139796E 02	1.8139796E 02	1.2535078E-05	9.7386069E-01	1.2207420E-05	2.6999844E 02
83000.	6.2355810E-05	1.8066486E 02	1.8066486E 02	1.2023779E-05	1.0116662E 00	1.2164052E-05	2.6945229E 02
83250.	5.9552895E-05	1.8065000E 02	1.8065000E 02	1.1484251E-05	1.0591176E 00	1.2163172E-05	2.6944122E 02
83500.	5.6875955E-05	1.8065000E 02	1.8065000E 02	1.0968027E-05	1.1089663E 00	1.2163172E-05	2.6944122E 02
83750.	5.4319540E-05	1.8065000E 02	1.8065000E 02	1.0475044E-05	1.1611571E 00	1.2163172E-05	2.6944122E 02
84000.	5.1878215E-05	1.8065000E 02	1.8065000E 02	1.0004256E-05	1.2157997E 00	1.2163172E-05	2.6944122E 02
84250.	4.9546789E-05	1.8065000E 02	1.8065000E 02	9.5546614E-06	1.2730092E 00	1.2163172E-05	2.6944122E 02
84500.	4.7320307E-05	1.8065000E 02	1.8065000E 02	9.1253040E-06	1.3329060E 00	1.2163172E-05	2.6944122E 02
84750.	4.5194038E-05	1.8065000E 02	1.8065000E 02	8.7152717E-06	1.3956160E 00	1.2163172E-05	2.6944122E 02
85000.	4.3163465E-05	1.8065000E 02	1.8065000E 02	8.3236936E-06	1.4612710E 00	1.2163172E-05	2.6944122E 02
85250.	4.1224272E-05	1.8065000E 02	1.8065000E 02	7.9497374E-06	1.5300093E 00	1.2163172E-05	2.6944122E 02
85500.	3.9372342E-05	1.8065000E 02	1.8065000E 02	7.5926090E-06	1.6019753E 00	1.2163172E-05	2.6944122E 02
85750.	3.7603741E-05	1.8065000E 02	1.8065000E 02	7.2515500E-06	1.6773203E 00	1.2163172E-05	2.6944122E 02
86000.	3.5914714E-05	1.8065000E 02	1.8065000E 02	6.9258360E-06	1.7562028E 00	1.2163172E-05	2.6944122E 02
86250.	3.4301675E-05	1.8065000E 02	1.8065000E 02	6.6147756E-06	1.8387883E 00	1.2163172E-05	2.6944122E 02
86500.	3.2761198E-05	1.8065000E 02	1.8065000E 02	6.3177083E-06	1.9252507E 00	1.2163172E-05	2.6944122E 02
86750.	3.1290016E-05	1.8065000E 02	1.8065000E 02	6.0340037E-06	2.0157714E 00	1.2163172E-05	2.6944122E 02
87000.	2.9885006E-05	1.8065000E 02	1.8065000E 02	5.7630599E-06	2.1105407E 00	1.2163172E-05	2.6944122E 02
87250.	2.8543187E-05	1.8065000E 02	1.8065000E 02	5.5043019E-06	2.2097574E 00	1.2163172E-05	2.6944122E 02
87500.	2.7261712E-05	1.8065000E 02	1.8065000E 02	5.2571808E-06	2.3136302E 00	1.2163172E-05	2.6944122E 02
87750.	2.6037863E-05	1.8065000E 02	1.8065000E 02	5.0211724E-06	2.4223769E 00	1.2163172E-05	2.6944122E 02
88000.	2.4869045E-05	1.8065000E 02	1.8065000E 02	4.7957760E-06	2.5362261E 00	1.2163172E-05	2.6944122E 02
88250.	2.3752779E-05	1.8065000E 02	1.8065000E 02	4.5805140E-06	2.6554165E 00	1.2163172E-05	2.6944122E 02
88500.	2.2686698E-05	1.8065000E 02	1.8065000E 02	4.3749296E-06	2.7801984E 00	1.2163172E-05	2.6944122E 02
88750.	2.1668542E-05	1.8065000E 02	1.8065000E 02	4.1785873E-06	2.9108335E 00	1.2163172E-05	2.6944122E 02
89000.	2.0696155E-05	1.8065000E 02	1.8065000E 02	3.9910710E-06	3.0475960E 00	1.2163172E-05	2.6944122E 02
89250.	1.9767475E-05	1.8065000E 02	1.8065000E 02	3.8119832E-06	3.1907728E 00	1.2163172E-05	2.6944122E 02
89500.	1.8880533E-05	1.8065000E 02	1.8065000E 02	3.6409443E-06	3.3406642E 00	1.2163172E-05	2.6944122E 02
89750.	1.8033452E-05	1.8065000E 02	1.8065000E 02	3.4775922E-06	3.4975844E 00	1.2163172E-05	2.6944122E 02

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
72000.	3.9897164E-05	5.6566718E-05	7.6008329E-01	2.8964400E 01	1.0169741E 01
72250.	3.8349976E-05	5.4556759E-05	7.5792378E-01		1.0169757E 01
72500.	3.6857865E-05	5.2611166E-05	7.5576879E-01		1.0169772E 01
72750.	3.5419037E-05	5.0728135E-05	7.5361782E-01		1.0169787E 01
73000.	3.4031804E-05	4.8905938E-05	7.5147093E-01		1.0169801E 01
73250.	3.2694463E-05	4.7142795E-05	7.4932821E-01		1.0169815E 01
73500.	3.1405413E-05	4.5437091E-05	7.4718909E-01		1.0169828E 01
73750.	3.0163064E-05	4.3787133E-05	7.4505390E-01		1.0169840E 01
74000.	2.8965901E-05	4.2191396E-05	7.4292182E-01		1.0169852E 01
74250.	2.7812427E-05	4.0648267E-05	7.4079321E-01		1.0169864E 01
74500.	2.6701201E-05	3.9156253E-05	7.3866751E-01		1.0169875E 01
74750.	2.5630825E-05	3.7713871E-05	7.3654450E-01		1.0169886E 01
75000.	2.4599944E-05	3.6319690E-05	7.3442382E-01		1.0169897E 01
75250.	2.3607244E-05	3.4972298E-05	7.3230540E-01		1.0169907E 01
75500.	2.2651426E-05	3.3670304E-05	7.3018862E-01		1.0169917E 01
75750.	2.1731263E-05	3.2412392E-05	7.2807317E-01		1.0169926E 01
76000.	2.0845549E-05	3.1197249E-05	7.2595872E-01		1.0169935E 01
76250.	1.9993120E-05	3.0023604E-05	7.2384508E-01		1.0169944E 01
76500.	1.9172819E-05	2.8890207E-05	7.2173114E-01		1.0169952E 01
76750.	1.8383580E-05	2.7795874E-05	7.1961697E-01		1.0169960E 01
77000.	1.7624314E-05	2.6739401E-05	7.1750195E-01		1.0169968E 01
77250.	1.6894006E-05	2.5719673E-05	7.1538536E-01		1.0169975E 01
77500.	1.6191631E-05	2.4735526E-05	7.1326679E-01		1.0169982E 01
77750.	1.5516232E-05	2.3785894E-05	7.1114566E-01		1.0169989E 01
78000.	1.4866875E-05	2.2869720E-05	7.0902130E-01		1.0169996E 01
78250.	1.4242634E-05	2.1985962E-05	7.0689307E-01		1.0170002E 01
78500.	1.3642633E-05	2.1133608E-05	7.0476035E-01		1.0170008E 01
78750.	1.3066017E-05	2.0311685E-05	7.0262225E-01		1.0170014E 01
79000.	1.2511956E-05	1.9519231E-05	7.0047820E-01		1.0170020E 01
79250.	1.1979641E-05	1.8755312E-05	6.9832718E-01		1.0170025E 01
79500.	1.1468298E-05	1.8019010E-05	6.9616869E-01		1.0170030E 01
79750.	1.0977180E-05	1.7309487E-05	6.9400159E-01		1.0170035E 01
80000.	1.0505556E-05	1.6625846E-05	6.9182519E-01		1.0170040E 01
80250.	1.0052714E-05	1.5967249E-05	6.8963866E-01		1.0170045E 01
80500.	9.6179799E-06	1.5332906E-05	6.8744068E-01	MOLECULAR WEIGHT CONSTANT TO 90,000 METERS	1.0170049E 01
80750.	9.2006903E-06	1.4722013E-05	6.8523062E-01		1.0170054E 01
81000.	8.8002070E-06	1.4133803E-05	6.8300741E-01		1.0170058E 01
81250.	8.4159068E-06	1.3567517E-05	6.8077012E-01		1.0170061E 01
81500.	8.0471972E-06	1.3022443E-05	6.7851731E-01		1.0170065E 01
81750.	7.6934987E-06	1.2497872E-05	6.7624797E-01		1.0170069E 01
82000.	7.3542544E-06	1.1993107E-05	6.7396140E-01		1.0170072E 01
82250.	7.0289205E-06	1.1507488E-05	6.7165588E-01		1.0170076E 01
82500.	6.7169775E-06	1.1040368E-05	6.6933023E-01		1.0170079E 01
82750.	6.4179222E-06	1.0591113E-05	6.6698355E-01		1.0170082E 01
83000.	6.1312594E-06	1.0159108E-05	6.6461403E-01		1.0170085E 01
83250.	5.8556570E-06	9.7032506E-06	6.6456598E-01		1.0170088E 01
83500.	5.5924417E-06	9.2670836E-06	6.6456598E-01		1.0170090E 01
83750.	5.3410771E-06	8.8505540E-06	6.6456598E-01		1.0170093E 01
84000.	5.1010289E-06	8.4527768E-06	6.6456598E-01		1.0170095E 01
84250.	4.8717868E-06	8.0729058E-06	6.6456598E-01		1.0170098E 01
84500.	4.6528635E-06	7.7101340E-06	6.6456598E-01		1.0170100E 01
84750.	4.4437939E-06	7.3636903E-06	6.6456598E-01		1.0170102E 01
85000.	4.2441337E-06	7.0328389E-06	6.6456598E-01		1.0170104E 01
85250.	4.0534588E-06	6.7168766E-06	6.6456598E-01		1.0170106E 01
85500.	3.8713640E-06	6.4151324E-06	6.6456598E-01		1.0170108E 01
85750.	3.6974628E-06	6.1269654E-06	6.6456598E-01		1.0170109E 01
86000.	3.5313858E-06	5.8517637E-06	6.6456598E-01		1.0170111E 01
86250.	3.3727806E-06	5.5889432E-06	6.6456598E-01		1.0170113E 01
86500.	3.2213101E-06	5.3379458E-06	6.6456598E-01		1.0170114E 01
86750.	3.0766532E-06	5.0982386E-06	6.6456598E-01		1.0170116E 01
87000.	2.9385028E-06	4.8693133E-06	6.6456598E-01		1.0170117E 01
87250.	2.8065657E-06	4.6506840E-06	6.6456598E-01		1.0170119E 01
87500.	2.6805622E-06	4.4419869E-06	6.6456598E-01		1.0170120E 01
87750.	2.5602248E-06	4.2424792E-06	6.6456598E-01		1.0170121E 01
88000.	2.4452984E-06	4.0520377E-06	6.6456598E-01		1.0170122E 01
88250.	2.3355393E-06	3.8701589E-06	6.6456598E-01		1.0170123E 01
88500.	2.2307148E-06	3.6964570E-06	6.6456598E-01		1.0170124E 01
88750.	2.1306026E-06	3.5305638E-06	6.6456598E-01		1.0170125E 01
89000.	2.0349907E-06	3.3721279E-06	6.6456598E-01		1.0170126E 01
89250.	1.9436763E-06	3.2208134E-06	6.6456598E-01		1.0170127E 01
89500.	1.8564660E-06	3.0762995E-06	6.6456598E-01		1.0170128E 01
89750.	1.7731751E-06	2.9382804E-06	6.6456598E-01	2.8964400E 01	1.0170129E 01

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	MOLECULAR TEMPERATURE	DENSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	newton-sec m^{-2}	m sec^{-1}
90000.	1.7224435E-05	1.8065000E 02	1.8065000E 02	3.3215805E-06	1.2163172E-05	2.6944122E 02
91000.	1.4357534E-05	1.8359648E 02	1.8365000E 02	2.7234957E-06	1.2340215E-05	2.7166927E 02
92000.	1.2003841E-05	1.8654122E 02	1.8665000E 02	2.2404228E-06	1.2516126E-05	2.7387919E 02
93000.	1.0065252E-05	1.8948421E 02	1.8965000E 02	1.8488836E-06	1.2690921E-05	2.7607143E 02
94000.	8.4635721E-06	1.9242545E 02	1.9265000E 02	1.5304616E-06	1.2864614E-05	2.7824640E 02
95000.	7.1362419E-06	1.9536494E 02	1.9565000E 02	1.2706545E-06	1.3037217E-05	2.8040450E 02
96000.	6.0330423E-06	1.9830268E 02	1.9865000E 02	1.0579997E-06	1.3208747E-05	2.8254611E 02
97000.	5.1135173E-06	2.0123868E 02	2.0165000E 02	8.8340379E-07	1.3379216E-05	2.8467161E 02
98000.	4.3449711E-06	2.0417293E 02	2.0465000E 02	7.3962724E-07	1.3548638E-05	2.8678136E 02
99000.	3.7008921E-06	2.0710543E 02	2.0765000E 02	6.2088653E-07	1.3717028E-05	2.8887571E 02
100000.	3.1597170E-06	2.1003618E 02	2.1065000E 02	5.2254595E-07	1.3884397E-05	2.9095497E 02
101000.	2.7057645E-06	2.1478336E 02	2.1565000E 02	4.3709746E-07	1.4161117E-05	2.9438778E 02
102000.	2.3253935E-06	2.1951949E 02	2.2065000E 02	3.6713880E-07	1.4435101E-05	2.9778102E 02
103000.	2.0053844E-06	2.2424457E 02	2.2565000E 02	3.0959935E-07	1.4706408E-05	3.0113603E 02
104000.	1.7351148E-06	2.2895861E 02	2.3065000E 02	2.6206711E-07	1.4975097E-05	3.0445407E 02
105000.	1.5060075E-06	2.3366159E 02	2.3565000E 02	2.2263706E-07	1.5241223E-05	3.0773633E 02
106000.	1.3111039E-06	2.3835353E 02	2.4065000E 02	1.8979684E-07	1.5504842E-05	3.1098395E 02
107000.	1.1447335E-06	2.4303442E 02	2.4565000E 02	1.6233993E-07	1.5766006E-05	3.1419801E 02
108000.	1.0022554E-06	2.4770427E 02	2.5065000E 02	1.3929915E-07	1.6024767E-05	3.1737952E 02
109000.	8.7985634E-07	2.5236306E 02	2.5565000E 02	1.1989573E-07	1.6281177E-05	3.2052946E 02
110000.	7.7438980E-07	2.5701081E 02	2.6065000E 02	1.0349983E-07	1.6535285E-05	3.2364874E 02
111000.	6.8403258E-07	2.6641332E 02	2.7065000E 02	8.8045367E-08	1.7036783E-05	3.2979880E 02
112000.	6.0696757E-07	2.7578200E 02	2.8065000E 02	7.5342182E-08	1.7529632E-05	3.3583625E 02
113000.	5.4086384E-07	2.8511684E 02	2.9065000E 02	6.4826916E-08	1.8014180E-05	3.4176707E 02
114000.	4.8386073E-07	2.9441785E 02	3.0065000E 02	5.6065657E-08	1.8490756E-05	3.4759671E 02
115000.	4.3446125E-07	3.0368503E 02	3.1065000E 02	4.8721141E-08	1.8959675E-05	3.5333018E 02
116000.	3.9145232E-07	3.1291837E 02	3.2065000E 02	4.2529020E-08	1.9421230E-05	3.5897208E 02
117000.	3.5384426E-07	3.2211787E 02	3.3065000E 02	3.7280470E-08	1.9875702E-05	3.6452667E 02
118000.	3.2082435E-07	3.3128354E 02	3.4065000E 02	3.2809278E-08	2.0323355E-05	3.6999789E 02
119000.	2.9172118E-07	3.4041538E 02	3.5065000E 02	2.8982235E-08	2.0764441E-05	3.7538938E 02
120000.	2.6597710E-07	3.4951338E 02	3.6065000E 02	2.5691890E-08	2.1199197E-05	3.8070451E 02
121000.	2.4341101E-07	3.6839206E 02	3.8065000E 02	2.2276765E-08	2.2050607E-05	3.9111815E 02
122000.	2.2377934E-07	3.8721781E 02	4.0065000E 02	1.9457748E-08	2.2879253E-05	4.0126162E 02
123000.	2.0658100E-07	4.0599062E 02	4.2065000E 02	1.7108315E-08	2.3686639E-05	4.1115493E 02
124000.	1.9141913E-07	4.2471051E 02	4.4065000E 02	1.5133149E-08	2.4474125E-05	4.2081570E 02
125000.	1.7797572E-07	4.4337744E 02	4.6065000E 02	1.3459454E-08	2.5242944E-05	4.3025962E 02
126000.	1.6599345E-07	4.6199146E 02	4.8065000E 02	1.2030946E-08	2.5994216E-05	4.3950065E 02
127000.	1.5526215E-07	4.8055254E 02	5.0065000E 02	1.0803615E-08	2.6728963E-05	4.4855134E 02
128000.	1.4560872E-07	4.9906068E 02	5.2065000E 02	9.7426983E-09	2.7448117E-05	4.5742298E 02
129000.	1.3688945E-07	5.1751589E 02	5.4065000E 02	8.8204658E-09	2.8152533E-05	4.6612582E 02
130000.	1.2898417E-07	5.3591816E 02	5.6065000E 02	8.0146089E-09	2.8842997E-05	4.7466910E 02
131000.	1.2179175E-07	5.5426750E 02	5.8065000E 02	7.3070349E-09	2.9520227E-05	4.8306132E 02
132000.	1.1522650E-07	5.7256391E 02	6.0065000E 02	6.6829568E-09	3.0184890E-05	4.9131021E 02
133000.	1.0921551E-07	5.9080738E 02	6.2065000E 02	6.1302094E-09	3.0837601E-05	4.9942288E 02
134000.	1.0369626E-07	6.0899793E 02	6.4065000E 02	5.6387136E-09	3.1478926E-05	5.0740585E 02
135000.	9.8615005E-08	6.2713553E 02	6.6065000E 02	5.2000715E-09	3.2109396E-05	5.1526515E 02
136000.	9.3925204E-08	6.4522020E 02	6.8065000E 02	4.8072428E-09	3.2729499E-05	5.2300637E 02
137000.	8.9586500E-08	6.6325194E 02	7.0065000E 02	4.4542972E-09	3.3339691E-05	5.3063467E 02
138000.	8.5563661E-08	6.8123074E 02	7.2065000E 02	4.1362113E-09	3.3940400E-05	5.3815483E 02
139000.	8.1825829E-08	6.9915662E 02	7.4065000E 02	3.8487096E-09	3.4532020E-05	5.4557136E 02
140000.	7.8345911E-08	7.1702955E 02	7.6065000E 02	3.5881386E-09	3.5114925E-05	5.5288841E 02
141000.	7.5100009E-08	7.3484955E 02	7.8065000E 02	3.3513623E-09	3.5689461E-05	5.6010988E 02
142000.	7.2066944E-08	7.5261663E 02	8.0065000E 02	3.1356758E-09	3.6255956E-05	5.6723942E 02
143000.	6.9227957E-08	7.7033076E 02	8.2064999E 02	2.9387408E-09	3.6814717E-05	5.7428046E 02
144000.	6.6566336E-08	7.8799196E 02	8.4065000E 02	2.7585267E-09	3.7366033E-05	5.8123620E 02
145000.	6.4067172E-08	8.0560023E 02	8.6064999E 02	2.5932640E-09	3.7910175E-05	5.8810970E 02
146000.	6.1717079E-08	8.2315556E 02	8.8065000E 02	2.4414047E-09	3.8447399E-05	5.9490377E 02
147000.	5.9504086E-08	8.4065795E 02	9.0065000E 02	2.3015928E-09	3.8977947E-05	6.0162112E 02
148000.	5.7417393E-08	8.5810742E 02	9.2064999E 02	2.1726345E-09	3.9502050E-05	6.0826430E 02
149000.	5.5447274E-08	8.7550395E 02	9.4065000E 02	2.0534772E-09	4.0019922E-05	6.1483570E 02
150000.	5.3584943E-08	8.9284424E 02	9.6064999E 02	1.9431903E-09	4.0531768E-05	6.2133762E 02
151000.	5.1813260E-08	9.0590969E 02	9.7565000E 02	1.8500549E-09	4.0911817E-05	6.2616974E 02
152000.	5.0126367E-08	9.1894822E 02	9.9065000E 02	1.7627216E-09	4.1288666E-05	6.3096486E 02
153000.	4.8519017E-08	9.3195982E 02	1.0056500E 03	1.6807491E-09	4.1662388E-05	6.3572381E 02
154000.	4.6986357E-08	9.4494449E 02	1.0206500E 03	1.6037353E-09	4.2033057E-05	6.4044740E 02
155000.	4.5523880E-08	9.5790220E 02	1.0356500E 03	1.5313132E-09	4.2400743E-05	6.4513641E 02
156000.	4.4127423E-08	9.7083302E 02	1.0506500E 03	1.4631480E-09	4.2765514E-05	6.4979159E 02
157000.	4.2793123E-08	9.8373690E 02	1.0656500E 03	1.3989338E-09	4.3127434E-05	6.5441364E 02
158000.	4.1517377E-08	9.9661385E 02	1.0806500E 03	1.3383898E-09	4.3486565E-05	6.5900328E 02
159000.	4.0296878E-08	1.0094639E 03	1.0956500E 03	1.2812601E-09	4.3842970E-05	6.6356118E 02

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
90000.	1.6936269E-06	2.8064633E-06	6.6456598E-01	2.8964400E 01	1.0170130E 01
91000.	1.4117332E-06	2.3011306E-06	6.7423916E-01	2.8955960E 01	1.0170133E 01
92000.	1.1803016E-06	1.8929737E-06	6.8385054E-01	2.8947520E 01	1.0170135E 01
93000.	9.8968600E-07	1.5621551E-06	6.9340090E-01	2.8939080E 01	1.0170137E 01
94000.	8.3219761E-07	1.2931146E-06	7.0289101E-01	2.8930640E 01	1.0170139E 01
95000.	7.0168521E-07	1.0735989E-06	7.1232166E-01	2.8922200E 01	1.0170140E 01
96000.	5.9321091E-07	8.9392306E-07	7.2169362E-01	2.8913760E 01	1.0170141E 01
97000.	5.0279678E-07	7.4640381E-07	7.3100764E-01	2.8905320E 01	1.0170142E 01
98000.	4.2722794E-07	6.2492440E-07	7.4026446E-01	2.8896880E 01	1.0170143E 01
99000.	3.6389759E-07	5.2459823E-07	7.4946484E-01	2.8888440E 01	1.0170143E 01
100000.	3.1068547E-07	4.4150850E-07	7.5860950E-01	2.8880000E 01	1.0170144E 01
101000.	2.6604969E-07	3.6931154E-07	7.7372877E-01	2.8848000E 01	1.0170144E 01
102000.	2.2864895E-07	3.1020220E-07	7.8869860E-01	2.8816000E 01	1.0170145E 01
103000.	1.9718342E-07	2.6158608E-07	8.0352218E-01	2.8784000E 01	1.0170145E 01
104000.	1.7060862E-07	2.2142523E-07	8.1820267E-01	2.8752000E 01	1.0170145E 01
105000.	1.4808119E-07	1.8811007E-07	8.3274316E-01	2.8720000E 01	1.0170145E 01
106000.	1.2891690E-07	1.6036277E-07	8.4714662E-01	2.8688000E 01	1.0170146E 01
107000.	1.1255820E-07	1.3716394E-07	8.6141597E-01	2.8656000E 01	1.0170146E 01
108000.	9.8548763E-08	1.1769636E-07	8.7555408E-01	2.8624000E 01	1.0170146E 01
109000.	8.6513629E-08	1.0130207E-07	8.8956368E-01	2.8592000E 01	1.0170146E 01
110000.	7.6143421E-08	8.7448876E-08	9.0344751E-01	2.8560000E 01	1.0170146E 01
111000.	6.7258868E-08	7.4391119E-08	9.3084816E-01	2.8511000E 01	1.0170146E 01
112000.	5.9681296E-08	6.3657969E-08	9.5777620E-01	2.8462000E 01	1.0170146E 01
113000.	5.3181515E-08	5.4773431E-08	9.8425070E-01	2.8413000E 01	1.0170147E 01
114000.	4.7576571E-08	4.7370886E-08	1.0102897E 00	2.8364000E 01	1.0170147E 01
115000.	4.2719269E-08	4.1165371E-08	1.0359102E 00	2.8315000E 01	1.0170147E 01
116000.	3.8490330E-08	3.5933537E-08	1.0611285E 00	2.8266000E 01	1.0170147E 01
117000.	3.4792442E-08	3.1498941E-08	1.0859597E 00	2.8216999E 01	1.0170147E 01
118000.	3.1545694E-08	2.7721151E-08	1.1104184E 00	2.8167999E 01	1.0170147E 01
119000.	2.8684067E-08	2.4487613E-08	1.1345183E 00	2.8119000E 01	1.0170147E 01
120000.	2.6152728E-08	2.1707542E-08	1.1582723E 00	2.8070000E 01	1.0170147E 01
121000.	2.3933873E-08	1.8822041E-08	1.2047912E 00	2.8031670E 01	1.0170147E 01
122000.	2.2003549E-08	1.6440203E-08	1.2500664E 00	2.7993340E 01	1.0170147E 01
123000.	2.0312489E-08	1.4455124E-08	1.2941800E 00	2.7955009E 01	1.0170147E 01
124000.	1.8821667E-08	1.2786271E-08	1.3372063E 00	2.7916680E 01	1.0170147E 01
125000.	1.7499817E-08	1.1372135E-08	1.3792127E 00	2.7878349E 01	1.0170147E 01
126000.	1.6321637E-08	1.0165163E-08	1.4202604E 00	2.7840019E 01	1.0170147E 01
127000.	1.5266460E-08	9.1281695E-09	1.4604051E 00	2.7801690E 01	1.0170147E 01
128000.	1.4317268E-08	8.2317816E-09	1.4996980E 00	2.7763360E 01	1.0170147E 01
129000.	1.3459928E-08	7.4525707E-09	1.5381856E 00	2.7725030E 01	1.0170147E 01
130000.	1.2682626E-08	6.7716876E-09	1.5759108E 00	2.7686700E 01	1.0170147E 01
131000.	1.1975416E-08	6.1738456E-09	1.6129130E 00	2.7648370E 01	1.0170147E 01
132000.	1.1329876E-08	5.6465508E-09	1.6492286E 00	2.7610039E 01	1.0170147E 01
133000.	1.0738833E-08	5.1795245E-09	1.6848911E 00	2.7571710E 01	1.0170147E 01
134000.	1.0196142E-08	4.7642509E-09	1.7199315E 00	2.7533379E 01	1.0170147E 01
135000.	9.6965170E-09	4.3936343E-09	1.7543789E 00	2.7495050E 01	1.0170147E 01
136000.	9.2353829E-09	4.0617262E-09	1.7882598E 00	2.7456720E 01	1.0170147E 01
137000.	8.8087711E-09	3.7635161E-09	1.8215992E 00	2.7418390E 01	1.0170147E 01
138000.	8.4132175E-09	3.4947596E-09	1.8544204E 00	2.7380059E 01	1.0170147E 01
139000.	8.0456877E-09	3.2518442E-09	1.8867451E 00	2.7341730E 01	1.0170147E 01
140000.	7.7035178E-09	3.0316831E-09	1.9185936E 00	2.7303399E 01	1.0170147E 01
141000.	7.3843582E-09	2.8316265E-09	1.9499848E 00	2.7265069E 01	1.0170147E 01
142000.	7.0861259E-09	2.6493891E-09	1.9809368E 00	2.7226740E 01	1.0170147E 01
143000.	6.8069769E-09	2.4829952E-09	2.0114661E 00	2.7188410E 01	1.0170147E 01
144000.	6.5452677E-09	2.3307289E-09	2.0415886E 00	2.7150080E 01	1.0170147E 01
145000.	6.2995325E-09	2.1910956E-09	2.0713192E 00	2.7111750E 01	1.0170147E 01
146000.	6.0684548E-09	2.0627869E-09	2.1006718E 00	2.7073420E 01	1.0170147E 01
147000.	5.8508579E-09	1.9446573E-09	2.1296597E 00	2.7035089E 01	1.0170147E 01
148000.	5.6456797E-09	1.8356981E-09	2.1582954E 00	2.6996760E 01	1.0170147E 01
149000.	5.4519637E-09	1.7350200E-09	2.1865906E 00	2.6958430E 01	1.0170147E 01
150000.	5.2688464E-09	1.6418366E-09	2.2145567E 00	2.6920000E 01	1.0170147E 01
151000.	5.0946420E-09	1.5631448E-09	2.2353216E 00	2.6894000E 01	1.0170147E 01
152000.	4.9287749E-09	1.4893553E-09	2.2559117E 00	2.6868000E 01	1.0170147E 01
153000.	4.7707291E-09	1.4200952E-09	2.2763309E 00	2.6842000E 01	1.0170147E 01
154000.	4.6200272E-09	1.3550249E-09	2.2965834E 00	2.6816000E 01	1.0170147E 01
155000.	4.4762262E-09	1.2938341E-09	2.3166729E 00	2.6790000E 01	1.0170147E 01
156000.	4.3389168E-09	1.2362401E-09	2.3366031E 00	2.6764000E 01	1.0170147E 01
157000.	4.2077191E-09	1.1819844E-09	2.3563775E 00	2.6738000E 01	1.0170147E 01
158000.	4.0822789E-09	1.1308297E-09	2.3759995E 00	2.6712000E 01	1.0170147E 01
159000.	3.9622708E-09	1.0825598E-09	2.3954726E 00	2.6686000E 01	1.0170147E 01

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	MOLECULAR TEMPERATURE	DENSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	newton-sec m^{-2}	m sec^{-1}
160000.	3.9128496E-08	1.0222870E 03	1.1106500E 03	1.2273083E-09	4.4106706E-05	6.6808798E 02
161000.	3.8006765E-08	1.0304854E 03	1.1206500E 03	1.1814862E-09	4.4431075E-05	6.7108889E 02
162000.	3.6927060E-08	1.0386659E 03	1.1306500E 03	1.1377695E-09	4.4664298E-05	6.7407643E 02
163000.	3.5887447E-08	1.0468284E 03	1.1406500E 03	1.0960438E-09	4.4896393E-05	6.7705080E 02
164000.	3.4886099E-08	1.0549730E 03	1.1506500E 03	1.0562018E-09	4.5127375E-05	6.8001215E 02
165000.	3.3921305E-08	1.0630997E 03	1.1606500E 03	1.0181436E-09	4.5357258E-05	6.8296066E 02
166000.	3.2991411E-08	1.0712083E 03	1.1706500E 03	9.8177412E-10	4.5586058E-05	6.8589650E 02
167000.	3.2094881E-08	1.0792991E 03	1.1806500E 03	9.4700518E-10	4.5813789E-05	6.8881981E 02
168000.	3.1230234E-08	1.0873719E 03	1.1906500E 03	9.1375313E-10	4.6040465E-05	6.9173079E 02
169000.	3.0396090E-08	1.0954267E 03	1.2006500E 03	8.8194002E-10	4.6266100E-05	6.9462955E 02
170000.	2.9591111E-08	1.1034635E 03	1.2106500E 03	8.5149170E-10	4.6490709E-05	6.9751629E 02
171000.	2.8813069E-08	1.1086877E 03	1.2176500E 03	8.2433703E-10	4.6647331E-05	6.9952990E 02
172000.	2.8059993E-08	1.1138985E 03	1.2246500E 03	7.9820295E-10	4.6803460E-05	7.0153775E 02
173000.	2.7330945E-08	1.1190961E 03	1.2316500E 03	7.7304559E-10	4.6959102E-05	7.0353985E 02
174000.	2.6625029E-08	1.1242804E 03	1.2386500E 03	7.4882312E-10	4.7114260E-05	7.0553628E 02
175000.	2.5941384E-08	1.1294514E 03	1.2456500E 03	7.2549574E-10	4.7268939E-05	7.0752708E 02
176000.	2.5279174E-08	1.1346091E 03	1.2526500E 03	7.0302521E-10	4.7423143E-05	7.0951229E 02
177000.	2.4637622E-08	1.1397536E 03	1.2596500E 03	6.8137571E-10	4.7576877E-05	7.1149195E 02
178000.	2.4015958E-08	1.1448846E 03	1.2666500E 03	6.6051251E-10	4.7730144E-05	7.1346613E 02
179000.	2.3413469E-08	1.1500024E 03	1.2736500E 03	6.4040319E-10	4.7882948E-05	7.1543486E 02
180000.	2.2829452E-08	1.1551070E 03	1.2806500E 03	6.2101602E-10	4.8035293E-05	7.1739818E 02
181000.	2.2263246E-08	1.1601982E 03	1.2876500E 03	6.0232157E-10	4.8187184E-05	7.1935616E 02
182000.	2.1714210E-08	1.1652761E 03	1.2946500E 03	5.8429129E-10	4.8338625E-05	7.2130880E 02
183000.	2.1181733E-08	1.1703408E 03	1.3016500E 03	5.6689814E-10	4.8489619E-05	7.2325619E 02
184000.	2.0665225E-08	1.1753922E 03	1.3086500E 03	5.5011615E-10	4.8640170E-05	7.2519835E 02
185000.	2.0164124E-08	1.1804302E 03	1.3156500E 03	5.3392071E-10	4.8790280E-05	7.2713531E 02
186000.	1.9677896E-08	1.1854550E 03	1.3226500E 03	5.1828839E-10	4.8939956E-05	7.2906713E 02
187000.	1.9206011E-08	1.1904665E 03	1.3296500E 03	5.0319647E-10	4.9089199E-05	7.3099384E 02
188000.	1.8747980E-08	1.1954647E 03	1.3366500E 03	4.8862371E-10	4.9238014E-05	7.3291548E 02
189000.	1.8303317E-08	1.2004496E 03	1.3436500E 03	4.7454937E-10	4.9386404E-05	7.3483211E 02
190000.	1.7871564E-08	1.2054212E 03	1.3506500E 03	4.6095390E-10	4.9534373E-05	7.3674375E 02
191000.	1.7451910E-08	1.2085380E 03	1.3556500E 03	4.4846974E-10	4.9639808E-05	7.3810617E 02
192000.	1.7043719E-08	1.2116445E 03	1.3606500E 03	4.3637082E-10	4.9745032E-05	7.3946609E 02
193000.	1.6646644E-08	1.2147417E 03	1.3656500E 03	4.2464403E-10	4.9850045E-05	7.4082351E 02
194000.	1.6260338E-08	1.2178287E 03	1.3706500E 03	4.1327655E-10	4.9954849E-05	7.4217845E 02
195000.	1.5884471E-08	1.2209057E 03	1.3756500E 03	4.0225603E-10	5.0059444E-05	7.4353091E 02
196000.	1.5518716E-08	1.2239729E 03	1.3806500E 03	3.9157048E-10	5.0163831E-05	7.4488092E 02
197000.	1.5162775E-08	1.2270301E 03	1.3856500E 03	3.8120879E-10	5.0268014E-05	7.4622849E 02
198000.	1.4816337E-08	1.2300773E 03	1.3906500E 03	3.7115965E-10	5.0371991E-05	7.4757363E 02
199000.	1.4479118E-08	1.2331147E 03	1.3956500E 03	3.6141266E-10	5.0475764E-05	7.4891635E 02
200000.	1.4150844E-08	1.2361421E 03	1.4006500E 03	3.5195770E-10	5.0579335E-05	7.5025666E 02
201000.	1.3831239E-08	1.2391596E 03	1.4056500E 03	3.4278486E-10	5.0682705E-05	7.5159460E 02
202000.	1.3520045E-08	1.2421672E 03	1.4106500E 03	3.3388477E-10	5.0785874E-05	7.5293015E 02
203000.	1.3217012E-08	1.2451648E 03	1.4156500E 03	3.2524638E-10	5.0888844E-05	7.5426334E 02
204000.	1.2921892E-08	1.2481526E 03	1.4206500E 03	3.1686633E-10	5.0991617E-05	7.5559417E 02
205000.	1.2634456E-08	1.2511304E 03	1.4256500E 03	3.0873182E-10	5.1094193E-05	7.5692267E 02
206000.	1.2354471E-08	1.2540982E 03	1.4306500E 03	3.0083510E-10	5.1196572E-05	7.5824883E 02
207000.	1.2081722E-08	1.2570561E 03	1.4356500E 03	2.9316897E-10	5.1298757E-05	7.5957268E 02
208000.	1.1815994E-08	1.2600042E 03	1.4406500E 03	2.8572594E-10	5.1400748E-05	7.6089423E 02
209000.	1.1557080E-08	1.2629423E 03	1.4456500E 03	2.7849841E-10	5.1502547E-05	7.6221349E 02
210000.	1.1304783E-08	1.2658705E 03	1.4506500E 03	2.7147970E-10	5.1604154E-05	7.6353047E 02
211000.	1.1058912E-08	1.2687887E 03	1.4556500E 03	2.6466296E-10	5.1705571E-05	7.6484517E 02
212000.	1.0819280E-08	1.2716970E 03	1.4606500E 03	2.5804174E-10	5.1806798E-05	7.6615764E 02
213000.	1.0585704E-08	1.2745954E 03	1.4656500E 03	2.5160961E-10	5.1907837E-05	7.6746784E 02
214000.	1.0358013E-08	1.2774839E 03	1.4706500E 03	2.4536062E-10	5.2008688E-05	7.6877581E 02
215000.	1.0136038E-08	1.2803624E 03	1.4756500E 03	2.3928894E-10	5.2109353E-05	7.7008157E 02
216000.	9.9196129E-09	1.2832310E 03	1.4806500E 03	2.3338883E-10	5.2209833E-05	7.7138512E 02
217000.	9.7085841E-09	1.2860897E 03	1.4856500E 03	2.2765497E-10	5.2310127E-05	7.7268646E 02
218000.	9.5027945E-09	1.2889384E 03	1.4906500E 03	2.2208202E-10	5.2410240E-05	7.7398562E 02
219000.	9.3020988E-09	1.2917773E 03	1.4956500E 03	2.1666498E-10	5.2510169E-05	7.7528260E 02
220000.	9.1063540E-09	1.2946062E 03	1.5006500E 03	2.1139897E-10	5.2609917E-05	7.7657742E 02
221000.	8.9154168E-09	1.2974252E 03	1.5056500E 03	2.0627917E-10	5.2709484E-05	7.7787007E 02
222000.	8.7291573E-09	1.3002342E 03	1.5106500E 03	2.0130113E-10	5.2808871E-05	7.7916059E 02
223000.	8.5474434E-09	1.3030333E 03	1.5156500E 03	1.9646042E-10	5.2908080E-05	7.8044897E 02
224000.	8.3701468E-09	1.3058225E 03	1.5206500E 03	1.9175273E-10	5.3007112E-05	7.8173523E 02
225000.	8.1971492E-09	1.3086018E 03	1.5256500E 03	1.8717407E-10	5.3105966E-05	7.8301938E 02
226000.	8.0283282E-09	1.3113712E 03	1.5306500E 03	1.8272038E-10	5.3204644E-05	7.8430142E 02
227000.	7.8635709E-09	1.3141306E 03	1.5356500E 03	1.7838787E-10	5.3303148E-05	7.8558137E 02
228000.	7.7027657E-09	1.3168801E 03	1.5406500E 03	1.7417285E-10	5.3401477E-05	7.8685923E 02
229000.	7.5458031E-09	1.3196197E 03	1.5456500E 03	1.7007170E-10	5.3499634E-05	7.8813503E 02

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
160000.	3.8473873E-09	1.0369750E-09	2.4147999E 00	2.6660000E 01	1.0170147E 01
161000.	3.7370909E-09	9.9825902E-10	2.4276052E 00	2.6634000E 01	1.0170147E 01
162000.	3.6309267E-09	9.6132199E-10	2.4403480E 00	2.6608000E 01	1.0170147E 01
163000.	3.5287047E-09	9.2606717E-10	2.4530291E 00	2.6582000E 01	1.0170147E 01
164000.	3.4302453E-09	8.9240400E-10	2.4656494E 00	2.6556000E 01	1.0170147E 01
165000.	3.3353799E-09	8.6024789E-10	2.4782096E 00	2.6530000E 01	1.0170147E 01
166000.	3.2439463E-09	8.2951866E-10	2.4907107E 00	2.6504000E 01	1.0170147E 01
167000.	3.1557932E-09	8.0014176E-10	2.5031534E 00	2.6478000E 01	1.0170147E 01
168000.	3.0707750E-09	7.7204651E-10	2.5155384E 00	2.6452000E 01	1.0170147E 01
169000.	2.9887562E-09	7.4516704E-10	2.5278666E 00	2.6426000E 01	1.0170147E 01
170000.	2.9096050E-09	7.1944070E-10	2.5401386E 00	2.6400000E 01	1.0170147E 01
171000.	2.8331025E-09	6.9649723E-10	2.5486960E 00	2.6372500E 01	1.0170147E 01
172000.	2.7590547E-09	6.7441608E-10	2.5572266E 00	2.6345000E 01	1.0170147E 01
173000.	2.6873697E-09	6.5316017E-10	2.5657305E 00	2.6317500E 01	1.0170147E 01
174000.	2.6179591E-09	6.3269417E-10	2.5742079E 00	2.6290000E 01	1.0170147E 01
175000.	2.5507383E-09	6.1298444E-10	2.5826592E 00	2.6262500E 01	1.0170147E 01
176000.	2.4856252E-09	5.9399869E-10	2.5910846E 00	2.6235000E 01	1.0170147E 01
177000.	2.4225433E-09	5.7570663E-10	2.5994842E 00	2.6207500E 01	1.0170147E 01
178000.	2.3614169E-09	5.5807893E-10	2.6078583E 00	2.6180000E 01	1.0170147E 01
179000.	2.3021760E-09	5.4108813E-10	2.6162072E 00	2.6152500E 01	1.0170147E 01
180000.	2.2447514E-09	5.2470765E-10	2.6245309E 00	2.6125000E 01	1.0170147E 01
181000.	2.1890781E-09	5.0891236E-10	2.6328299E 00	2.6097500E 01	1.0170147E 01
182000.	2.1350930E-09	4.9367825E-10	2.6411043E 00	2.6070000E 01	1.0170147E 01
183000.	2.0827361E-09	4.7898246E-10	2.6493542E 00	2.6042500E 01	1.0170147E 01
184000.	2.0319495E-09	4.6480306E-10	2.6575799E 00	2.6015000E 01	1.0170147E 01
185000.	1.9826777E-09	4.5111924E-10	2.6657816E 00	2.5987500E 01	1.0170147E 01
186000.	1.9348683E-09	4.3791121E-10	2.6739595E 00	2.5960000E 01	1.0170147E 01
187000.	1.8884693E-09	4.2515978E-10	2.6821137E 00	2.5932500E 01	1.0170147E 01
188000.	1.8434325E-09	4.1284699E-10	2.6902446E 00	2.5905000E 01	1.0170147E 01
189000.	1.7997101E-09	4.0095532E-10	2.6983523E 00	2.5877500E 01	1.0170147E 01
190000.	1.7572572E-09	3.8946827E-10	2.7064370E 00	2.5850000E 01	1.0170147E 01
191000.	1.7159939E-09	3.7892017E-10	2.7121977E 00	2.5821249E 01	1.0170147E 01
192000.	1.6758577E-09	3.6869758E-10	2.7179469E 00	2.5792499E 01	1.0170147E 01
193000.	1.6368144E-09	3.5878940E-10	2.7236845E 00	2.5763749E 01	1.0170147E 01
194000.	1.5988302E-09	3.4918481E-10	2.7294108E 00	2.5735000E 01	1.0170147E 01
195000.	1.5618723E-09	3.3987338E-10	2.7351256E 00	2.5706249E 01	1.0170147E 01
196000.	1.5259087E-09	3.3084497E-10	2.7408290E 00	2.5677499E 01	1.0170147E 01
197000.	1.4909101E-09	3.2209018E-10	2.7465213E 00	2.5648749E 01	1.0170147E 01
198000.	1.4568458E-09	3.1359948E-10	2.7522024E 00	2.5620000E 01	1.0170147E 01
199000.	1.4236882E-09	3.0536407E-10	2.7578723E 00	2.5591249E 01	1.0170147E 01
200000.	1.3914099E-09	2.9737541E-10	2.7635311E 00	2.5562499E 01	1.0170147E 01
201000.	1.3599841E-09	2.8962511E-10	2.7691790E 00	2.5533749E 01	1.0170147E 01
202000.	1.3293854E-09	2.8210527E-10	2.7748159E 00	2.5505000E 01	1.0170147E 01
203000.	1.2995890E-09	2.7480822E-10	2.7804420E 00	2.5476249E 01	1.0170147E 01
204000.	1.2705708E-09	2.6772650E-10	2.7860572E 00	2.5447499E 01	1.0170147E 01
205000.	1.2423081E-09	2.6085308E-10	2.7916617E 00	2.5418749E 01	1.0170147E 01
206000.	1.2147780E-09	2.5418100E-10	2.7972554E 00	2.5390000E 01	1.0170147E 01
207000.	1.1879593E-09	2.4770375E-10	2.8028386E 00	2.5361249E 01	1.0170147E 01
208000.	1.1618311E-09	2.4141492E-10	2.8084112E 00	2.5332499E 01	1.0170147E 01
209000.	1.1363729E-09	2.3530833E-10	2.8139732E 00	2.5303749E 01	1.0170147E 01
210000.	1.1115654E-09	2.2937809E-10	2.8195248E 00	2.5275000E 01	1.0170147E 01
211000.	1.0873895E-09	2.2361851E-10	2.8250659E 00	2.5246249E 01	1.0170147E 01
212000.	1.0638273E-09	2.1802412E-10	2.8305967E 00	2.5217499E 01	1.0170147E 01
213000.	1.0408604E-09	2.1258950E-10	2.8361172E 00	2.5188749E 01	1.0170147E 01
214000.	1.0184723E-09	2.0730962E-10	2.8416275E 00	2.5160000E 01	1.0170147E 01
215000.	9.9664617E-10	2.0217955E-10	2.8471276E 00	2.5131250E 01	1.0170147E 01
216000.	9.7536570E-10	1.9719443E-10	2.8526176E 00	2.5102499E 01	1.0170147E 01
217000.	9.5461588E-10	1.9234979E-10	2.8580974E 00	2.5073749E 01	1.0170147E 01
218000.	9.3438121E-10	1.8764111E-10	2.8635673E 00	2.5045000E 01	1.0170147E 01
219000.	9.1464741E-10	1.8306416E-10	2.8690272E 00	2.5016250E 01	1.0170147E 01
220000.	8.9540042E-10	1.7861481E-10	2.8744772E 00	2.4987499E 01	1.0170147E 01
221000.	8.7662612E-10	1.7428899E-10	2.8799173E 00	2.4958749E 01	1.0170147E 01
222000.	8.5831180E-10	1.7008296E-10	2.8853475E 00	2.4930000E 01	1.0170147E 01
223000.	8.4044441E-10	1.6599295E-10	2.8907681E 00	2.4901250E 01	1.0170147E 01
224000.	8.2301136E-10	1.6201534E-10	2.8961789E 00	2.4872499E 01	1.0170147E 01
225000.	8.0600103E-10	1.5814675E-10	2.9015801E 00	2.4843749E 01	1.0170147E 01
226000.	7.8940138E-10	1.5438374E-10	2.9069716E 00	2.4815000E 01	1.0170147E 01
227000.	7.7320129E-10	1.5072313E-10	2.9123536E 00	2.4786250E 01	1.0170147E 01
228000.	7.5738980E-10	1.4716178E-10	2.9177261E 00	2.4757499E 01	1.0170147E 01
229000.	7.4195613E-10	1.4369665E-10	2.9230891E 00	2.4728749E 01	1.0170147E 01

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	MOLECULAR TEMPERATURE	DENSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	newton-sec m^{-2}	m sec^{-1}
230000.	7.3925818E-09	1.3223493E 03	1.5506500E 03	1.6608106E-10	5.3597617E-05	7.8940877E 02
231000.	7.2428844E-09	1.3241963E 03	1.5546500E 03	1.6229931E-10	5.3675881E-05	7.9042627E 02
232000.	7.0966346E-09	1.3260353E 03	1.5586500E 03	1.5861403E-10	5.3754035E-05	7.9144247E 02
233000.	6.9537457E-09	1.3278662E 03	1.5626500E 03	1.5502254E-10	5.3832081E-05	7.9245737E 02
234000.	6.8141302E-09	1.3296890E 03	1.5666500E 03	1.5152218E-10	5.3910018E-05	7.9347096E 02
235000.	6.6777033E-09	1.3315039E 03	1.5706500E 03	1.4811037E-10	5.3987848E-05	7.9448327E 02
236000.	6.5443868E-09	1.3333106E 03	1.5746500E 03	1.4478470E-10	5.4065570E-05	7.9549429E 02
237000.	6.4140990E-09	1.3351093E 03	1.5786500E 03	1.4154273E-10	5.4143183E-05	7.9650403E 02
238000.	6.2867616E-09	1.3369000E 03	1.5826500E 03	1.3838208E-10	5.4220692E-05	7.9751249E 02
239000.	6.1623034E-09	1.3386826E 03	1.5866500E 03	1.3530059E-10	5.4298093E-05	7.9851967E 02
240000.	6.0406505E-09	1.3404572E 03	1.5906500E 03	1.3229604E-10	5.4375389E-05	7.9952559E 02
241000.	5.9217323E-09	1.3422237E 03	1.5946500E 03	1.2936630E-10	5.4452580E-05	8.0053023E 02
242000.	5.8054790E-09	1.3439822E 03	1.5986500E 03	1.2650929E-10	5.4529665E-05	8.0153363E 02
243000.	5.6918242E-09	1.3457326E 03	1.6026500E 03	1.2372303E-10	5.4606646E-05	8.0253576E 02
244000.	5.5807045E-09	1.3474750E 03	1.6066500E 03	1.2100561E-10	5.4683524E-05	8.0353664E 02
245000.	5.4720553E-09	1.3492094E 03	1.6106500E 03	1.1835512E-10	5.4760296E-05	8.0453628E 02
246000.	5.3658158E-09	1.3509356E 03	1.6146500E 03	1.1576975E-10	5.4836967E-05	8.0553468E 02
247000.	5.2619249E-09	1.3526538E 03	1.6186500E 03	1.1324771E-10	5.4913533E-05	8.0653186E 02
248000.	5.1603259E-09	1.3543640E 03	1.6226500E 03	1.1078731E-10	5.4989998E-05	8.0752779E 02
249000.	5.0609626E-09	1.3560662E 03	1.6266500E 03	1.0838687E-10	5.5066360E-05	8.0852250E 02
250000.	4.9637800E-09	1.3577603E 03	1.6306500E 03	1.0604484E-10	5.5142621E-05	8.0951596E 02
251000.	4.8687236E-09	1.3594463E 03	1.6346500E 03	1.0375955E-10	5.5218779E-05	8.1050824E 02
252000.	4.7757415E-09	1.3611243E 03	1.6386500E 03	1.0152953E-10	5.5294838E-05	8.1149930E 02
253000.	4.6847841E-09	1.3627942E 03	1.6426500E 03	9.9353300E-11	5.5370796E-05	8.1248914E 02
254000.	4.5958012E-09	1.3644561E 03	1.6466500E 03	9.7229418E-11	5.5446653E-05	8.1347779E 02
255000.	4.5087449E-09	1.3661100E 03	1.6506500E 03	9.5156492E-11	5.5522412E-05	8.1446522E 02
256000.	4.4235698E-09	1.3677558E 03	1.6546500E 03	9.3133194E-11	5.5598070E-05	8.1545147E 02
257000.	4.3402283E-09	1.3693935E 03	1.6586500E 03	9.1158165E-11	5.5673630E-05	8.1643653E 02
258000.	4.2586772E-09	1.3710232E 03	1.6626500E 03	8.9230154E-11	5.5749090E-05	8.1742039E 02
259000.	4.1788747E-09	1.3726449E 03	1.6666500E 03	8.7347945E-11	5.5824453E-05	8.1840308E 02
260000.	4.1007767E-09	1.3742585E 03	1.6706500E 03	8.5510293E-11	5.5899718E-05	8.1938457E 02
261000.	4.0243445E-09	1.3758640E 03	1.6746500E 03	8.3716075E-11	5.5974885E-05	8.2036492E 02
262000.	3.9495377E-09	1.3774615E 03	1.6786500E 03	8.1964134E-11	5.6049955E-05	8.2134407E 02
263000.	3.8763164E-09	1.3790510E 03	1.6826500E 03	8.0253351E-11	5.6124928E-05	8.2232206E 02
264000.	3.8046447E-09	1.3806324E 03	1.6866500E 03	7.8582690E-11	5.6199805E-05	8.2329890E 02
265000.	3.7344853E-09	1.3822056E 03	1.6906500E 03	7.6951092E-11	5.6274586E-05	8.2427458E 02
266000.	3.6658013E-09	1.3837711E 03	1.6946500E 03	7.5357531E-11	5.6349271E-05	8.2524910E 02
267000.	3.5985599E-09	1.3853283E 03	1.6986500E 03	7.3801059E-11	5.6423861E-05	8.2622247E 02
268000.	3.5327263E-09	1.3868776E 03	1.7026500E 03	7.2280703E-11	5.6498355E-05	8.2719469E 02
269000.	3.4682674E-09	1.3884187E 03	1.7066500E 03	7.0795534E-11	5.6572756E-05	8.2816577E 02
270000.	3.4051519E-09	1.3899518E 03	1.7106500E 03	6.9344668E-11	5.6647062E-05	8.2913573E 02
271000.	3.3433475E-09	1.3914769E 03	1.7146500E 03	6.7927213E-11	5.6721274E-05	8.3010454E 02
272000.	3.2828238E-09	1.3929939E 03	1.7186500E 03	6.6542312E-11	5.6795392E-05	8.3107224E 02
273000.	3.2235518E-09	1.3945029E 03	1.7226500E 03	6.5189155E-11	5.6869417E-05	8.3203880E 02
274000.	3.1655008E-09	1.3960038E 03	1.7266500E 03	6.3866904E-11	5.6943349E-05	8.3300422E 02
275000.	3.1086450E-09	1.3974967E 03	1.7306500E 03	6.2574823E-11	5.7017189E-05	8.3396854E 02
276000.	3.0529552E-09	1.3989815E 03	1.7346500E 03	6.1312119E-11	5.7090937E-05	8.3493176E 02
277000.	2.9984053E-09	1.4004583E 03	1.7386500E 03	6.0078065E-11	5.7164592E-05	8.3589386E 02
278000.	2.9449691E-09	1.4019270E 03	1.7426500E 03	5.8871938E-11	5.7238156E-05	8.3685485E 02
279000.	2.8926212E-09	1.4033877E 03	1.7466500E 03	5.7693040E-11	5.7311629E-05	8.3781472E 02
280000.	2.8413364E-09	1.4048403E 03	1.7506500E 03	5.6540688E-11	5.7385010E-05	8.3877352E 02
281000.	2.7910914E-09	1.4062849E 03	1.7546500E 03	5.5414231E-11	5.7458303E-05	8.3973122E 02
282000.	2.7418610E-09	1.4077214E 03	1.7586500E 03	5.4312999E-11	5.7531503E-05	8.4068781E 02
283000.	2.6936236E-09	1.4091499E 03	1.7626500E 03	5.3236388E-11	5.7604614E-05	8.4164335E 02
284000.	2.6463566E-09	1.4105704E 03	1.7666500E 03	5.2183788E-11	5.7677636E-05	8.4259777E 02
285000.	2.6000374E-09	1.4119828E 03	1.7706500E 03	5.1154591E-11	5.7750568E-05	8.4355112E 02
286000.	2.5546459E-09	1.4133871E 03	1.7746500E 03	5.0148246E-11	5.7823412E-05	8.4450340E 02
287000.	2.5101599E-09	1.4147834E 03	1.7786500E 03	4.9164162E-11	5.7896167E-05	8.4545461E 02
288000.	2.4665603E-09	1.4161716E 03	1.7826500E 03	4.8201817E-11	5.7968833E-05	8.4640476E 02
289000.	2.4238261E-09	1.4175518E 03	1.7866500E 03	4.7260654E-11	5.8041411E-05	8.4735382E 02
290000.	2.3819396E-09	1.4189240E 03	1.7906500E 03	4.6340187E-11	5.8113902E-05	8.4830183E 02
291000.	2.3408808E-09	1.4202881E 03	1.7946500E 03	4.5439891E-11	5.8186305E-05	8.4924878E 02
292000.	2.3006322E-09	1.4216441E 03	1.7986500E 03	4.4559293E-11	5.8258622E-05	8.5019467E 02
293000.	2.2611749E-09	1.4229921E 03	1.8026500E 03	4.3697893E-11	5.8330851E-05	8.5113952E 02
294000.	2.2224918E-09	1.4243321E 03	1.8066500E 03	4.2855237E-11	5.8402995E-05	8.5208331E 02
295000.	2.1845663E-09	1.4256640E 03	1.8106500E 03	4.2030879E-11	5.8475052E-05	8.5302607E 02
296000.	2.1473817E-09	1.4269878E 03	1.8146500E 03	4.1224380E-11	5.8547023E-05	8.5396777E 02
297000.	2.1109216E-09	1.4283036E 03	1.8186500E 03	4.0435306E-11	5.8618908E-05	8.5490845E 02
298000.	2.0751696E-09	1.4296114E 03	1.8226500E 03	3.9663230E-11	5.8690707E-05	8.5584810E 02
299000.	2.0401117E-09	1.4309111E 03	1.8266500E 03	3.8907771E-11	5.8762424E-05	8.5678670E 02

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
230000.	7.2689034E-10	1.4032488E-10	2.9284427E 00	2.4700000E 01	1.0170147E 01
231000.	7.1217104E-10	1.3712962E-10	2.9327188E 00	2.4670860E 01	1.0170147E 01
232000.	6.9779074E-10	1.3401585E-10	2.9369890E 00	2.4641719E 01	1.0170147E 01
233000.	6.8374090E-10	1.3098134E-10	2.9412532E 00	2.4612580E 01	1.0170147E 01
234000.	6.7001294E-10	1.2802382E-10	2.9455115E 00	2.4583440E 01	1.0170147E 01
235000.	6.5659848E-10	1.2514112E-10	2.9497639E 00	2.4554300E 01	1.0170147E 01
236000.	6.4348988E-10	1.2233121E-10	2.9540105E 00	2.4525160E 01	1.0170147E 01
237000.	6.3067907E-10	1.1959200E-10	2.9582511E 00	2.4496019E 01	1.0170147E 01
238000.	6.1815837E-10	1.1692152E-10	2.9624860E 00	2.4466880E 01	1.0170147E 01
239000.	6.0592077E-10	1.1431791E-10	2.9667150E 00	2.4437740E 01	1.0170147E 01
240000.	5.9395900E-10	1.1177931E-10	2.9709383E 00	2.4408600E 01	1.0170147E 01
241000.	5.8226613E-10	1.0930392E-10	2.9751558E 00	2.4379460E 01	1.0170147E 01
242000.	5.7083530E-10	1.0688998E-10	2.9793675E 00	2.4350320E 01	1.0170147E 01
243000.	5.5965996E-10	1.0453582E-10	2.9835736E 00	2.4321180E 01	1.0170147E 01
244000.	5.4873389E-10	1.0223982E-10	2.9877740E 00	2.4292040E 01	1.0170147E 01
245000.	5.3805075E-10	1.0000038E-10	2.9919687E 00	2.4262900E 01	1.0170147E 01
246000.	5.2760453E-10	9.7815955E-11	2.9961577E 00	2.4233760E 01	1.0170147E 01
247000.	5.1738926E-10	9.5685037E-11	3.0003411E 00	2.4204620E 01	1.0170147E 01
248000.	5.0739933E-10	9.3606200E-11	3.0045190E 00	2.4175480E 01	1.0170147E 01
249000.	4.9762924E-10	9.1578043E-11	3.0086912E 00	2.4146340E 01	1.0170147E 01
250000.	4.8807356E-10	8.9599197E-11	3.0128579E 00	2.4117200E 01	1.0170147E 01
251000.	4.7872695E-10	8.7668320E-11	3.0170190E 00	2.4088060E 01	1.0170147E 01
252000.	4.6958430E-10	8.5784129E-11	3.0211747E 00	2.4058920E 01	1.0170147E 01
253000.	4.6064073E-10	8.3945396E-11	3.0253249E 00	2.4029780E 01	1.0170147E 01
254000.	4.5189131E-10	8.2150890E-11	3.0294695E 00	2.4000640E 01	1.0170147E 01
255000.	4.4333133E-10	8.0399437E-11	3.0336088E 00	2.3971500E 01	1.0170147E 01
256000.	4.3495632E-10	7.8689916E-11	3.0377425E 00	2.3942360E 01	1.0170147E 01
257000.	4.2676160E-10	7.7021178E-11	3.0418710E 00	2.3913220E 01	1.0170147E 01
258000.	4.1874292E-10	7.5392167E-11	3.0459939E 00	2.3884080E 01	1.0170147E 01
259000.	4.1089618E-10	7.3801855E-11	3.0501116E 00	2.3854940E 01	1.0170147E 01
260000.	4.0321704E-10	7.2249190E-11	3.0542238E 00	2.3825800E 01	1.0170147E 01
261000.	3.9570171E-10	7.0733223E-11	3.0583308E 00	2.3796660E 01	1.0170147E 01
262000.	3.8834617E-10	6.9252976E-11	3.0624324E 00	2.3767520E 01	1.0170147E 01
263000.	3.8114653E-10	6.7807505E-11	3.0665288E 00	2.3738380E 01	1.0170147E 01
264000.	3.7409928E-10	6.6395932E-11	3.0706199E 00	2.3709240E 01	1.0170147E 01
265000.	3.6720071E-10	6.5017367E-11	3.0747057E 00	2.3680100E 01	1.0170147E 01
266000.	3.6044722E-10	6.3670937E-11	3.0787863E 00	2.3650960E 01	1.0170147E 01
267000.	3.5383558E-10	6.2355846E-11	3.0828618E 00	2.3621820E 01	1.0170147E 01
268000.	3.4736236E-10	6.1071270E-11	3.0869319E 00	2.3592680E 01	1.0170147E 01
269000.	3.4102430E-10	5.9816424E-11	3.0909970E 00	2.3563540E 01	1.0170147E 01
270000.	3.3481835E-10	5.8590562E-11	3.0950569E 00	2.3534400E 01	1.0170147E 01
271000.	3.2874131E-10	5.7392928E-11	3.0991116E 00	2.3505260E 01	1.0170147E 01
272000.	3.2279020E-10	5.6222801E-11	3.1031613E 00	2.3476120E 01	1.0170147E 01
273000.	3.1696215E-10	5.5079493E-11	3.1072059E 00	2.3446980E 01	1.0170147E 01
274000.	3.1125417E-10	5.3962300E-11	3.1112453E 00	2.3417840E 01	1.0170147E 01
275000.	3.0566371E-10	5.2870597E-11	3.1152798E 00	2.3388700E 01	1.0170147E 01
276000.	3.0018791E-10	5.1803716E-11	3.1193091E 00	2.3359560E 01	1.0170147E 01
277000.	2.9482418E-10	5.0761041E-11	3.1233335E 00	2.3330420E 01	1.0170147E 01
278000.	2.8956996E-10	4.9741963E-11	3.1273528E 00	2.3301280E 01	1.0170147E 01
279000.	2.8442274E-10	4.8745891E-11	3.1313672E 00	2.3272140E 01	1.0170147E 01
280000.	2.7938007E-10	4.7772247E-11	3.1353766E 00	2.3243000E 01	1.0170147E 01
281000.	2.7443963E-10	4.6820484E-11	3.1393811E 00	2.3213860E 01	1.0170147E 01
282000.	2.6959895E-10	4.5890033E-11	3.1433806E 00	2.3184720E 01	1.0170147E 01
283000.	2.6485591E-10	4.4980385E-11	3.1473752E 00	2.3155580E 01	1.0170147E 01
284000.	2.6020829E-10	4.4091025E-11	3.1513649E 00	2.3126440E 01	1.0170147E 01
285000.	2.5565386E-10	4.3221437E-11	3.1553498E 00	2.3097300E 01	1.0170147E 01
286000.	2.5119065E-10	4.2371158E-11	3.1593298E 00	2.3068160E 01	1.0170147E 01
287000.	2.4681647E-10	4.1539688E-11	3.1633049E 00	2.3039020E 01	1.0170147E 01
288000.	2.4252946E-10	4.0726585E-11	3.1672752E 00	2.3009880E 01	1.0170147E 01
289000.	2.3832753E-10	3.9931379E-11	3.1712407E 00	2.2980739E 01	1.0170147E 01
290000.	2.3420896E-10	3.9153661E-11	3.1752014E 00	2.2951600E 01	1.0170147E 01
291000.	2.3017177E-10	3.8392984E-11	3.1791574E 00	2.2922460E 01	1.0170147E 01
292000.	2.2621425E-10	3.7648951E-11	3.1831086E 00	2.2893320E 01	1.0170147E 01
293000.	2.2233453E-10	3.6921138E-11	3.1870550E 00	2.2864180E 01	1.0170147E 01
294000.	2.1853094E-10	3.6209163E-11	3.1909968E 00	2.2835039E 01	1.0170147E 01
295000.	2.1480184E-10	3.5512648E-11	3.1949338E 00	2.2805900E 01	1.0170147E 01
296000.	2.1114559E-10	3.4831222E-11	3.1988661E 00	2.2776760E 01	1.0170147E 01
297000.	2.0756057E-10	3.4164520E-11	3.2027937E 00	2.2747620E 01	1.0170147E 01
298000.	2.0404519E-10	3.3512179E-11	3.2067167E 00	2.2718480E 01	1.0170147E 01
299000.	2.0059805E-10	3.2873878E-11	3.2106351E 00	2.2689340E 01	1.0170147E 01

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	MOLECULAR TEMPERATURE	DENSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	newton-sec m^{-2}	m sec^{-1}
300000.	2.0057311E-09	1.4321902E 03	1.8306500E 03	3.8168505E-11	5.8834054E-05	8.5772430E 02
302000.	1.9388602E-09	1.4339029E 03	1.8372500E 03	3.6763428E-11	5.8952060E-05	8.5926906E 02
304000.	1.8744851E-09	1.4355909E 03	1.8438500E 03	3.5415564E-11	5.9069838E-05	8.6081107E 02
306000.	1.8125028E-09	1.4372541E 03	1.8504500E 03	3.4122362E-11	5.9187388E-05	8.6235031E 02
308000.	1.7528153E-09	1.4388925E 03	1.8570500E 03	3.2881401E-11	5.9304712E-05	8.6388681E 02
310000.	1.6953286E-09	1.4405061E 03	1.8636500E 03	3.1690368E-11	5.9421813E-05	8.6542059E 02
312000.	1.6399540E-09	1.4420949E 03	1.8702500E 03	3.0547084E-11	5.9538689E-05	8.6695164E 02
314000.	1.5866056E-09	1.4436590E 03	1.8768500E 03	2.9449450E-11	5.9655344E-05	8.6848003E 02
316000.	1.5352017E-09	1.4451982E 03	1.8834500E 03	2.8395473E-11	5.9771778E-05	8.7000570E 02
318000.	1.4856637E-09	1.4467126E 03	1.8900500E 03	2.7383248E-11	5.9887992E-05	8.7152870E 02
320000.	1.4379174E-09	1.4482023E 03	1.8966500E 03	2.6410980E-11	6.0003988E-05	8.7304906E 02
322000.	1.3918915E-09	1.4496672E 03	1.9032500E 03	2.5476943E-11	6.0119767E-05	8.7456676E 02
324000.	1.3475168E-09	1.4511072E 03	1.9098500E 03	2.4579480E-11	6.0235330E-05	8.7608185E 02
326000.	1.3047288E-09	1.4525225E 03	1.9164500E 03	2.3717042E-11	6.0350677E-05	8.7759430E 02
328000.	1.2634642E-09	1.4539130E 03	1.9230500E 03	2.2888120E-11	6.0465811E-05	8.7910416E 02
330000.	1.2236637E-09	1.4552787E 03	1.9296500E 03	2.2091301E-11	6.0580732E-05	8.8061143E 02
332000.	1.1852696E-09	1.4566196E 03	1.9362500E 03	2.1325217E-11	6.0695443E-05	8.8211613E 02
334000.	1.1482273E-09	1.4579357E 03	1.9428500E 03	2.0588579E-11	6.0809942E-05	8.8361827E 02
336000.	1.1124841E-09	1.4592270E 03	1.9494500E 03	1.9880142E-11	6.0924233E-05	8.8511784E 02
338000.	1.0779898E-09	1.4604935E 03	1.9560500E 03	1.9198728E-11	6.1038315E-05	8.8661491E 02
340000.	1.0446960E-09	1.4617353E 03	1.9626500E 03	1.8543206E-11	6.1152192E-05	8.8810942E 02
342000.	1.0125567E-09	1.4629522E 03	1.9692500E 03	1.7912503E-11	6.1265862E-05	8.8960143E 02
344000.	9.8152788E-10	1.4641444E 03	1.9758500E 03	1.7305591E-11	6.1379327E-05	8.9109095E 02
346000.	9.5156696E-10	1.4653117E 03	1.9824500E 03	1.6721486E-11	6.1492588E-05	8.9257798E 02
348000.	9.2263318E-10	1.4664543E 03	1.9890500E 03	1.6159247E-11	6.1605647E-05	8.9406253E 02
350000.	8.9468797E-10	1.4675721E 03	1.9956500E 03	1.5617984E-11	6.1718505E-05	8.9554464E 02
352000.	8.6769385E-10	1.4686650E 03	2.0022500E 03	1.5096837E-11	6.1831163E-05	8.9702429E 02
354000.	8.4161512E-10	1.4697332E 03	2.0088500E 03	1.4594989E-11	6.1943621E-05	8.9850150E 02
356000.	8.1641749E-10	1.4707766E 03	2.0154500E 03	1.4111658E-11	6.2055880E-05	8.9997628E 02
358000.	7.9206777E-10	1.4717952E 03	2.0220500E 03	1.3646089E-11	6.2167941E-05	9.0144866E 02
360000.	7.6853477E-10	1.4727891E 03	2.0286500E 03	1.3197576E-11	6.2279808E-05	9.0291862E 02
362000.	7.4578808E-10	1.4737581E 03	2.0352500E 03	1.2765429E-11	6.2391479E-05	9.0438620E 02
364000.	7.2379869E-10	1.4747023E 03	2.0418500E 03	1.2348998E-11	6.2502956E-05	9.0585142E 02
366000.	7.0253869E-10	1.4756217E 03	2.0484500E 03	1.1947654E-11	6.2614238E-05	9.0731425E 02
368000.	6.8198121E-10	1.4765164E 03	2.0550500E 03	1.1560797E-11	6.2725328E-05	9.0877473E 02
370000.	6.6210057E-10	1.4773863E 03	2.0616500E 03	1.1187854E-11	6.2836227E-05	9.1023288E 02
372000.	6.4287257E-10	1.4782313E 03	2.0682500E 03	1.0828284E-11	6.2946935E-05	9.1168869E 02
374000.	6.2427294E-10	1.4790516E 03	2.0748500E 03	1.0481551E-11	6.3057455E-05	9.1314217E 02
376000.	6.0627922E-10	1.4798471E 03	2.0814500E 03	1.0147159E-11	6.3167787E-05	9.1459335E 02
378000.	5.8886955E-10	1.4806177E 03	2.0880500E 03	9.8246245E-12	6.3277930E-05	9.1604222E 02
380000.	5.7202296E-10	1.4813637E 03	2.0946500E 03	9.5134873E-12	6.3387887E-05	9.1748883E 02
382000.	5.5571926E-10	1.4820848E 03	2.1012500E 03	9.2133057E-12	6.3497657E-05	9.1893313E 02
384000.	5.3993908E-10	1.4827811E 03	2.1078500E 03	8.9236559E-12	6.3607243E-05	9.2037518E 02
386000.	5.2466391E-10	1.4834526E 03	2.1144500E 03	8.6441346E-12	6.3716646E-05	9.2181497E 02
388000.	5.0987570E-10	1.4840993E 03	2.1210500E 03	8.3743510E-12	6.3825865E-05	9.2325252E 02
390000.	4.9555736E-10	1.4847213E 03	2.1276500E 03	8.1139344E-12	6.3934903E-05	9.2468783E 02
392000.	4.8169243E-10	1.4853184E 03	2.1342500E 03	7.8625296E-12	6.4043758E-05	9.2612091E 02
394000.	4.6826477E-10	1.4858908E 03	2.1408500E 03	7.6197901E-12	6.4152434E-05	9.2755179E 02
396000.	4.5525939E-10	1.4864383E 03	2.1474500E 03	7.3853930E-12	6.4260931E-05	9.2898046E 02
398000.	4.4266133E-10	1.4869611E 03	2.1540500E 03	7.1590199E-12	6.4369250E-05	9.3040694E 02
400000.	4.3045664E-10	1.4874591E 03	2.1606500E 03	6.9403720E-12	6.4477389E-05	9.3183123E 02
402000.	4.1861271E-10	1.4880479E 03	2.1658500E 03	6.7332042E-12	6.4562467E-05	9.3295186E 02
404000.	4.0712851E-10	1.4886223E 03	2.1710500E 03	6.5328014E-12	6.4647434E-05	9.3407116E 02
406000.	3.9599224E-10	1.4891824E 03	2.1762500E 03	6.3389257E-12	6.4732293E-05	9.3518910E 02
408000.	3.8519245E-10	1.4897281E 03	2.1814500E 03	6.1513475E-12	6.4817043E-05	9.3630573E 02
410000.	3.7471793E-10	1.4902594E 03	2.1866500E 03	5.9698436E-12	6.4901686E-05	9.3742101E 02
412000.	3.6455822E-10	1.4907764E 03	2.1918500E 03	5.7942047E-12	6.4986220E-05	9.3853498E 02
414000.	3.5470273E-10	1.4912790E 03	2.1970500E 03	5.6242206E-12	6.5070646E-05	9.3964763E 02
416000.	3.4514181E-10	1.4917673E 03	2.2022500E 03	5.4596992E-12	6.5154967E-05	9.4075894E 02
418000.	3.3586559E-10	1.4922412E 03	2.2074500E 03	5.3004458E-12	6.5239180E-05	9.4186896E 02
420000.	3.2686502E-10	1.4927007E 03	2.2126500E 03	5.1462808E-12	6.5323289E-05	9.4297767E 02
422000.	3.1813105E-10	1.4931459E 03	2.2178500E 03	4.9970266E-12	6.5407290E-05	9.4408507E 02
424000.	3.0965513E-10	1.4935767E 03	2.2230500E 03	4.8525140E-12	6.5491187E-05	9.4519119E 02
426000.	3.0142895E-10	1.4939931E 03	2.2282500E 03	4.7125807E-12	6.5574978E-05	9.4629600E 02
428000.	2.9344432E-10	1.4943952E 03	2.2334500E 03	4.5770667E-12	6.5658665E-05	9.4739953E 02
430000.	2.8569375E-10	1.4947829E 03	2.2386500E 03	4.4458243E-12	6.5742248E-05	9.4850178E 02
432000.	2.7816958E-10	1.4951562E 03	2.2438500E 03	4.3187053E-12	6.5825728E-05	9.4960274E 02
434000.	2.7086468E-10	1.4955153E 03	2.2490500E 03	4.1955704E-12	6.5909103E-05	9.5070243E 02
436000.	2.6377198E-10	1.4958599E 03	2.2542500E 03	4.0762832E-12	6.5992375E-05	9.5180085E 02
438000.	2.5688480E-10	1.4961901E 03	2.2594500E 03	3.9607135E-12	6.6075546E-05	9.5289800E 02

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
300000.	1.9721751E-10	3.2249259E-11	3.2145488E 00	2.2660000E 01	1.0170147E 01
302000.	1.9064230E-10	3.1062084E-11	3.2209964E 00	2.2605600E 01	1.0170147E 01
304000.	1.8431249E-10	2.9923249E-11	3.2274314E 00	2.2551200E 01	1.0170147E 01
306000.	1.7821795E-10	2.8830599E-11	3.2338541E 00	2.2496800E 01	1.0170147E 01
308000.	1.7234906E-10	2.7782089E-11	3.2402644E 00	2.2442400E 01	1.0170147E 01
310000.	1.6669656E-10	2.6775764E-11	3.2466625E 00	2.2388000E 01	1.0170147E 01
312000.	1.6125175E-10	2.5809783E-11	3.2530483E 00	2.2333600E 01	1.0170147E 01
314000.	1.5600616E-10	2.4882371E-11	3.2594221E 00	2.2279200E 01	1.0170147E 01
316000.	1.5095177E-10	2.3991847E-11	3.2657837E 00	2.2224800E 01	1.0170147E 01
318000.	1.4608084E-10	2.3136601E-11	3.2721334E 00	2.2170400E 01	1.0170147E 01
320000.	1.4138610E-10	2.2315113E-11	3.2784711E 00	2.2116000E 01	1.0170147E 01
322000.	1.3686051E-10	2.1525929E-11	3.2847970E 00	2.2061600E 01	1.0170147E 01
324000.	1.3249728E-10	2.0767646E-11	3.2911111E 00	2.2007200E 01	1.0170147E 01
326000.	1.2829006E-10	2.0038957E-11	3.2974133E 00	2.1952800E 01	1.0170147E 01
328000.	1.2423264E-10	1.9338586E-11	3.3037040E 00	2.1898400E 01	1.0170147E 01
330000.	1.2031917E-10	1.8665339E-11	3.3099830E 00	2.1844000E 01	1.0170147E 01
332000.	1.1654399E-10	1.8018061E-11	3.3162505E 00	2.1789600E 01	1.0170147E 01
334000.	1.1290174E-10	1.7395662E-11	3.3225065E 00	2.1735200E 01	1.0170147E 01
336000.	1.0938722E-10	1.6797091E-11	3.3287511E 00	2.1680800E 01	1.0170147E 01
338000.	1.0599549E-10	1.6221351E-11	3.3349842E 00	2.1626400E 01	1.0170147E 01
340000.	1.0272181E-10	1.5667489E-11	3.3412062E 00	2.1572000E 01	1.0170147E 01
342000.	9.9561659E-11	1.5134597E-11	3.3474168E 00	2.1517600E 01	1.0170147E 01
344000.	9.6510686E-11	1.4621806E-11	3.3536163E 00	2.1463200E 01	1.0170147E 01
346000.	9.3564718E-11	1.4128285E-11	3.3598046E 00	2.1408800E 01	1.0170147E 01
348000.	9.0719748E-11	1.3653240E-11	3.3659819E 00	2.1354400E 01	1.0170147E 01
350000.	8.7971978E-11	1.3195917E-11	3.3721481E 00	2.1300000E 01	1.0170147E 01
352000.	8.5317729E-11	1.2755590E-11	3.3783035E 00	2.1245600E 01	1.0170147E 01
354000.	8.2753484E-11	1.2331570E-11	3.3844479E 00	2.1191200E 01	1.0170147E 01
356000.	8.0275878E-11	1.1923194E-11	3.3905815E 00	2.1136800E 01	1.0170147E 01
358000.	7.7881643E-11	1.1529827E-11	3.3967043E 00	2.1082400E 01	1.0170147E 01
360000.	7.5567713E-11	1.1150870E-11	3.4028164E 00	2.1028000E 01	1.0170147E 01
362000.	7.3331100E-11	1.0785742E-11	3.4089178E 00	2.0973600E 01	1.0170147E 01
364000.	7.1168948E-11	1.0433891E-11	3.4150086E 00	2.0919200E 01	1.0170147E 01
366000.	6.9078517E-11	1.0094788E-11	3.4210888E 00	2.0864800E 01	1.0170147E 01
368000.	6.7057161E-11	9.7679259E-12	3.4271585E 00	2.0810400E 01	1.0170147E 01
370000.	6.5102358E-11	9.4528193E-12	3.4332178E 00	2.0756000E 01	1.0170147E 01
372000.	6.3211727E-11	9.1490122E-12	3.4392665E 00	2.0701600E 01	1.0170147E 01
374000.	6.1382881E-11	8.8560518E-12	3.4453051E 00	2.0647200E 01	1.0170147E 01
376000.	5.9613612E-11	8.5735176E-12	3.4513333E 00	2.0592800E 01	1.0170147E 01
378000.	5.7901772E-11	8.3010025E-12	3.4573513E 00	2.0538400E 01	1.0170147E 01
380000.	5.6245297E-11	8.0381171E-12	3.4633591E 00	2.0484000E 01	1.0170147E 01
382000.	5.4642204E-11	7.7844882E-12	3.4693566E 00	2.0429600E 01	1.0170147E 01
384000.	5.3090586E-11	7.5397579E-12	3.4753442E 00	2.0375200E 01	1.0170147E 01
386000.	5.1588625E-11	7.3035854E-12	3.4813217E 00	2.0320800E 01	1.0170147E 01
388000.	5.0134544E-11	7.0756403E-12	3.4872891E 00	2.0266400E 01	1.0170147E 01
390000.	4.8726665E-11	6.8556096E-12	3.4932467E 00	2.0212000E 01	1.0170147E 01
392000.	4.7363369E-11	6.6431931E-12	3.4991943E 00	2.0157600E 01	1.0170147E 01
394000.	4.6043067E-11	6.4380981E-12	3.5051321E 00	2.0103200E 01	1.0170147E 01
396000.	4.4764287E-11	6.2400517E-12	3.5110601E 00	2.0048800E 01	1.0170147E 01
398000.	4.3525558E-11	6.0487851E-12	3.5169784E 00	1.9994400E 01	1.0170147E 01
400000.	4.2325508E-11	5.8640456E-12	3.5228868E 00	1.9940000E 01	1.0170147E 01
402000.	4.1160929E-11	5.6890058E-12	3.5275352E 00	1.9900000E 01	1.0170147E 01
404000.	4.0031723E-11	5.5196818E-12	3.5321777E 00	1.9860000E 01	1.0170147E 01
406000.	3.8936727E-11	5.3558727E-12	3.5368142E 00	1.9820000E 01	1.0170147E 01
408000.	3.7874815E-11	5.1973845E-12	3.5414447E 00	1.9780000E 01	1.0170147E 01
410000.	3.6844887E-11	5.0440286E-12	3.5460694E 00	1.9740000E 01	1.0170147E 01
412000.	3.5845914E-11	4.8956280E-12	3.5506881E 00	1.9700000E 01	1.0170147E 01
414000.	3.4876853E-11	4.7520055E-12	3.5553010E 00	1.9660000E 01	1.0170147E 01
416000.	3.3936757E-11	4.6129984E-12	3.5599080E 00	1.9620000E 01	1.0170147E 01
418000.	3.3024653E-11	4.4784423E-12	3.5645092E 00	1.9580000E 01	1.0170147E 01
420000.	3.2139654E-11	4.3481855E-12	3.5691047E 00	1.9540000E 01	1.0170147E 01
422000.	3.1280870E-11	4.2220779E-12	3.5736943E 00	1.9500000E 01	1.0170147E 01
424000.	3.0447457E-11	4.0999767E-12	3.5782783E 00	1.9460000E 01	1.0170147E 01
426000.	2.9638602E-11	3.9817445E-12	3.5828564E 00	1.9420000E 01	1.0170147E 01
428000.	2.8853498E-11	3.8672462E-12	3.5874288E 00	1.9380000E 01	1.0170147E 01
430000.	2.8091408E-11	3.7563572E-12	3.5919957E 00	1.9340000E 01	1.0170147E 01
432000.	2.7351578E-11	3.6489520E-12	3.5965567E 00	1.9300000E 01	1.0170147E 01
434000.	2.6633309E-11	3.5449132E-12	3.6011122E 00	1.9260000E 01	1.0170147E 01
436000.	2.5935906E-11	3.4441252E-12	3.6056620E 00	1.9220000E 01	1.0170147E 01
438000.	2.5258710E-11	3.3464783E-12	3.6102062E 00	1.9180000E 01	1.0170147E 01

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	MOLECULAR TEMPERATURE	DENSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	newton-sec m^{-2}	m sec^{-1}
440000.	2.5019664E-10	1.4965061E 03	2.2646500E 03	3.8487362E-12	6.6158612E-05	9.5399390E 02
442000.	2.4370127E-10	1.4968076E 03	2.2698500E 03	3.7402308E-12	6.6241579E-05	9.5508853E 02
444000.	2.3739258E-10	1.4970948E 03	2.2750500E 03	3.6350798E-12	6.6324444E-05	9.5618191E 02
446000.	2.3126473E-10	1.4973676E 03	2.2802500E 03	3.5331714E-12	6.6407207E-05	9.5727403E 02
448000.	2.2531199E-10	1.4976261E 03	2.2854500E 03	3.4343957E-12	6.6489869E-05	9.5836493E 02
450000.	2.1952890E-10	1.4978702E 03	2.2906500E 03	3.3386486E-12	6.6572431E-05	9.5945457E 02
452000.	2.1391031E-10	1.4980998E 03	2.2958500E 03	3.2458315E-12	6.6654892E-05	9.6054298E 02
454000.	2.0845093E-10	1.4983152E 03	2.3010500E 03	3.1558441E-12	6.6737255E-05	9.6163017E 02
456000.	2.0314599E-10	1.4985162E 03	2.3062500E 03	3.0685954E-12	6.6819517E-05	9.6271610E 02
458000.	1.9799069E-10	1.4987029E 03	2.3114500E 03	2.9839931E-12	6.6901681E-05	9.6380085E 02
460000.	1.9298021E-10	1.4988752E 03	2.3166500E 03	2.9019512E-12	6.6983746E-05	9.6488435E 02
462000.	1.8811034E-10	1.4990331E 03	2.3218500E 03	2.8223851E-12	6.7065712E-05	9.6596664E 02
464000.	1.8337669E-10	1.4991767E 03	2.3270500E 03	2.7452138E-12	6.7147580E-05	9.6704772E 02
466000.	1.7877516E-10	1.4993058E 03	2.3322500E 03	2.6703602E-12	6.7229351E-05	9.6812760E 02
468000.	1.7430157E-10	1.4994207E 03	2.3374500E 03	2.5977463E-12	6.7311026E-05	9.6920626E 02
470000.	1.6995216E-10	1.4995212E 03	2.3426500E 03	2.5273014E-12	6.7392603E-05	9.7028373E 02
472000.	1.6572313E-10	1.4996073E 03	2.3478500E 03	2.4589548E-12	6.7474083E-05	9.7136002E 02
474000.	1.6161082E-10	1.4996790E 03	2.3530500E 03	2.3926382E-12	6.7555466E-05	9.7243510E 02
476000.	1.5761171E-10	1.4997363E 03	2.3582500E 03	2.3282864E-12	6.7636753E-05	9.7350900E 02
478000.	1.5372238E-10	1.4997794E 03	2.3634500E 03	2.2658358E-12	6.7717947E-05	9.7458172E 02
480000.	1.4993956E-10	1.4998080E 03	2.3686500E 03	2.2052260E-12	6.7799044E-05	9.7565325E 02
482000.	1.4626006E-10	1.4998223E 03	2.3738500E 03	2.1463978E-12	6.7880046E-05	9.7672361E 02
484000.	1.4268077E-10	1.4998223E 03	2.3790500E 03	2.0892944E-12	6.7960953E-05	9.7779280E 02
486000.	1.3919874E-10	1.4998078E 03	2.3842500E 03	2.0338610E-12	6.8041767E-05	9.7886081E 02
488000.	1.3581101E-10	1.4997790E 03	2.3894500E 03	1.9800438E-12	6.8122485E-05	9.7992767E 02
490000.	1.3251486E-10	1.4997359E 03	2.3946500E 03	1.9277925E-12	6.8203111E-05	9.8099338E 02
492000.	1.2930755E-10	1.4996784E 03	2.3998500E 03	1.8770573E-12	6.8283644E-05	9.8205791E 02
494000.	1.2618645E-10	1.4996065E 03	2.4050500E 03	1.8277902E-12	6.8364083E-05	9.8312130E 02
496000.	1.2314902E-10	1.4995202E 03	2.4102500E 03	1.7799451E-12	6.8444428E-05	9.8418353E 02
498000.	1.2019283E-10	1.4994196E 03	2.4154500E 03	1.7334778E-12	6.8524683E-05	9.8524462E 02
500000.	1.1731545E-10	1.4993047E 03	2.4206500E 03	1.6883441E-12	6.8604845E-05	9.8630458E 02
502000.	1.1451121E-10	1.4995694E 03	2.4240500E 03	1.6456754E-12	6.8657209E-05	9.8699701E 02
504000.	1.1177938E-10	1.4998289E 03	2.4274500E 03	1.6041654E-12	6.8709534E-05	9.8768895E 02
506000.	1.0911792E-10	1.5000833E 03	2.4308500E 03	1.5637801E-12	6.8761820E-05	9.8838041E 02
508000.	1.0652497E-10	1.5003325E 03	2.4342500E 03	1.5244880E-12	6.8814067E-05	9.8907138E 02
510000.	1.0399854E-10	1.5005765E 03	2.4376500E 03	1.4862561E-12	6.8866274E-05	9.8976188E 02
512000.	1.0153685E-10	1.5008154E 03	2.4410500E 03	1.4490546E-12	6.8918444E-05	9.9045190E 02
514000.	9.9138149E-11	1.5010491E 03	2.4444500E 03	1.4128544E-12	6.8970575E-05	9.9114143E 02
516000.	9.6800666E-11	1.5012776E 03	2.4478500E 03	1.3776259E-12	6.9022667E-05	9.9183048E 02
518000.	9.4522758E-11	1.5015010E 03	2.4512500E 03	1.3433418E-12	6.9074719E-05	9.9251904E 02
520000.	9.2302788E-11	1.5017193E 03	2.4546500E 03	1.3099750E-12	6.9126735E-05	9.9320714E 02
522000.	9.0139147E-11	1.5019323E 03	2.4580500E 03	1.2774988E-12	6.9178711E-05	9.9389477E 02
524000.	8.8030359E-11	1.5021402E 03	2.4614500E 03	1.2458886E-12	6.9230649E-05	9.9458191E 02
526000.	8.5974921E-11	1.5023429E 03	2.4648500E 03	1.2151197E-12	6.9282550E-05	9.9526858E 02
528000.	8.3971362E-11	1.5025405E 03	2.4682500E 03	1.1851677E-12	6.9334410E-05	9.9595479E 02
530000.	8.2018286E-11	1.5027328E 03	2.4716499E 03	1.1560097E-12	6.9386234E-05	9.9664050E 02
532000.	8.0114324E-11	1.5029201E 03	2.4750500E 03	1.1276231E-12	6.9438021E-05	9.9732577E 02
534000.	7.8258179E-11	1.5031021E 03	2.4784500E 03	1.0999864E-12	6.9489769E-05	9.9801055E 02
536000.	7.6448556E-11	1.5032790E 03	2.4818500E 03	1.0730785E-12	6.9541479E-05	9.9869486E 02
538000.	7.4684181E-11	1.5034507E 03	2.4852500E 03	1.0468785E-12	6.9593151E-05	9.9937871E 02
540000.	7.2963864E-11	1.5036173E 03	2.4886500E 03	1.0213668E-12	6.9644787E-05	1.0000621E 03
542000.	7.1286404E-11	1.5037787E 03	2.4920500E 03	9.9652387E-13	6.9696384E-05	1.0007450E 03
544000.	6.9650681E-11	1.5039350E 03	2.4954500E 03	9.7233125E-13	6.9747944E-05	1.0014274E 03
546000.	6.8055573E-11	1.5040860E 03	2.4988500E 03	9.4877069E-13	6.9799466E-05	1.0021094E 03
548000.	6.6500008E-11	1.5042319E 03	2.5022500E 03	9.2582468E-13	6.9850951E-05	1.0027909E 03
550000.	6.4982911E-11	1.5043727E 03	2.5056500E 03	9.0347577E-13	6.9902399E-05	1.0034720E 03
552000.	6.3503272E-11	1.5045083E 03	2.5090500E 03	8.8170750E-13	6.9953810E-05	1.0041526E 03
554000.	6.2060105E-11	1.5046387E 03	2.5124500E 03	8.6050388E-13	7.0005184E-05	1.0048327E 03
556000.	6.0652455E-11	1.5047639E 03	2.5158500E 03	8.3984936E-13	7.0056520E-05	1.0055124E 03
558000.	5.9279361E-11	1.5048840E 03	2.5192500E 03	8.1972843E-13	7.0107821E-05	1.0061916E 03
560000.	5.7939934E-11	1.5049989E 03	2.5226499E 03	8.0012667E-13	7.0159083E-05	1.0068703E 03
562000.	5.6633257E-11	1.5051087E 03	2.5260500E 03	7.8102934E-13	7.0210310E-05	1.0075486E 03
564000.	5.5358504E-11	1.5052133E 03	2.5294500E 03	7.6242301E-13	7.0261499E-05	1.0082265E 03
566000.	5.4114844E-11	1.5053127E 03	2.5328500E 03	7.4429430E-13	7.0312652E-05	1.0089039E 03
568000.	5.2901430E-11	1.5054069E 03	2.5362500E 03	7.2662964E-13	7.0363768E-05	1.0095808E 03
570000.	5.1717495E-11	1.5054960E 03	2.5396500E 03	7.0941664E-13	7.0414848E-05	1.0102573E 03
572000.	5.0562249E-11	1.5055800E 03	2.5430500E 03	6.9264266E-13	7.0465892E-05	1.0109333E 03
574000.	4.9434978E-11	1.5056587E 03	2.5464500E 03	6.7629619E-13	7.0516899E-05	1.0116089E 03
576000.	4.8334925E-11	1.5057323E 03	2.5498500E 03	6.6036518E-13	7.0567870E-05	1.0122840E 03
578000.	4.7261423E-11	1.5058008E 03	2.5532500E 03	6.4483888E-13	7.0618805E-05	1.0129586E 03

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
440000.	2.4601083E-11	3.2518666E-12	3.6147448E 00	1.9140000E 01	1.0170147E 01
442000.	2.3962413E-11	3.1601885E-12	3.6192779E 00	1.9100000E 01	1.0170147E 01
444000.	2.3342098E-11	3.0713445E-12	3.6238054E 00	1.9060000E 01	1.0170147E 01
446000.	2.2739566E-11	2.9852403E-12	3.6283273E 00	1.9020000E 01	1.0170147E 01
448000.	2.2154250E-11	2.9017829E-12	3.6328438E 00	1.8980000E 01	1.0170147E 01
450000.	2.1585616E-11	2.8208845E-12	3.6373548E 00	1.8940000E 01	1.0170147E 01
452000.	2.1033157E-11	2.7424616E-12	3.6418602E 00	1.8900000E 01	1.0170147E 01
454000.	2.0496353E-11	2.6664296E-12	3.6463604E 00	1.8860000E 01	1.0170147E 01
456000.	1.9974735E-11	2.5927117E-12	3.6508549E 00	1.8820000E 01	1.0170147E 01
458000.	1.9467820E-11	2.5212297E-12	3.6553442E 00	1.8780000E 01	1.0170147E 01
460000.	1.8975164E-11	2.4519109E-12	3.6598280E 00	1.8740000E 01	1.0170147E 01
462000.	1.8496324E-11	2.3846841E-12	3.6643064E 00	1.8700000E 01	1.0170147E 01
464000.	1.8030879E-11	2.3194807E-12	3.6687796E 00	1.8660000E 01	1.0170147E 01
466000.	1.7578424E-11	2.2562355E-12	3.6732473E 00	1.8620000E 01	1.0170147E 01
468000.	1.7138550E-11	2.1948827E-12	3.6777098E 00	1.8580000E 01	1.0170147E 01
470000.	1.6710885E-11	2.1353625E-12	3.6821670E 00	1.8540000E 01	1.0170147E 01
472000.	1.6295057E-11	2.0776153E-12	3.6866188E 00	1.8500000E 01	1.0170147E 01
474000.	1.5890706E-11	2.0215832E-12	3.6910654E 00	1.8460000E 01	1.0170147E 01
476000.	1.5497486E-11	1.9672112E-12	3.6955068E 00	1.8420000E 01	1.0170147E 01
478000.	1.5115059E-11	1.9144455E-12	3.6999429E 00	1.8380000E 01	1.0170147E 01
480000.	1.4743106E-11	1.8632352E-12	3.7043739E 00	1.8340000E 01	1.0170147E 01
482000.	1.4381312E-11	1.8135303E-12	3.7087997E 00	1.8300000E 01	1.0170147E 01
484000.	1.4029371E-11	1.7652825E-12	3.7132202E 00	1.8260000E 01	1.0170147E 01
486000.	1.3686994E-11	1.7184459E-12	3.7176357E 00	1.8220000E 01	1.0170147E 01
488000.	1.3353888E-11	1.6729747E-12	3.7220460E 00	1.8180000E 01	1.0170147E 01
490000.	1.3029787E-11	1.6288266E-12	3.7264512E 00	1.8140000E 01	1.0170147E 01
492000.	1.2714423E-11	1.5859596E-12	3.7308513E 00	1.8100000E 01	1.0170147E 01
494000.	1.2407534E-11	1.5443330E-12	3.7352462E 00	1.8060000E 01	1.0170147E 01
496000.	1.2108872E-11	1.5039077E-12	3.7396361E 00	1.8020000E 01	1.0170147E 01
498000.	1.1818200E-11	1.4646467E-12	3.7440211E 00	1.7980000E 01	1.0170147E 01
500000.	1.1535275E-11	1.4265124E-12	3.7484009E 00	1.7940000E 01	1.0170147E 01
502000.	1.1259543E-11	1.3904608E-12	3.7512619E 00	1.7918000E 01	1.0170147E 01
504000.	1.0990930E-11	1.3553883E-12	3.7541209E 00	1.7896000E 01	1.0170147E 01
506000.	1.0729237E-11	1.3212660E-12	3.7569776E 00	1.7874000E 01	1.0170147E 01
508000.	1.0474280E-11	1.2880674E-12	3.7598323E 00	1.7852000E 01	1.0170147E 01
510000.	1.0225864E-11	1.2557646E-12	3.7626848E 00	1.7830000E 01	1.0170147E 01
512000.	9.9838128E-12	1.2243324E-12	3.7655352E 00	1.7808000E 01	1.0170147E 01
514000.	9.7479562E-12	1.1937462E-12	3.7683835E 00	1.7786000E 01	1.0170147E 01
516000.	9.5181185E-12	1.1639810E-12	3.7712297E 00	1.7764000E 01	1.0170147E 01
518000.	9.2941386E-12	1.1350137E-12	3.7740737E 00	1.7742000E 01	1.0170147E 01
520000.	9.0758557E-12	1.1068215E-12	3.7769157E 00	1.7720000E 01	1.0170147E 01
522000.	8.8631114E-12	1.0793818E-12	3.7797555E 00	1.7698000E 01	1.0170147E 01
524000.	8.6557605E-12	1.0526737E-12	3.7825933E 00	1.7676000E 01	1.0170147E 01
526000.	8.4536555E-12	1.0266765E-12	3.7854290E 00	1.7654000E 01	1.0170147E 01
528000.	8.2566516E-12	1.0013696E-12	3.7882626E 00	1.7632000E 01	1.0170147E 01
530000.	8.0646114E-12	9.7673345E-13	3.7910941E 00	1.7610000E 01	1.0170147E 01
532000.	7.8774006E-12	9.5274907E-13	3.7939236E 00	1.7588000E 01	1.0170147E 01
534000.	7.6948915E-12	9.2939839E-13	3.7967510E 00	1.7566000E 01	1.0170147E 01
536000.	7.5169567E-12	9.0666342E-13	3.7995763E 00	1.7544000E 01	1.0170147E 01
538000.	7.3434709E-12	8.8452656E-13	3.8023995E 00	1.7522000E 01	1.0170147E 01
540000.	7.1743174E-12	8.6297128E-13	3.8052208E 00	1.7500000E 01	1.0170147E 01
542000.	7.0093778E-12	8.4198101E-13	3.8080399E 00	1.7478000E 01	1.0170147E 01
544000.	6.8485421E-12	8.2154022E-13	3.8108571E 00	1.7456000E 01	1.0170147E 01
546000.	6.6916999E-12	8.0163348E-13	3.8136721E 00	1.7434000E 01	1.0170147E 01
548000.	6.5387459E-12	7.8224598E-13	3.8164851E 00	1.7412000E 01	1.0170147E 01
550000.	6.3895743E-12	7.6336299E-13	3.8192961E 00	1.7390000E 01	1.0170147E 01
552000.	6.2440858E-12	7.4497059E-13	3.8221051E 00	1.7368000E 01	1.0170147E 01
554000.	6.1021836E-12	7.2705526E-13	3.8249120E 00	1.7346000E 01	1.0170147E 01
556000.	5.9637735E-12	7.0960388E-13	3.8277169E 00	1.7324000E 01	1.0170147E 01
558000.	5.8287613E-12	6.9260335E-13	3.8305198E 00	1.7302000E 01	1.0170147E 01
560000.	5.6970595E-12	6.7604147E-13	3.8333207E 00	1.7280000E 01	1.0170147E 01
562000.	5.5685779E-12	6.5990578E-13	3.8361196E 00	1.7258000E 01	1.0170147E 01
564000.	5.4432353E-12	6.4418496E-13	3.8389165E 00	1.7236000E 01	1.0170147E 01
566000.	5.3209499E-12	6.2886768E-13	3.8417113E 00	1.7214000E 01	1.0170147E 01
568000.	5.2016386E-12	6.1394249E-13	3.8445041E 00	1.7192000E 01	1.0170147E 01
570000.	5.0852258E-12	5.9939892E-13	3.8472950E 00	1.7170000E 01	1.0170147E 01
572000.	4.9716340E-12	5.8522629E-13	3.8500840E 00	1.7148000E 01	1.0170147E 01
574000.	4.8607928E-12	5.7141486E-13	3.8528709E 00	1.7126000E 01	1.0170147E 01
576000.	4.7526278E-12	5.5795445E-13	3.8556558E 00	1.7104000E 01	1.0170147E 01
578000.	4.6470737E-12	5.4483600E-13	3.8584388E 00	1.7082000E 01	1.0170147E 01

TABLE 14.10 (Cont'd.)

GEOMETRIC ALTITUDE	PRESSURE	KINETIC TEMPERATURE	MOLECULAR TEMPERATURE	DENSITY	COEFFICIENT OF VISCOSITY	SPEED OF SOUND
meters	newtons cm^{-2}	degrees K	degrees K	kg m^{-3}	newton-sec m^{-2}	m sec^{-1}
580000.	4.6213737E-11	1.5058640E 03	2.5566500E 03	6.2970561E-13	7.0669703E-05	1.0136329E 03
582000.	4.5191225E-11	1.5059221E 03	2.5600500E 03	6.1495511E-13	7.0720567E-05	1.0143067E 03
584000.	4.4193244E-11	1.5059751E 03	2.5634500E 03	6.0057713E-13	7.0771394E-05	1.0149800E 03
586000.	4.3219147E-11	1.5060228E 03	2.5668500E 03	5.8656136E-13	7.0822185E-05	1.0156529E 03
588000.	4.2268324E-11	1.5060654E 03	2.5702500E 03	5.7289814E-13	7.0872940E-05	1.0163253E 03
590000.	4.1340184E-11	1.5061029E 03	2.5736500E 03	5.5957806E-13	7.0923660E-05	1.0169973E 03
592000.	4.0434149E-11	1.5061352E 03	2.5770500E 03	5.4659193E-13	7.0974344E-05	1.0176688E 03
594000.	3.9549641E-11	1.5061623E 03	2.5804500E 03	5.3393065E-13	7.1024992E-05	1.0183399E 03
596000.	3.8686114E-11	1.5061842E 03	2.5838500E 03	5.2158557E-13	7.1075606E-05	1.0190106E 03
598000.	3.7843038E-11	1.5062010E 03	2.5872500E 03	5.0954831E-13	7.1126183E-05	1.0196808E 03
600000.	3.7019889E-11	1.5062126E 03	2.5906500E 03	4.9781058E-13	7.1176726E-05	1.0203506E 03
602000.	3.6215577E-11	1.5062921E 03	2.5928500E 03	4.8658169E-13	7.1209410E-05	1.0207837E 03
604000.	3.5429846E-11	1.5063697E 03	2.5950500E 03	4.7562129E-13	7.1242081E-05	1.0212167E 03
606000.	3.4662245E-11	1.5064451E 03	2.5972500E 03	4.6492264E-13	7.1274736E-05	1.0216495E 03
608000.	3.3912334E-11	1.5065186E 03	2.5994500E 03	4.5447915E-13	7.1307377E-05	1.0220821E 03
610000.	3.3179683E-11	1.5065899E 03	2.6016500E 03	4.4428445E-13	7.1340003E-05	1.0225145E 03
612000.	3.2463859E-11	1.5066593E 03	2.6038500E 03	4.3433210E-13	7.1372615E-05	1.0229468E 03
614000.	3.1764455E-11	1.5067267E 03	2.6060500E 03	4.2461606E-13	7.1405212E-05	1.0233788E 03
616000.	3.1081098E-11	1.5067919E 03	2.6082500E 03	4.1513073E-13	7.1437795E-05	1.0238107E 03
618000.	3.0413369E-11	1.5068552E 03	2.6104500E 03	4.0586995E-13	7.1470361E-05	1.0242424E 03
620000.	2.9760908E-11	1.5069164E 03	2.6126499E 03	3.9682836E-13	7.1502915E-05	1.0246739E 03
622000.	2.9123341E-11	1.5069756E 03	2.6148500E 03	3.8800040E-13	7.1535454E-05	1.0251052E 03
624000.	2.8500294E-11	1.5070327E 03	2.6170500E 03	3.7938056E-13	7.1567978E-05	1.0255363E 03
626000.	2.7891442E-11	1.5070878E 03	2.6192500E 03	3.7096400E-13	7.1600487E-05	1.0259673E 03
628000.	2.7296429E-11	1.5071409E 03	2.6214500E 03	3.6274548E-13	7.1632982E-05	1.0263981E 03
630000.	2.6714925E-11	1.5071919E 03	2.6236500E 03	3.5472012E-13	7.1665463E-05	1.0268287E 03
632000.	2.6146607E-11	1.5072410E 03	2.6258500E 03	3.4688313E-13	7.1697928E-05	1.0272591E 03
634000.	2.5591154E-11	1.5072879E 03	2.6280500E 03	3.3922980E-13	7.1730380E-05	1.0276894E 03
636000.	2.5048265E-11	1.5073328E 03	2.6302500E 03	3.3175568E-13	7.1762818E-05	1.0281194E 03
638000.	2.4517629E-11	1.5073758E 03	2.6324500E 03	3.2445621E-13	7.1795239E-05	1.0285493E 03
640000.	2.3998967E-11	1.5074166E 03	2.6346500E 03	3.1732726E-13	7.1827648E-05	1.0289790E 03
642000.	2.3491983E-11	1.5074555E 03	2.6368500E 03	3.1036448E-13	7.1860043E-05	1.0294085E 03
644000.	2.2996400E-11	1.5074923E 03	2.6390500E 03	3.0356381E-13	7.1892422E-05	1.0298379E 03
646000.	2.2511953E-11	1.5075270E 03	2.6412500E 03	2.9692135E-13	7.1924787E-05	1.0302670E 03
648000.	2.2038369E-11	1.5075597E 03	2.6434500E 03	2.9043309E-13	7.1957139E-05	1.0306960E 03
650000.	2.1575395E-11	1.5075904E 03	2.6456500E 03	2.8409535E-13	7.1989475E-05	1.0311248E 03
652000.	2.1122777E-11	1.5076191E 03	2.6478500E 03	2.7790439E-13	7.2021797E-05	1.0315534E 03
654000.	2.0680276E-11	1.5076457E 03	2.6500500E 03	2.7185668E-13	7.2054106E-05	1.0319819E 03
656000.	2.0247647E-11	1.5076703E 03	2.6522500E 03	2.6594870E-13	7.2086399E-05	1.0324102E 03
658000.	1.9824656E-11	1.5076928E 03	2.6544500E 03	2.6017698E-13	7.2118679E-05	1.0328383E 03
660000.	1.9411084E-11	1.5077133E 03	2.6566499E 03	2.5453834E-13	7.2150944E-05	1.0332662E 03
662000.	1.9006698E-11	1.5077318E 03	2.6588500E 03	2.4902938E-13	7.2183195E-05	1.0336939E 03
664000.	1.8611281E-11	1.5077482E 03	2.6610500E 03	2.4364696E-13	7.2215433E-05	1.0341215E 03
666000.	1.8224638E-11	1.5077626E 03	2.6632500E 03	2.3838819E-13	7.2247656E-05	1.0345489E 03
668000.	1.7846547E-11	1.5077750E 03	2.6654500E 03	2.3324987E-13	7.2279864E-05	1.0349761E 03
670000.	1.7476821E-11	1.5077853E 03	2.6676500E 03	2.2822927E-13	7.2312059E-05	1.0354031E 03
672000.	1.7115252E-11	1.5077936E 03	2.6698500E 03	2.2332338E-13	7.2344239E-05	1.0358300E 03
674000.	1.6761651E-11	1.5077999E 03	2.6720500E 03	2.1852944E-13	7.2376407E-05	1.0362567E 03
676000.	1.6415844E-11	1.5078041E 03	2.6742500E 03	2.1384493E-13	7.2408558E-05	1.0366832E 03
678000.	1.6077632E-11	1.5078063E 03	2.6764500E 03	2.0926697E-13	7.2440697E-05	1.0371095E 03
680000.	1.5746857E-11	1.5078064E 03	2.6786500E 03	2.0479326E-13	7.2472821E-05	1.0375357E 03
682000.	1.5423325E-11	1.5078045E 03	2.6808500E 03	2.0042101E-13	7.2504931E-05	1.0379616E 03
684000.	1.5106879E-11	1.5078006E 03	2.6830500E 03	1.9614794E-13	7.2537029E-05	1.0383874E 03
686000.	1.4797364E-11	1.5077946E 03	2.6852500E 03	1.9197178E-13	7.2569111E-05	1.0388131E 03
688000.	1.4494605E-11	1.5077867E 03	2.6874500E 03	1.8789003E-13	7.2601179E-05	1.0392385E 03
690000.	1.4198453E-11	1.5077766E 03	2.6896500E 03	1.8390054E-13	7.2633234E-05	1.0396638E 03
692000.	1.3908750E-11	1.5077646E 03	2.6918500E 03	1.8000104E-13	7.2665275E-05	1.0400889E 03
694000.	1.3625348E-11	1.5077505E 03	2.6940500E 03	1.7618937E-13	7.2697302E-05	1.0405139E 03
696000.	1.3348109E-11	1.5077343E 03	2.6962500E 03	1.7246356E-13	7.2729314E-05	1.0409386E 03
698000.	1.3076882E-11	1.5077162E 03	2.6984500E 03	1.6882143E-13	7.2761313E-05	1.0413632E 03
700000.	1.2811533E-11	1.5076960E 03	2.7006500E 03	1.6526106E-13	7.2793300E-05	1.0417877E 03

TABLE 14.10 (Concluded)

GEOMETRIC ALTITUDE	PRESSURE RATIO	DENSITY RATIO	VISCOSITY RATIO	MOLECULAR WEIGHT	PRESSURE DIFFERENCE
meters	unitless	unitless	unitless	unitless	newtons cm^{-2}
580000.	4.5440578E-12	5.3204963E-13	3.8612197E 00	1.7060000E 01	1.0170147E 01
582000.	4.4435173E-12	5.1958667E-13	3.8639988E 00	1.7038000E 01	1.0170147E 01
584000.	4.3453888E-12	5.0743845E-13	3.8667759E 00	1.7016000E 01	1.0170147E 01
586000.	4.2496088E-12	4.9559628E-13	3.8695509E 00	1.6994000E 01	1.0170147E 01
588000.	4.1561172E-12	4.8405197E-13	3.8723241E 00	1.6972000E 01	1.0170147E 01
590000.	4.0648560E-12	4.7279759E-13	3.8750953E 00	1.6950000E 01	1.0170147E 01
592000.	3.9757683E-12	4.6182538E-13	3.8778645E 00	1.6928000E 01	1.0170147E 01
594000.	3.8887973E-12	4.5112764E-13	3.8806318E 00	1.6906000E 01	1.0170147E 01
596000.	3.8038893E-12	4.4069706E-13	3.8833972E 00	1.6884000E 01	1.0170147E 01
598000.	3.7209922E-12	4.3052656E-13	3.8861607E 00	1.6862000E 01	1.0170147E 01
600000.	3.6400543E-12	4.2060913E-13	3.8889222E 00	1.6840000E 01	1.0170147E 01
602000.	3.5609688E-12	4.1112165E-13	3.8907080E 00	1.6826600E 01	1.0170147E 01
604000.	3.4837103E-12	4.0186101E-13	3.8924930E 00	1.6813200E 01	1.0170147E 01
606000.	3.4082344E-12	3.9282153E-13	3.8942772E 00	1.6799800E 01	1.0170147E 01
608000.	3.3344978E-12	3.8399763E-13	3.8960607E 00	1.6786400E 01	1.0170147E 01
610000.	3.2624585E-12	3.7538395E-13	3.8978432E 00	1.6773000E 01	1.0170147E 01
612000.	3.1920736E-12	3.6697503E-13	3.8996251E 00	1.6759600E 01	1.0170147E 01
614000.	3.1233034E-12	3.5876577E-13	3.9014061E 00	1.6746200E 01	1.0170147E 01
616000.	3.0561109E-12	3.5075145E-13	3.9031864E 00	1.6732800E 01	1.0170147E 01
618000.	2.9904551E-12	3.4292684E-13	3.9049657E 00	1.6719400E 01	1.0170147E 01
620000.	2.9263006E-12	3.3528744E-13	3.9067444E 00	1.6706000E 01	1.0170147E 01
622000.	2.8636105E-12	3.2782854E-13	3.9085222E 00	1.6692600E 01	1.0170147E 01
624000.	2.8023482E-12	3.2054548E-13	3.9102992E 00	1.6679199E 01	1.0170147E 01
626000.	2.7424816E-12	3.1343417E-13	3.9120755E 00	1.6665800E 01	1.0170147E 01
628000.	2.6839758E-12	3.0649020E-13	3.9138509E 00	1.6652400E 01	1.0170147E 01
630000.	2.6267982E-12	2.9970942E-13	3.9156256E 00	1.6639000E 01	1.0170147E 01
632000.	2.5709172E-12	2.9308781E-13	3.9173994E 00	1.6625600E 01	1.0170147E 01
634000.	2.5163012E-12	2.8662138E-13	3.9191725E 00	1.6612200E 01	1.0170147E 01
636000.	2.4629205E-12	2.8030636E-13	3.9209448E 00	1.6598800E 01	1.0170147E 01
638000.	2.4107448E-12	2.7413891E-13	3.9227163E 00	1.6585400E 01	1.0170147E 01
640000.	2.3597463E-12	2.6811552E-13	3.9244870E 00	1.6572000E 01	1.0170147E 01
642000.	2.3098961E-12	2.6223255E-13	3.9262570E 00	1.6558600E 01	1.0170147E 01
644000.	2.2611669E-12	2.5648654E-13	3.9280261E 00	1.6545200E 01	1.0170147E 01
646000.	2.2135327E-12	2.5087421E-13	3.9297944E 00	1.6531800E 01	1.0170147E 01
648000.	2.1669666E-12	2.4539216E-13	3.9315620E 00	1.6518400E 01	1.0170147E 01
650000.	2.1214438E-12	2.4003729E-13	3.9333288E 00	1.6505000E 01	1.0170147E 01
652000.	2.0769392E-12	2.3480643E-13	3.9350948E 00	1.6491600E 01	1.0170147E 01
654000.	2.0334294E-12	2.2969662E-13	3.9368601E 00	1.6478200E 01	1.0170147E 01
656000.	1.9908903E-12	2.2470486E-13	3.9386245E 00	1.6464800E 01	1.0170147E 01
658000.	1.9492988E-12	2.1982822E-13	3.9403882E 00	1.6451400E 01	1.0170147E 01
660000.	1.9086335E-12	2.1506403E-13	3.9421511E 00	1.6438000E 01	1.0170147E 01
662000.	1.8688714E-12	2.1040941E-13	3.9439132E 00	1.6424600E 01	1.0170147E 01
664000.	1.8299913E-12	2.0586171E-13	3.9456746E 00	1.6411200E 01	1.0170147E 01
666000.	1.7919739E-12	2.0141848E-13	3.9474352E 00	1.6397800E 01	1.0170147E 01
668000.	1.7547973E-12	1.9707703E-13	3.9491949E 00	1.6384400E 01	1.0170147E 01
670000.	1.7184432E-12	1.9283503E-13	3.9509540E 00	1.6371000E 01	1.0170147E 01
672000.	1.6828913E-12	1.8868995E-13	3.9527123E 00	1.6357600E 01	1.0170147E 01
674000.	1.6481227E-12	1.8463947E-13	3.9544698E 00	1.6344200E 01	1.0170147E 01
676000.	1.6141206E-12	1.8068144E-13	3.9562265E 00	1.6330800E 01	1.0170147E 01
678000.	1.5808652E-12	1.7681344E-13	3.9579825E 00	1.6317400E 01	1.0170147E 01
680000.	1.5483411E-12	1.7303352E-13	3.9597377E 00	1.6304000E 01	1.0170147E 01
682000.	1.5165292E-12	1.6933933E-13	3.9614921E 00	1.6290600E 01	1.0170147E 01
684000.	1.4854140E-12	1.6572893E-13	3.9632458E 00	1.6277200E 01	1.0170147E 01
686000.	1.4549803E-12	1.6220042E-13	3.9649987E 00	1.6263800E 01	1.0170147E 01
688000.	1.4252109E-12	1.5875168E-13	3.9667508E 00	1.6250400E 01	1.0170147E 01
690000.	1.3960912E-12	1.5538089E-13	3.9685022E 00	1.6237000E 01	1.0170147E 01
692000.	1.3676056E-12	1.5208613E-13	3.9702529E 00	1.6223600E 01	1.0170147E 01
694000.	1.3397395E-12	1.4886558E-13	3.9720027E 00	1.6210200E 01	1.0170147E 01
696000.	1.3124794E-12	1.4571757E-13	3.9737518E 00	1.6196800E 01	1.0170147E 01
698000.	1.2858105E-12	1.4264028E-13	3.9755002E 00	1.6183400E 01	1.0170147E 01
700000.	1.2597195E-12	1.3963205E-13	3.9772478E 00	1.6170000E 01	1.0170147E 01

TABLE 14.12. EXTREME HORIZONTAL DENSITY GRADIENT (EXPRESSED AS PERCENTAGE CHANGE OF U.S. 62 PER 60 n.mi., BUT NOT TO EXCEED TOTAL DISTANCE OF 600 n.mi.)

Altitude (km)	High Latitude (above 37.5° N & S)		Low Latitude (37.5° N - 37.5° S)	
	January	July	January	July
90	1.0	0.2	0.3	0.1
80	3.6	0.6	2.0	0.5
70	4.0	0.7	2.2	0.6
60	3.7	0.6	2.0	0.5
50	3.3	0.5	1.5	0.4
40	2.8	0.4	1.1	0.3
30	1.8	0.3	0.5	0.2

TABLE 14.13 EXTREME VERTICAL DENSITY GRADIENT (EXPRESSED AS PERCENTAGE CHANGE OF U.S. 62 PER 2-km AND 10-km INTERVALS)[c]

Altitude (km)	Δ Density							
	High Latitude (above 37.5 deg N & S)				Low Latitude (37.5 deg N - 37.5 deg S)			
	Jan		July		Jan		July	
	2 km	10 km	2 km	10 km	2 km	10 km	2 km	10 km
90	25	50	18	30	25	50	18	30
80	13	20	6	20	10	20	6	20
70	6	15	5	15	5	15	5	15
60	5	15	4	12	4	12	4	12
50	5	15	4	10	4	12	4	10
40	4	12	4	10	4	12	4	10
30	40	12	4	10	4	12	4	10

c. These extreme gradients cannot exist for altitude intervals greater than those shown in the column headings. For example, in simulations it is not realistic to increase the density at the extreme 2-km rate from 90 to 88 km, and then to add another 2-km extreme rate from 88 to 86 km.

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SECTION XV. DISTRIBUTION OF SURFACE EXTREMES IN THE UNITED STATES

By

Glenn E. Daniels

15.1 Introduction.

Component parts manufactured, transported, or tested in geographical areas not discussed in other sections of this document can use this section for environments needed in design and planning. These environments may be applicable to transportation, fabrication, or testing.

15.2 Environments Included.

(a) Air temperature, extreme maximum and minimum,

(b) Snow fall - snow loads, 24-hour maximum and storm maximum,

(c) Hail, maximum size,

(d) Atmosphere pressure, extreme maximum and minimum.

15.3 Source of Data.

The extremes presented have been prepared using data from Weather Bureau stations and published articles. These extremes represent the highest or lowest extreme value measured at each station. The length of record varies from station to station, but most values represent more than 15 years of record. Where the local surroundings have a geographical area with a special influence on an extreme value (such as the minimum temperature on a high mountain peak or other local condition), it will not in general be shown on the maps presented unless a Weather Bureau station is located there. If there is a contractor at such a locality and an item of equipment is especially sensitive to an environment, a study is needed of the local environment where fabrication is to be made.

15.4 Extreme Design Environments.*

15.4.1 Air Temperature.

The distribution of extreme maximum air temperature in the United States is shown in Figure 15.1 while Figure 15.2 shows the extreme minimum temperature distribution.

15.4.2 Snow Fall - Snow Load.

The maps in Figures 15.3 and 15.4 show the maximum depth of snow and the corresponding snow loads. Figure 15.3 shows the maximum depth for a 24-hour period; Figure 15.4 shows the maximum depth and the corresponding snow loads for a storm period. The storm total map shows the same snow depth as in the 24-hour map in the southern low elevation areas of the United States since snow storms seldom exceed 24 hours in these areas.

The terrain combined with the general movement of weather patterns has a great effect on the amount of fall, accumulation, and melting of the snow. Also the length of a single storm varies for various areas. In some areas in mountain regions much greater amounts of snowfall have been recorded than shown on the maps. Also the snow in these areas may remain for the entire winter. For example, in a small valley near Soda Springs, California, a seasonal snow accumulation of 7.9 meters (26 feet) with a density about 0.35 was recorded. This gives a snow load of 2772 kg m^{-2} (567.7 lb ft^{-2}). Such a snow pack can do considerable damage to improperly protected equipment buried deep in the snow. This snow pack at Soda Springs is the greatest on record in the United States and was nearly double previous records in the same area. A study of the maximum snow loads in the Wasatch Mountains of Utah (Ref. 15.1) showed that for a 100 year return period at 2740 m (9000 ft), a snow load of 1220 kg m^{-2} (250 lbs ft^{-2}) could be expected.

15.4.3 Hail.

The distribution of maximum sized hail stones in the United States is shown in Figure 15.5. The sizes are for single hailstones and not conglomerates of several hail stones frozen together.

15.4.4 Atmospheric Pressure.

Atmospheric pressure extremes normally given in the literature are given as the pressure which would have occurred if the station was at sea level.

* All values of extreme maxima and minima in this section are for design purposes and may or may not exactly reflect extrapolations (theoretical or otherwise) of actual measured values over the available period of record.

The surface weather map published by the United States Weather Bureau uses sea level pressures for the pressure values to assist in map analysis and forecasting. These sea level pressure values are obtained from the station pressures by use of the hydrostatic equation:

$$dP = -\rho g dZ$$

where

dP = pressure difference

ρ = density

g = gravity

dZ = altitude difference.

These sea level data are valid only for design purposes at locations with elevation near sea level. As an example, when the highest officially reported sea level pressure observed in the United States of 106330 newtons m^{-2} (1063.3 mb) occurred at Helena, Montana (Ref. 15.2), the actual station pressure was about 92100 newtons m^{-2} (921 mb) because the station is 1187 m (3893 ft) above mean sea level.

Figures 15.6 and 15.7 show the general distribution of extreme maximum and minimum station pressures in the United States.

Because of the direct relationship of pressure and station elevation, Figures 15.8 through 15.11 should be used with the station elevation to obtain the extreme maximum and minimum pressure values for any location in the United States. Similar maps and graphs in U. S. Customary Units are given in Reference 15.3. Table 15.1 gives a list of the station elevations for a number of locations in the United States. These are elevations of the barometer at the local Weather Bureau office.

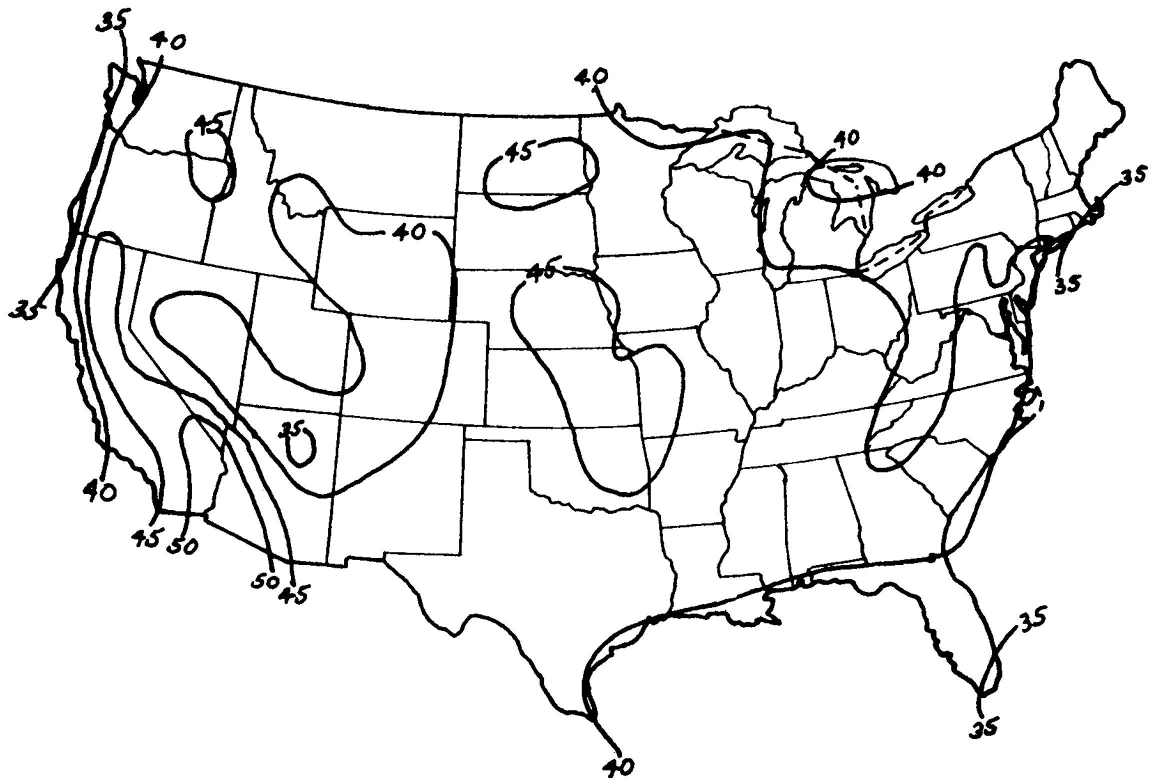

FIGURE 15.1 EXTREME MAXIMUM TEMPERATURE (degrees Celsius)

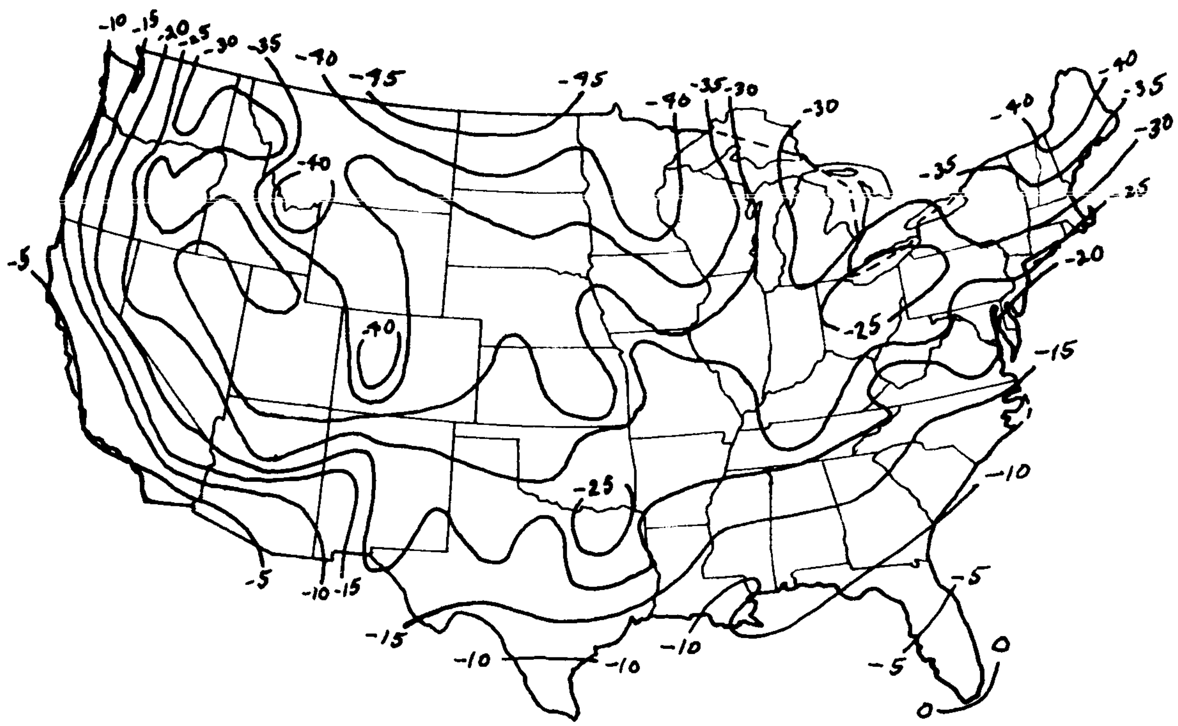

FIGURE 15.2 EXTREME MINIMUM TEMPERATURE (degrees Celsius)

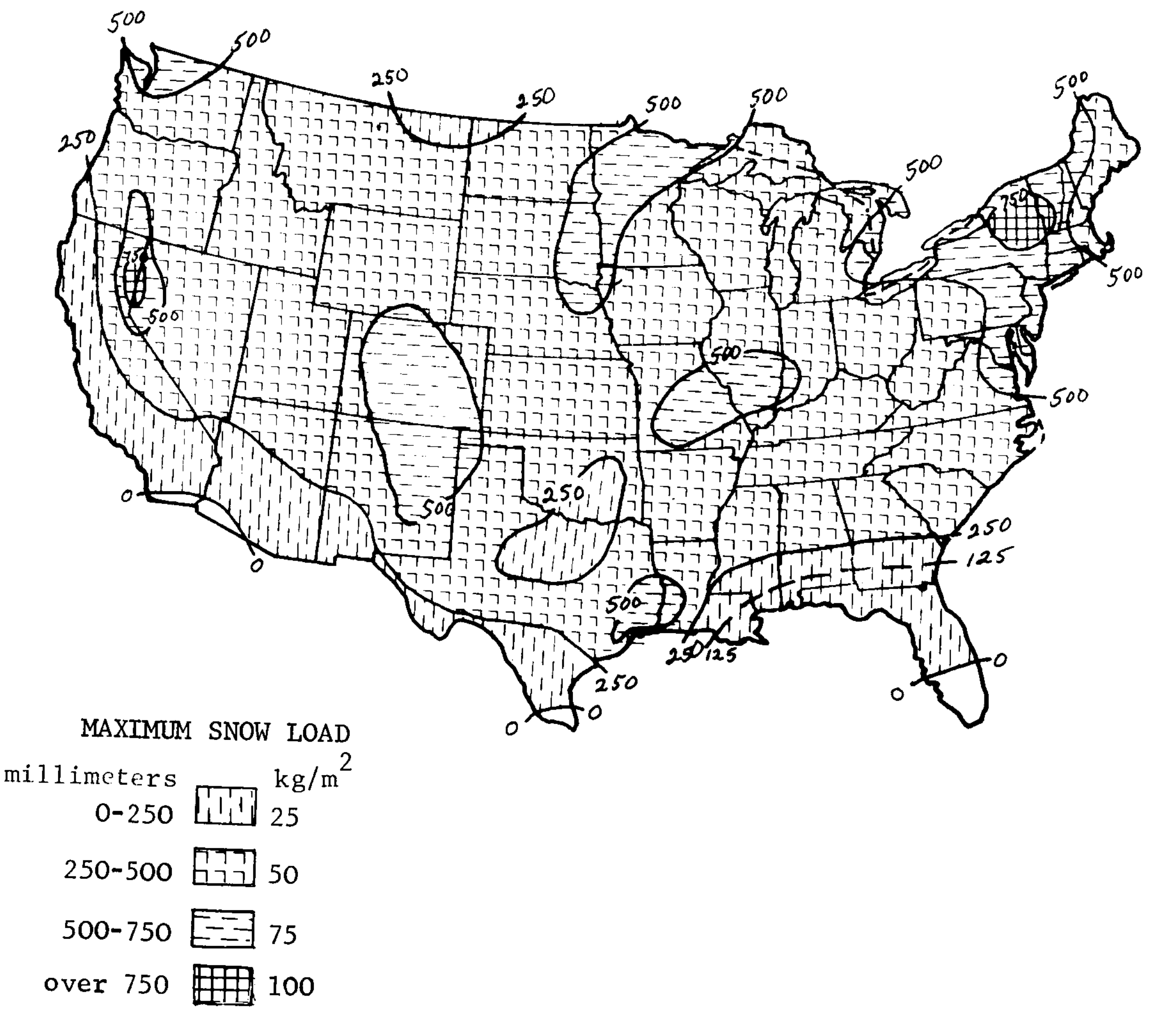

FIGURE 15.3 EXTREME 24-HOUR MAXIMUM SNOW FALL (MILLIMETERS)

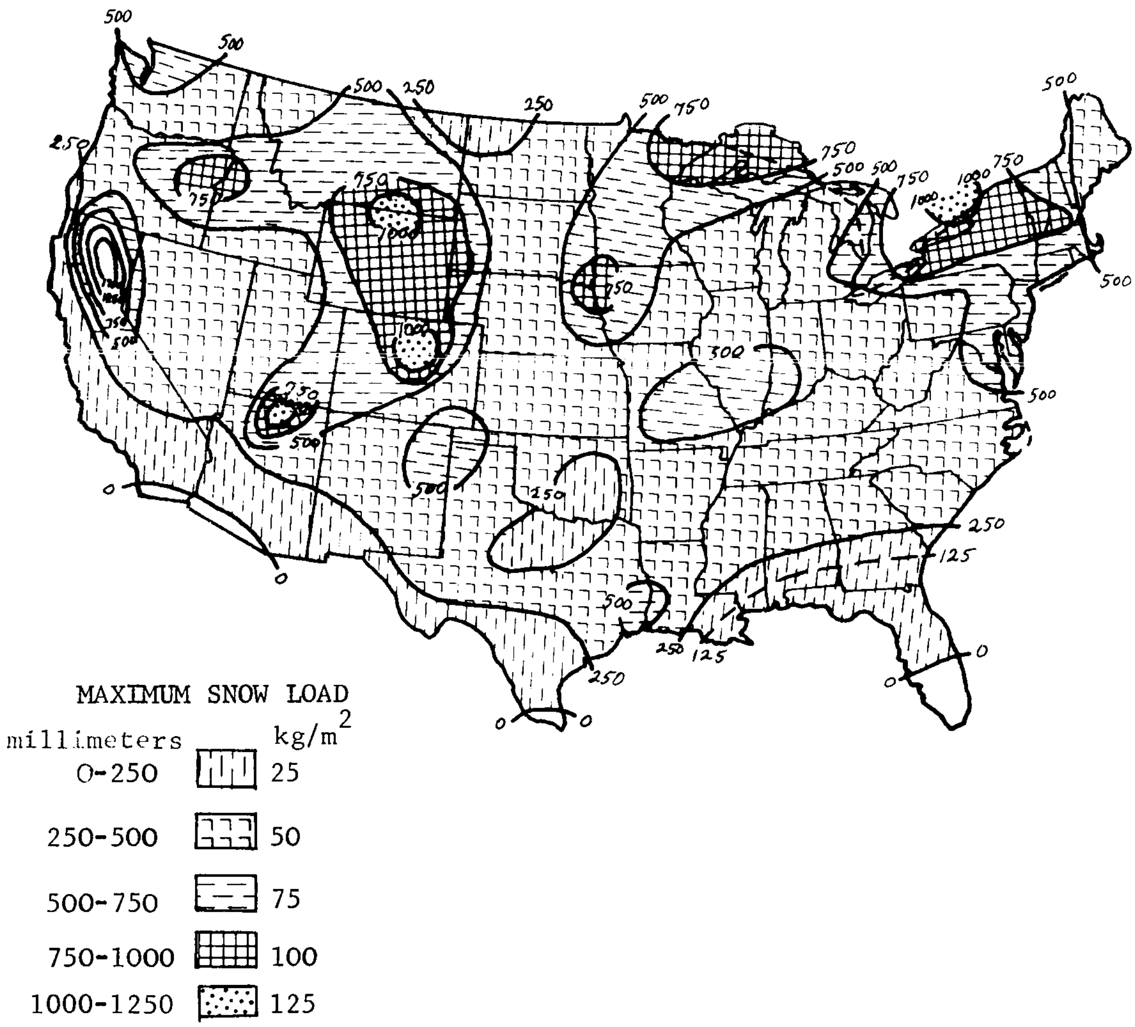

FIGURE 15.4 EXTREME STORM MAXIMUM SNOW FALL (MILLIMETERS)

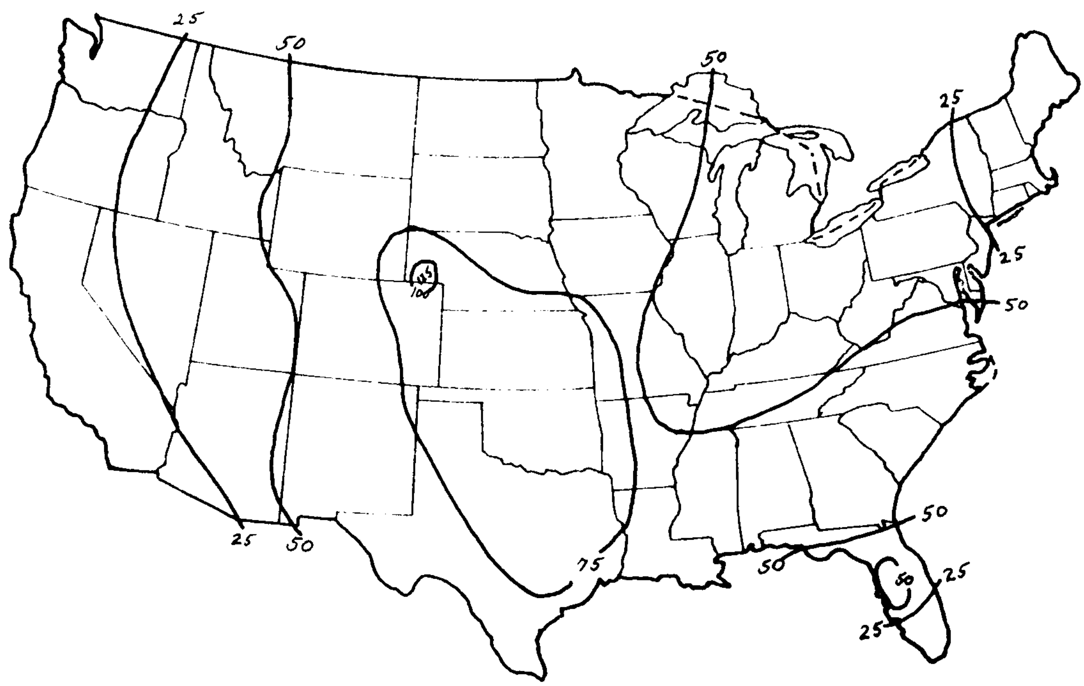

FIGURE 15.5 EXTREME MAXIMUM HAIL STONE DIAMETERS (MILLIMETERS)

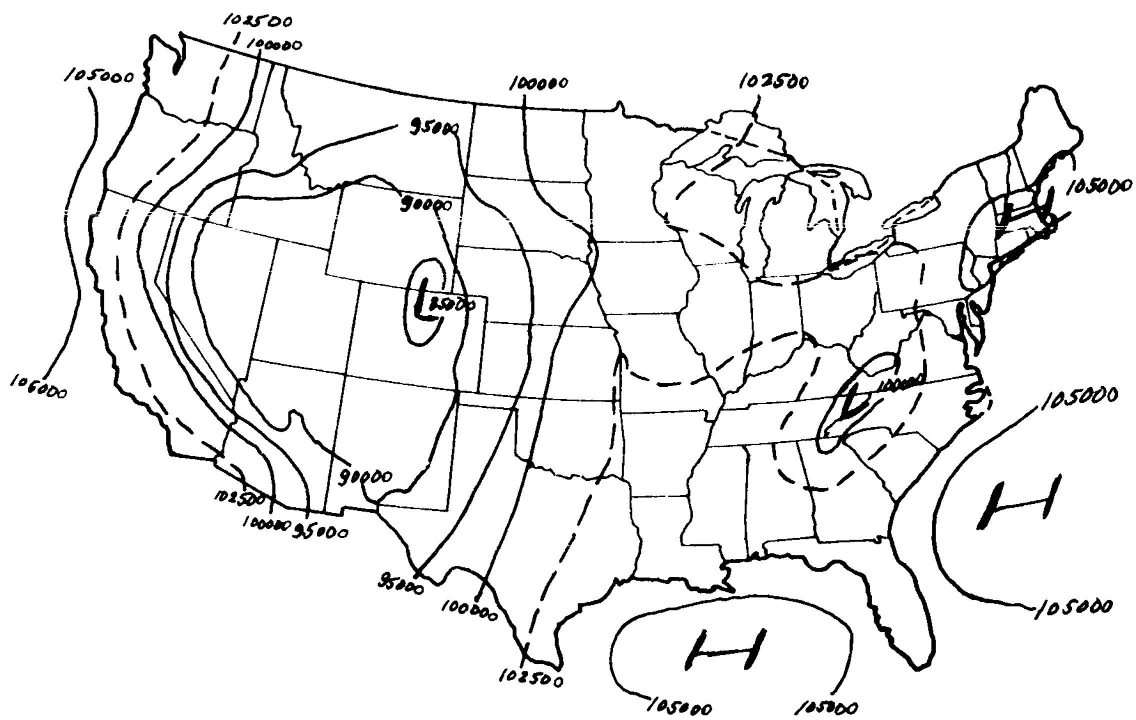

FIGURE 15.6 MAXIMUM ABSOLUTE STATION PRESSURE (Newton/m^2)

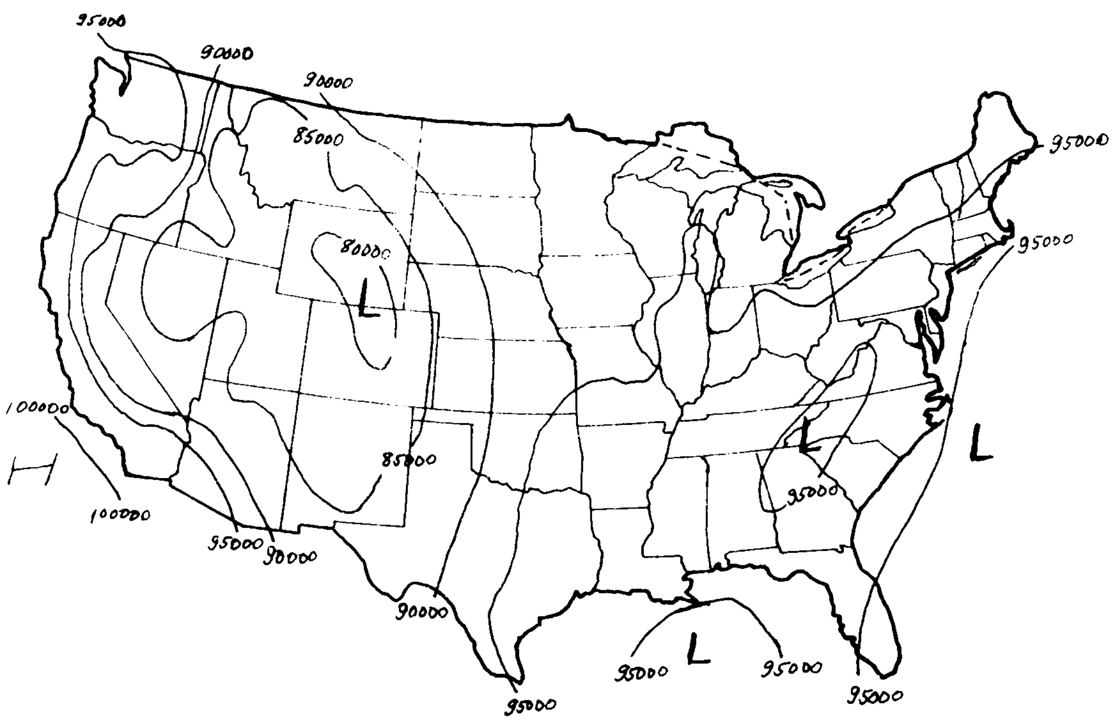

FIGURE 15.7 MINIMUM ABSOLUTE STATION PRESSURE (Newton/m^2)

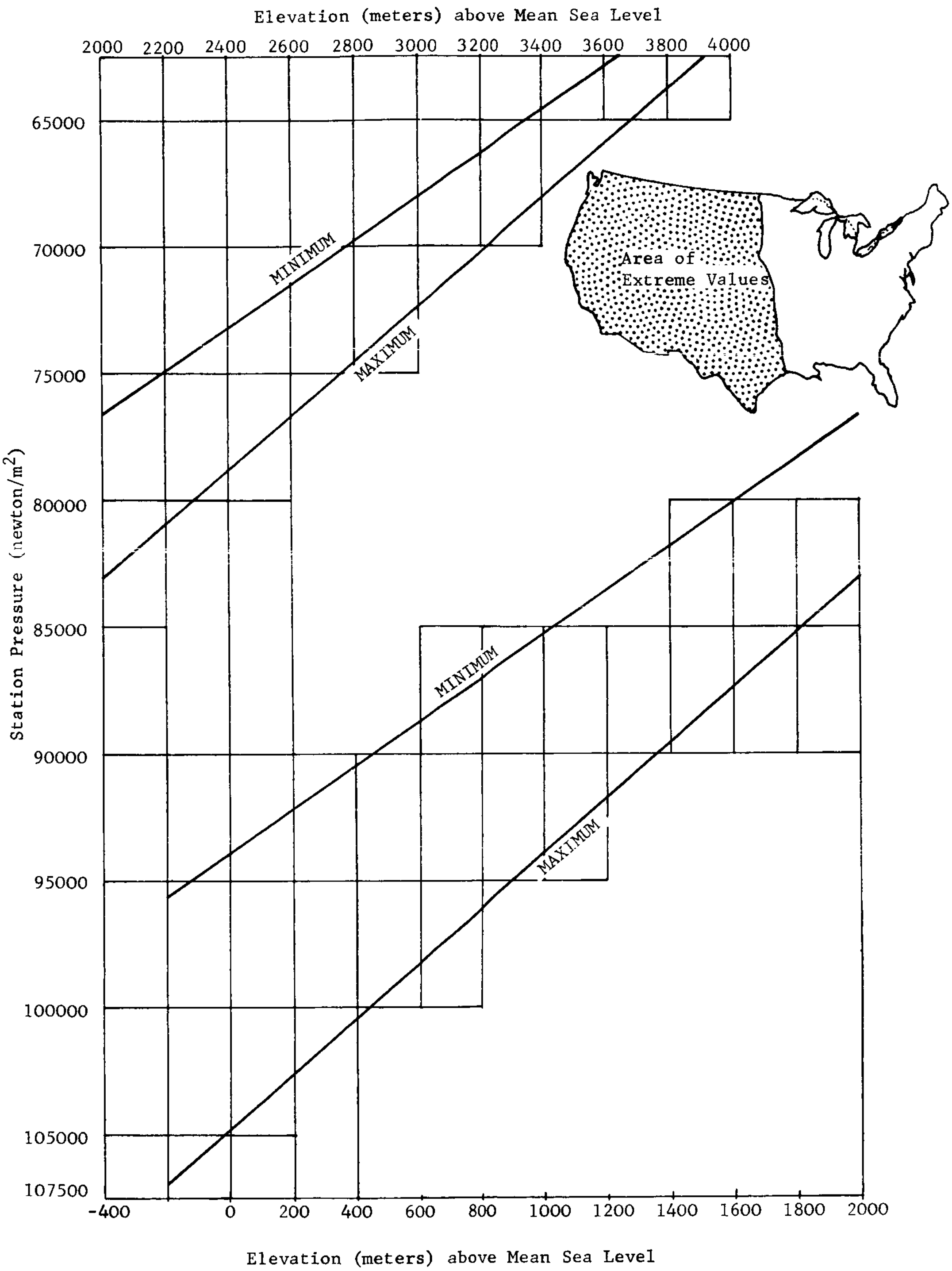

FIGURE 15.8 EXTREME PRESSURE VALUES VS. ELEVATION FOR WESTERN UNITED STATES

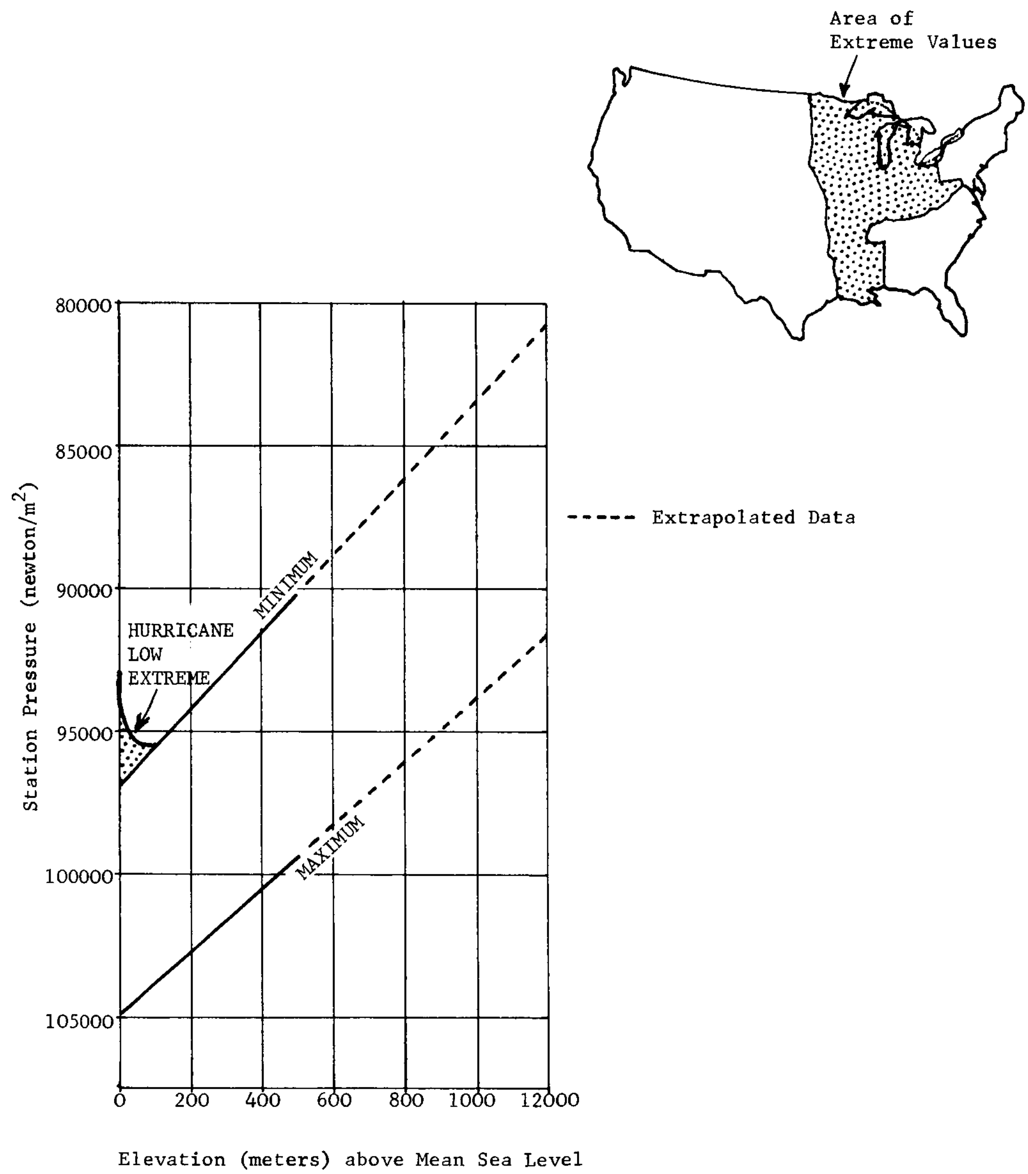

FIGURE 15.9 EXTREME PRESSURE VALUES VS. ELEVATION FOR CENTRAL UNITED STATES

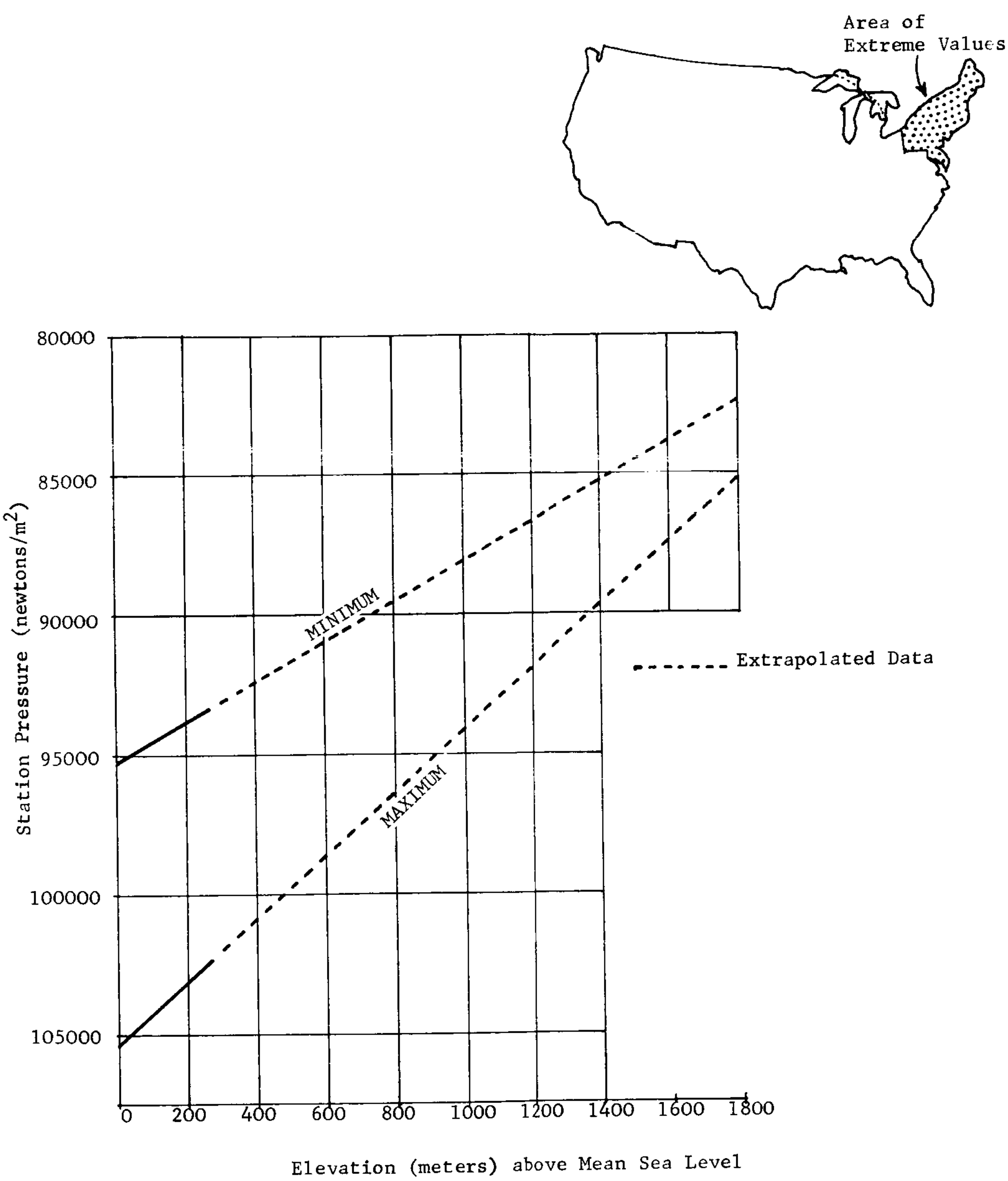

FIGURE 15.10 EXTREME PRESSURE VALUES VS. ELEVATION FOR NORTHEASTERN UNITED STATES

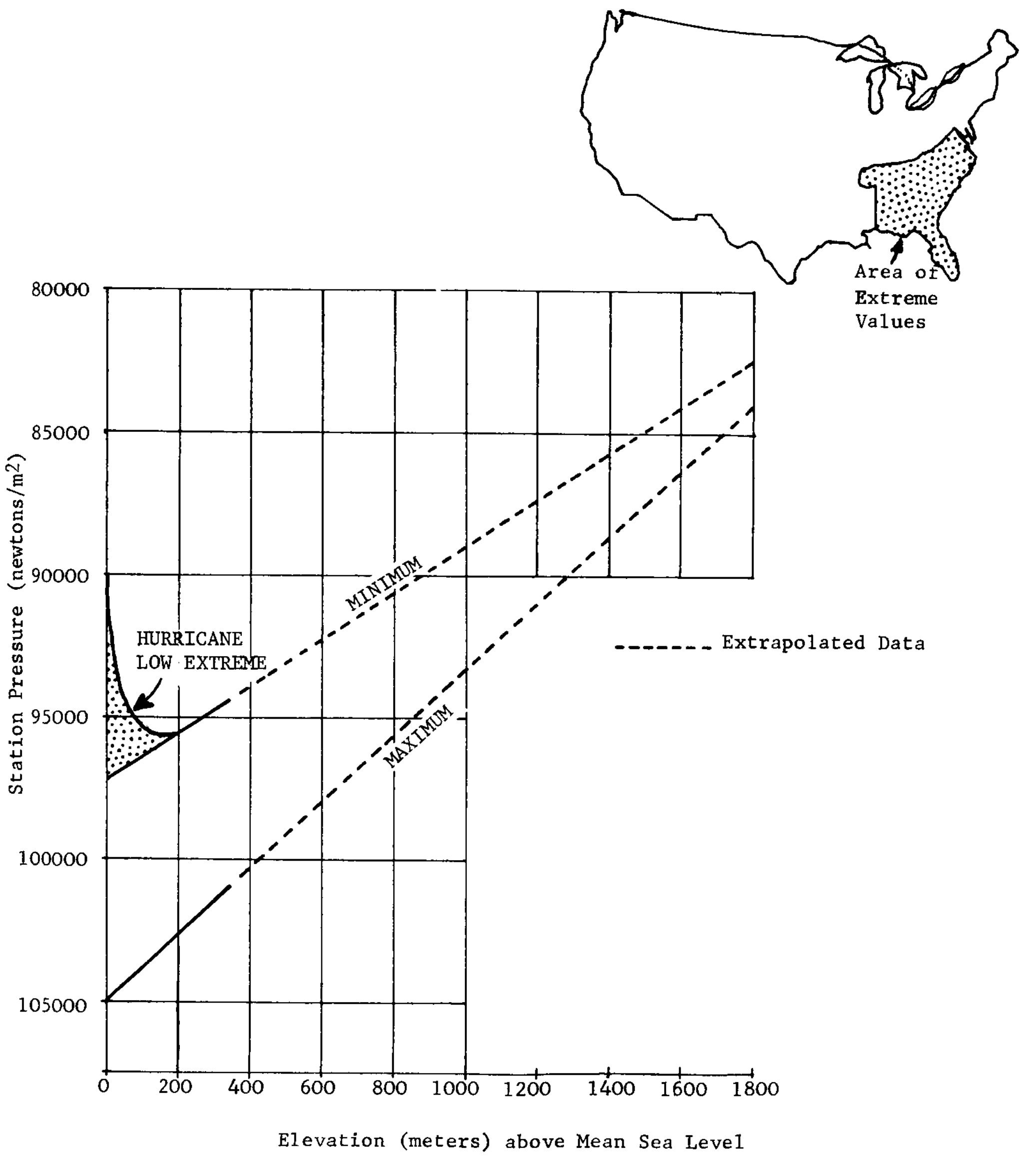

FIGURE 15.11 EXTREME PRESSURE VALUES VS. ELEVATION FOR SOUTHEASTERN UNITED STATES

TABLE 15.1 ELEVATIONS OF CITIES OF THE UNITED STATES
(Values are elevation of barometer at U. S. Weather Bureau Station)

Location	Elevation, MSL (feet)	Elevation, MSL (meters)
ALABAMA		
Birmingham	610	185.9
Mobile	211	64.3
ARIZONA		
Phoenix	1100	335.2
Yuma	199	60.7
ARKANSAS		
Fort Smith	499	152.1
Little Rock	257	78.3
Texarkana	361	110.0
CALIFORNIA		
Eureka	43	13.1
Fresno	331	100.9
Los Angeles	312	95.1
Sacramento	20	6.1
San Diego	19	5.8
San Francisco	52	15.8
COLORADO		
Denver	5292	1613.0
Grand Junction	4849	1478.0
Pueblo	4639	1414.0
CONNECTICUT		
Hartford	15	4.6
New Haven	6	1.8
DISTRICT OF COLUMBIA		
Washington	72	21.9
FLORIDA		
Apalachicola	13	4.0
Fort Myers	15	4.6
Jacksonville	18	5.5
Key West	5	1.5
Miami	7	2.1
Pensacola	13	4.0
GEORGIA		
Atlanta	1054	321.3
Savannah	48	14.6
IDAHO		
Boise	2842	866.2
Pocatello	4444	1354.5
ILLINOIS		
Cairo	314	95.7
Chicago	610	185.9
Springfield	587	178.9
INDIANA		
Evansville	383	116.7
Indianapolis	718	218.8
IOWA		
Des Moines	807	246.0
Sioux City	1094	333.4
KANSAS		
Dodge City	2594	790.7
Goodland	3645	1111.0
Wichita	1321	402.6
KENTUCKY		
Louisville	457	139.3
LOUISIANA		
Lake Charles	12	3.7
New Orleans	3	0.9
Shreveport	174	53.0
MAINE		
Caribou	624	190.2
Portland	61	18.6
MARYLAND		
Baltimore	14	4.3
MASSACHUSETTS		
Boston	15	4.6
Nantucket	43	13.1
MICHIGAN		
Alpena	587	178.9
Detroit	619	188.7
Marquette	677	206.3
Sault Ste. Marie	721	219.8
MINNESOTA		
Duluth	1162	354.2
International Falls	1179	359.4
Minneapolis	830	253.0
MISSISSIPPI		
Jackson	305	93.0
MISSOURI		
Kansas City	741	225.9
St. Louis	809	246.6
MONTANA		
Havre	2488	758.3
Helena	3893	1186.6
NEBRASKA		
Omaha	978	298.1
NEVADA		
Elko	5075	1546.9
Las Vegas	2162	659.0
Winnemucca	4299	1310.3
NEW HAMPSHIRE		
Concord	339	103.3
NEW JERSEY		
Atlantic City	10	3.0
Newark	11	3.4
Trenton	56	17.1
NEW YORK		
Albany	19	5.8
Buffalo	693	211.2
New York City	10	3.0
Rochester	543	165.5
Syracuse	424	129.2
NORTH CAROLINA		
Cape Hatteras	7	2.1
Raleigh	400	121.9
Wilmington	30	9.1
NORTH DAKOTA		
Fargo	900	274.3
Bismarck	1650	502.9
Williston	1877	572.1

TABLE 15.1 (Concluded)

Location	Elevation, MSL (feet)	Elevation, MSL (meters)
OHIO		
Cincinnati	553	168.6
Cleveland	653	199.0
Columbus	724	220.7
Toledo	676	206.0
OKLAHOMA		
Oklahoma City	1254	382.2
Tulsa	672	205.2
OREGON		
Medford	1312	399.9
Pendleton	1492	454.8
Portland	21	6.4
Roseburg	479	146.0
PENNSYLVANIA		
Harrisburg	335	102.1
Philadelphia	7	2.1
Pittsburg	749	228.3
RHODE ISLAND		
Block Island	110	33.5
Providence	12	3.7
SOUTH CAROLINA		
Charleston	9	2.7
Columbia	217	66.1
Greenville	1018	310.3
SOUTH DAKOTA		
Huron	1282	390.8
Rapid City	3165	964.7
Sioux Falls	1420	432.8
TENNESSEE		
Chattanooga	670	204.2
Memphis	263	80.2
Nashville	577	175.9

Location	Elevation, MSL (feet)	Elevation, MSL (meters)
TEXAS		
Abilene	1759	536.1
Amarillo	3590	1094.2
Brownsville	16	4.9
Corpus Christi	43	13.1
Dallas	476	145.1
El Paso	3920	1194.8
Galveston	5	1.5
San Antonio	792	241.4
Wichita Falls	1002	305.4
UTAH		
Salt Lake City	4220	1286.3
VERMONT		
Burlington	331	100.9
VIRGINIA		
Norfolk	11	3.4
Richmond	162	49.4
WASHINGTON		
Tatoosh Island	101	30.8
Seattle	14	4.3
Spokane	2357	718.4
Walla Walla	949	289.3
WEST VIRGINIA		
Charleston	950	289.6
WISCONSIN		
Green Bay	689	210.0
La Crosse	652	198.7
Madison	857	261.2
Milwaukee	620	189.0
WYOMING		
Casper	5319	1621.2
Cheyenne	6131	1868.7
Lander	5563	1695.6
Sheridan	3942	1201.5

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SECTION XVI. CLOUD COVER FOR EARTH ORIENTED SPACE MISSION ANALYSIS

By

Sayre C. Brown*

16.1 Introduction

For earth oriented space missions the cloud cover of the earth's surface is defined as the fraction of definite area covered by the vertical projection of the clouds within the area. In general, the same cloud cover prevails over a number of contiguous areas. As seen on the grand scale from weather satellites, most clouds form part of large scale organized cloud systems. These systems maintain their identity from day-to-day while moving at speeds characteristic of synoptic systems. The cloud systems and subsystems within them move and deform continuously. New systems are born, only occasionally explosively, while old systems dissipate more gradually. Accordingly, the cloud cover over one area cannot be considered independently of that over another nearby area, nor is the cloud cover today necessarily independent of that yesterday.

Computer simulation of earth observations from space involves "flying" the mission over many samples of the cloud field that might be observed. The use of real cloud fields, described by satellite observations or surface observations, would seem appropriate. Since it is difficult to obtain a sufficient sample to get reasonable statistical stability, a procedure of computing conditional cloud statistics "to order," following the path of the simulation was adopted. The simulation of cloud then takes the form of a simple Markhov chain proceeding from each potential earth observation to the next.

16.2 The Cloud Model

The cloud model to be used for simulation results from the following considerations:

1. Each observation from space has associated with it a certain characteristic area of the earth's surface over which the cloud cover must be described to evaluate the success of the observation. This may vary from a few acres for ground truth sites to some 129,500 km^2 (50,000 mi^2) for atmospheric sounding experiments. The requirements for finding a small area,

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*Based on NASA CR-61226 (Ref 16.1) and Reference 16.2

whether by an astronaut in real time or later in the data presentation, increases the minimum size of area to be considered since geographic "lead-ins" are required. A practical minimum area is perhaps a 93 to 111 km (50 to 60 n. mi.) diameter circle, corresponding (fortunately) to the ground observer's field of view.

2. The cloud cover distribution is a strong function of the size of the area over which the cloud is described, ranging from a bimodel 0 and 100 percent for a very small area to a possible constant 40 percent for the globe as a whole. Evidence from cloud studies suggests that the distribution changes quite rapidly with viewed area size over the range of interest.

3. Most earth oriented-observations will be made from fairly low orbit, ranging from 278 km (150 n. mi.) to perhaps 1111 km (600 n. mi.). Thus, the attempted observations will occur in a sequential chain in orbit order, or in the form of isolated diverted attempts to observe specific targets. Observations from earth synchronous height would also be made in organized sequence.

4. The same point may be observed at intervals of about one orbit, two orbits, 12 hours, 24 hours, or much longer. The success of certain experiments may depend on the ability to make unbroken sequential observations.

5. Computer simulation of cloud contingent events may take one of two forms, either derived statistical distributions of certain parameters of mission or experiment success or Monte Carlo simulation of the contingent parts of the mission or experiment. Hybrid applications may also occur; it may be desirable to work out probability distributions of the observational success consequences of cloud cover, then perform a Monte Carlo simulation using observational success as the random variable rather than cloud cover.

The cloud "model" adopted to meet these requirements and those of computational convenience has the following description:

1. The earth is divided into a number of regions, described by 29 regional types (Fig. 16.1). The cloud distributions, conditional and unconditional, are the same everywhere within each region.

2. Regional boundaries are also impermeable boundaries between cloud systems so that there is no conditionality across boundaries. This is literally true for many boundaries, and seems to be effectively true for many of the others.

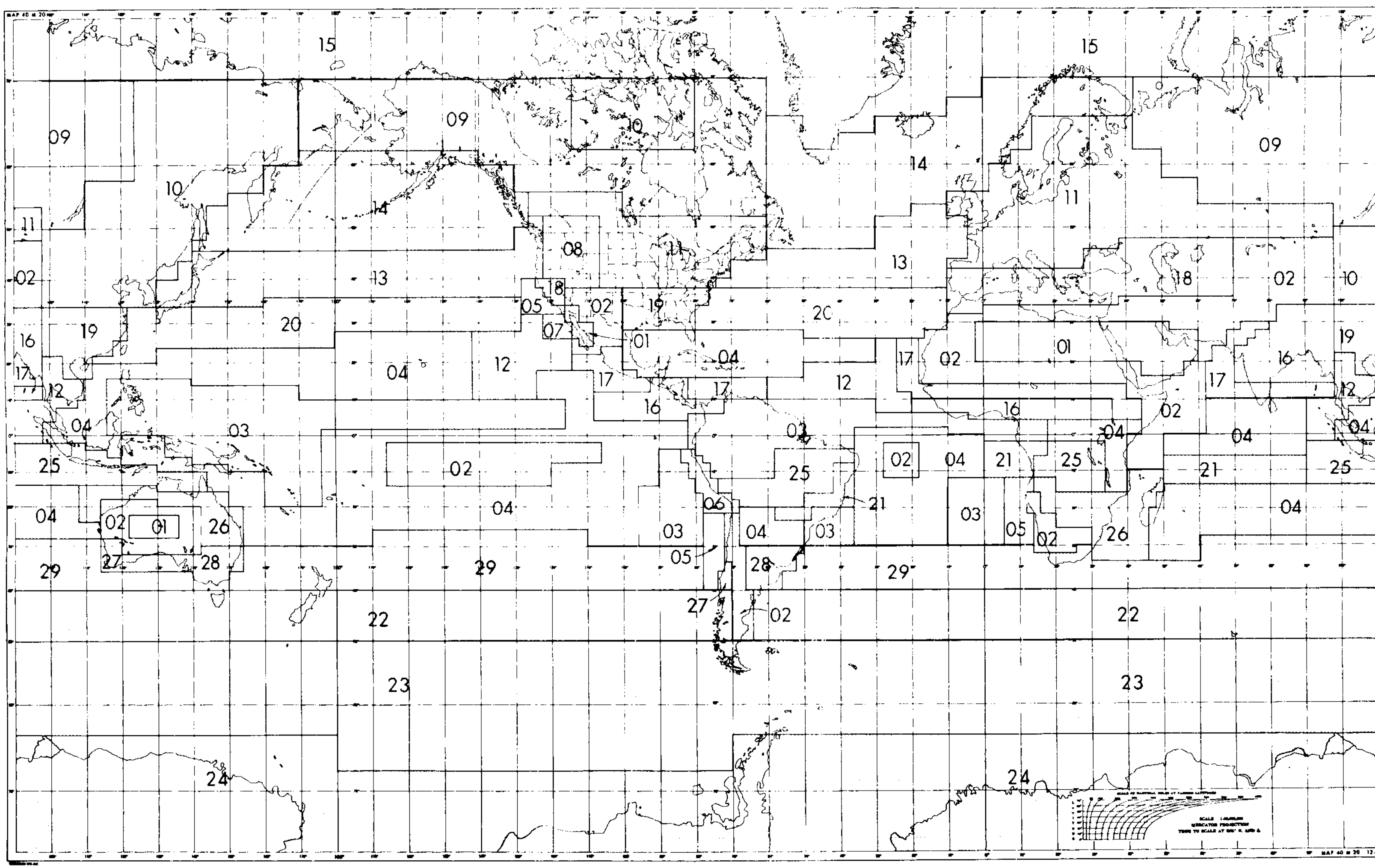

FIGURE 16. 1. CLOUD REGION LOCATION MAP

3. Because cloud cover must always be interpreted in terms of its effect on earth observation before it can be used effectively in simulation, only 5 categories are used to describe cloud cover. The most important events, clear and overcast, are given unique categories (Table 16.1).

TABLE 16.1. CLOUD CATEGORY DESIGNATION

Category	Tenths	Eighths (Octas)
1	0	0
2	1,2,3	1,2
3	4,5	3,4
4	6,7,8,9	5,6,7
5	10	8

4. Diurnal and seasonal cloud variations for most regions are so strong that unconditional tabulations at 3-hour intervals and by month are given.

5. Spatial and temporal conditional distributions are given for one distance (370 km) and one time interval (24 hours). Only two seasons are represented, and no account is taken of any diurnal changes in the conditional distributions.

6. The assumption is made that spatial conditionality is independent of direction. Serious consequences of this assumption are avoided by the limited meridional extent of most regions and the impermeability of region boundaries.

7. Conditional distributions for distances and times other than those presented are to be found by straight line interpolation (or extrapolation) between the given elements and the degenerate (0 or 1) conditionality at zero distance or time.

8. Joint probability distributions of dependent events are to be found by

$$P(ab) = P(a) \cdot P(b|a)$$

However, since $P(a)$ and $P(b|a)$ are drawn from different populations, $P(ab) \neq P(ba)$. Further, the two marginal distributions $P'(a) = \sum_{a} (ab)$ and $P'(b) = \sum_{a} (ab)$ will not be equal.

9. Sample cloud covers are generated by a simple Markhov chain process; the cloud cover of the first point encountered in a region is found from a random sample from the appropriate unconditional distribution. Subsequent cloud covers are found from random samples from an appropriately scaled distribution conditional on the cloud cover of the prior sample. If the space between observations exceeds 1482 km (800 n. mi.) or 36 hours, a new unconditional start is made to the chain.

16.3 Glossary of Terms

We have chosen for convenience to keep track of the various scaled and unscaled probability distributions by use of a set of FORTRAN mnemonics which are somewhat descriptive of the content of the distribution. Table 16.2 defines these mnemonics. These terms will be used throughout the remaining sections to designate the various distributions. Techniques for computing the distributions will be described.

16.4 Scaling for Distance

Data for 370 km (200 n. mi.) distance from the initial point are tabulated in the data bank. We present here the mathematical technique for scaling these conditional statistics for distances other than 370 km (200 n. mi.). As mentioned in paragraph 16.2, the assumption is made that the conditional probabilities decay linearly with distance. This decay will be demonstrated and discussed in paragraph 16.4.1 below.

The procedure for scaling for distance based on the linear assumption is thus a relatively simple one. Two conditions are imposed. The first concerns the area within 370 km (200 n. mi.), i.e., scaling for distances less than 370 km, the second is for scaling beyond 370 km. For scaling within 370 km, one uses the following two formulas. For probabilities on the diagonal on the 5 by 5 conditional matrix, i.e., 1 given 1, 2 given 2, etc., one uses

$$P(C) = 1 - \frac{\text{Scale (d)}}{200} \text{ (1-SCOND)} \tag{1}$$

If the value in question is not on the diagonal, i.e., probability of 1 given 2, 1 given 3, etc., the following formula is used for scaling.

$$P(C) = \frac{\text{Scale (d)}}{200} \text{ (SCOND)} \tag{2}$$

In equations (1) and (2) scale (d) units are nautical miles

TABLE 16.2 DEFINITION OF TERMS

UNCON	Unconditional Distribution for Sampling Area Size 56 to 111 km (30 to 60 n. mi.).
SCOND	Spatial Conditional Distribution for Sampling Area Size 56 to 111 km (30 to 60 n. mi.) and Distance 370 km (200 n. mi.) from UNCON.
TCOND	Temporal Conditional Distribution for Sampling Area Size 56 to 111 km (30 to 60 n. mi.) and 24 hours after UNCON.
SUNCON	Scaled Unconditional Distribution for Enlarged Sampling Area Size.
CONNEW	Conditional Distribution Scaled for Enlarged Sampling Area Size.
CONDIS	Spatial Conditional Distribution Scaled for Distance Other then 370 km (200 n. mi.).
CONTIM	Temporal Conditional Distribution Scaled for Time Other than 24 hours.
SCSCON	Spatial Conditional Distribution Scaled for Both Enlarged Area Size and Distance Other than 370 km (200 n. mi.).
SCTCON	Temporal Conditional Distribution Scaled for Both Enlarged Area Size and Time Other than 24 hours.
TSCON	Conditional Distribution Scaled for Both Time and Distance for 56 to 111 km (30 to 60 n. mi.) Sampling: Area Size.
TSSCON	Conditional Distribution Scaled for Time, Distance and Enlarged Sampling Area Size.
DICON	Pseudo-Conditional Distrubition Matrix Generated while Scaling TCOND for Diurnal Effects.
DITCON	Diurnally Scaled Temporal Conditionals.

When the required distance is greater than 370 km (200 n. mi.), the following condition is also imposed. For values on the diagonal, the scaled values (scaled using the formulas immediately above) must remain greater than the unconditional probability of the diagonal value, i. e., the scaled probability of 2 given 2 must be greater than the unconditional probability of 2. If this test fails, the entire horizontal line of the 5 by 5 matrix is replaced with the unconditional statistics as demonstrated in Table 16.3. In a similar manner for values not on the diagonal, the scaled values must remain below the unconditional probability of the given cloud group, i. e., $P(2|1)$ and $P(2|3)$ etc., must be smaller than the unconditional probability of 2. If this test fails, the entire horizontal line of the 5 by 5 matrix is also replaced by the unconditional statistics. Thus if either the diagonal value is less than the unconditional value or if the nondiagonal value on any given line is greater than the unconditional value, the whole line is replaced by the unconditional statistics. This amounts to saying that if either of these tests fails, the cloud cover statistics for this cloud category beyond this point are no longer conditional upon the first point but assume the unconditional distributions.

16.4.1 Example of Scaling for Distance

Two examples are presented below to demonstrate the scaling of the conditional probability distributions (as tabulated in the data bank) for distances other than 370 km (200 n. mi.). In example one (Table 16.3) the scaling has been accomplished for a distance of 648 km (350 n. mi.). Note that, in this case, the additional test for SCALE greater than 370 km has been imposed. The difference in the 5 by 5 matrix shown at the top of the Table (SCOND) values and those shown at the bottom (new CONDIS) values are significant.

In Table 16.4 we show an example of scaling for distances less than 370 km (296 km or 160 n. mi.). The additional test for conditionality with regard to the unconditional probabilities is not imposed in this case. Note the increase in the values on the diagonal of the 5 by 5 matrix between the SCOND and the CONDIS matrices shown in Table 16.4. Thus as one moves closer than 370 km the conditional probabilities become more diagonalized.

16.5 Scaling for Time

Scaling the conditional distributions for time is handled in a somewhat similar way to that for distance. In this case, we assume that the statistics are no longer conditional for times beyond 36 hours.

TABLE 16.3 EXAMPLES OF SCALING FOR DISTANCES GREATER THAN 370 km (200 n. mi.)
REGION 19, JANUARY - 1600 L

Cloud Group	UNCON	SCOND (≈370 km or 200 n. mi.)					CONDIS (648 km or 350 n. mi.)				
		1	2	3	4	5	1	2	3	4	5
1	0.16	0.76	0.05	0.05	0.05	0.09	0.58	0.09	0.09	0.09	0.16
2	0.10	0.17	0.17	0.08	0.08	0.50	0.30	0.45	0.14	0.14	0.87
3	0.06	0.13	0.12	0.15	0.30	0.30	0.23	0.21	0.50	0.52	0.52
4	0.21	0.14	0.09	0.14	0.45	0.18	0.24	0.16	0.24	0.04	0.32
5	0.47	0.13	0.06	0.12	0.16	0.53	0.23	0.10	0.21	0.28	0.18

TEST FOR CONDITIONALITY

1) Are Diagonal values greater than corresponding UNCON - Ans. No

2) Are all Non-Diagonal values in each row less than or equal to corresponding UNCON - Check

Cloud Group 1 Yes
2 No
3 No
4 No
5 No

If NO replace Matrix values with UNCON

		New CONDIS (648 km or 350 n. mi.)				
		1	2	3	4	5
G	1	0.58	0.09	0.09	0.09	0.16
I	2	0.16	0.10	0.06	0.21	0.47
V	3	0.16	0.10	0.06	0.21	0.47
E	4	0.16	0.10	0.06	0.21	0.47
N	5	0.16	0.10	0.06	0.21	0.47

ON the diagonal

$$P(C) = 1 - \frac{\text{Scale (T)}}{24} (1 - \text{TCOND}) \quad .$$

OFF the diagonal

$$P(C) = \frac{\text{Scale (T)}}{24} (\text{TCOND}) \quad .$$

The first formula is used for values which lie on the diagonal of the 5 by 5 matrix while the second formula is used for those which lie off the diagonal (similar to the discussion above).

16.5.1 Example of Scaling for Time Less than 24 Hours

Data are presented in Table 16.5 exemplifying a scaling of the TCOND (time conditionals) for an observation 20 hours after the initial observation. The formulas presented above have been used to scale the TCOND values. This results in a new 5 by 5 conditional distribution (CONTIM). Note that as time decreases from 24 to 20 hours the values of the parameters on the diagonal increase.

16.6 Diurnal Change

The 24-hour conditional distributions, and any scaling of them for other time intervals, contain no direct provision for introducing the effect of diurnal variation, which in some regions is the principal factor affecting cloud cover. A recommended procedure is as follows:

1. Generate a pseudo-conditional distribution (DICON) between the unconditional distributions at the local times of the first and second cloud events. This can be done by first forming a joint probability distribution between UNCON (A), the unconditional distribution of event A, and UNCON (B), the unconditional distribution of event B (later in time than A). The assumption is made that the event B corresponding to a specific event A is the one occurring at the same cumulative probability level in the unconditional distribution at the second time as does the event A in the unconditional distribution at the first time. This satisfies the intuition that diurnal change is superposed on more gross synoptic scale variability, so that if event A represents a lesser

TABLE 16.4 EXAMPLE OF SCALING FOR DISTANCE LESS THAN 370 km (200 n. mi.)
REGION 19, JANUARY - 1300 L

Cloud Group	UNCON	SCOND							CONDIS (296.3 km or 160 n. mi.)				
		1	2	3	4	5			1	2	3	4	5
1	0.15	0.76	0.05	0.05	0.05	0.09	G	1	0.81	0.04	0.04	0.04	0.07
2	0.12	0.17	0.17	0.08	0.08	0.50	I	2	0.14	0.34	0.06	0.06	0.40
3	0.04	0.13	0.12	0.15	0.30	0.30	V	3	0.10	0.10	0.32	0.24	0.24
4	0.17	0.14	0.09	0.14	0.45	0.18	E	4	0.11	0.07	0.11	0.56	0.15
5	0.52	0.13	0.06	0.12	0.16	0.53	N	5	0.10	0.05	0.10	0.13	0.62

TABLE 16.5 EXAMPLE OF SCALING FOR TIME LESS THAN 24 HOURS
REGION 19, JANUARY - 1300 L

Cloud Group	UNCON	TCOND							CONTIM (20 hours)				
		1	2	3	4	5			1	2	3	4	5
1	0.15	0.52	0.07	0.06	0.18	0.17	G	1	0.60	0.06	0.05	0.15	0.14
2	0.12	0.33	0.18	0.08	0.19	0.22	I	2	0.28	0.32	0.06	0.16	0.18
3	0.04	0.21	0.18	0.11	0.32	0.18	V	3	0.18	0.15	0.26	0.26	0.15
4	0.17	0.23	0.10	0.05	0.35	0.27	E	4	0.19	0.08	0.04	0.46	0.23
5	0.52	0.23	0.04	0.07	0.20	0.46	N	5	0.19	0.03	0.06	0.17	0.55

cloud cover than normal, the succeeding event B should also represent a smaller cloud cover than normal at that time. As an aid to the reader, we define $P_A(1)$, $P_A(2)$, etc., to be the probability of cloud group 1, 2, etc., for event A, and $P_B(1)$, $P_B(2)$, etc., to be the corresponding probabilities for event B.

The cloud categorization intervals fall at different cumulative probabilities in the distributions of events A and B. Thus it is necessary to divide up the intervals of the distribution of event A and assign them to intervals of the distribution of event B, assuming uniform distribution within an interval. To form the joint probability matrix shown in Table 16.6 (C), we find the fractional part of $P_A(1)$ that is contained in (jointly distributed with) $P_B(1)$. In the example shown in Table 16.6 (B), all of $P_A(1)$, 0.2, is contained in $P_B(1)$. Thus, 0.2 is entered in the joint probability matrix at position A = 1, B = 1 (cell number of joint table). Since $P_B(1)$ is 10 percent greater than $P_A(1)$, this additional 0.1 in $P_B(1)$ could not have occurred jointly with $P_A(1)$. Therefore, it is placed in the matrix (Table 16.6 (C)) at position A = 2, B = 1.

TABLE 16.6 COMPUTATION OF A PSEUDO-CONDITIONAL DISTRIBUTION FOR DIURNAL VARIATION

	Cloud Category	UNCON EVENT (A) Prob.	UNCON EVENT (A) Cum.	UNCON EVENT (B) Prob.	UNCON EVENT (B) Cum.
(A)	1	0.2	0.2	0.3	0.3
	2	0.5	0.7	0.3	0.6
	3	0.2	0.9	0.2	0.8
	4	0.05	0.95	0.1	0.9
	5	0.05	1.0	0.1	1.0

TABLE 16.6 (Continued)

	UNCON					
	Event (A)			Event (B)		
Cloud Category	Probability	Rated Probability	Joint Cell Number	Rated Probability	Probability	Cloud Category
1	0.2	0.2	1-1	0.2	0.3	1
			2-1	0.1		
		0.1				
2	0.5	0.3	2-2	0.3	0.3	2
		0.1				
(B)			2-3			
		0.1		0.1		
3	0.2	0.1	3-3	0.1	0.2	3
			3-4			
4	0.05	0.05	4-5	0.1	0.1	4
				0.05		
5	0.05	0.05	5-5	0.05	0.1	5

JOINT PROBABILITY

			(B)					
			1	2	3	4	5	Total = UNCON(A)
	1		0.2	0	0	0	0	0.2
	2		0.1	0.3	0.1	0	0	0.5
(C)	3	(A)	0	0	0.1	0.1	0	0.2
	4		0	0	0	0	0.05	0.05
	5		0	0	0	0	0.05	0.05

TABLE 16. 12 (Concluded)

			DICON				
					$C_{(B)}$		
			1	2	3	4	5
	1		1.0	0	0	0	0
	2		0.2	0.6	0.2	0	0
(D)	3	$C_{(A)}$	0	0	0.5	0.5	0
	4		0	0	0	0	1.0
	5		0	0	0	0	1.0

In a similar way, we rate (jointly distribute) $P_A(2)$ with $P_B(2)$ and find that only 0.3 are contained in both. Therefore, 0.3 is located in the joint matrix at A = 2, B = 2. Again there is an additional part to be allocated; this time 0.1 of $P_A(2)$ must have occurred with $P_B(3)$; it is thus entered in the matrix at A = 2, B = 3. (For Monte Carlo computational procedures, it may be more convenient to work with the UNCON cumulative probabilities.)

This process is continued for all categories as shown. These individual entries, divided by the marginal total UNCON (A), become the entries in DICON (C_B C_A).

If any element of UNCON (A) is zero, a suitable flag should be entered in the cell number of the joint distribution into which an entry would fall if that element were very small. In forming the DICON matrix, by division through each row by the corresponding element of UNCON (A), the rule is "flag divided by zero is 1.0." This results in an appropriate entry in DICON to take care of the eventuality of a "forbidden" event A materializing as a result of other manipulations. If an element of UNCON (B) is zero, no special provisions are required, as the resulting distribution will "lock out" that category.

2. Form the diurnal-temporal conditional distribution (DITCON) by

$$\text{DITCON}\,(a_i | b_j) = \sum_{k=1}^{5} \text{DICON}\,(a_i | c_k) \cdot \text{CONTIM}\,(c_k | b_j)$$

where CONTIM is the scaled derived temporal conditional appropriate to the time interval.

3. Use DITCON in place of the temporal conditional in question. The DITCON operation is not required for time intervals of less than 2 hours or approximately 24 hours.

If it is desired that the resulting distribution avoid total lockout of cloud categories of zero probability in UNCON (2), the formula for DITCON may be reversed

$$\text{DITCON}\,(a_i | b_j) = \sum_{k=1}^{5} \text{CONTIM}\,(a_i | c_k) \cdot \text{DICON}\,(c_k | b_j)$$

The two formulas differ in the effective order in which the operations of diurnal change and temporal conditionality are performed. The first procedure, recommended for most applications, performs the conditionality operation first.

As noted earlier, the straight line estimate of temporal conditional distribution at time intervals less than 24 hours tends to overestimate the persistence, i.e., produces a distribution too strongly diagonalized. A large part of this overestimate may be caused by the ignored diurnal change. The DITCON operation reduces the diagonalization in a fashion directly related to the degree of diurnal change, lending some confidence to its validity.

16.7 Scaling for Both Time and Distance

Certain simulation situations may require that a point or area on the earth be observed on a given orbit and a second nearby point be observed on a somewhat later orbit. For this situation, where the time difference between the first and the second observation is less than 36 hours and where the distance between the two observed points is less than 1482 km (800 n. mi.), the conditional probabilities must be scaled for both time and distance concurrently.

The following procedure has been established to accomplish this concurrent scaling for time and distance.

16.7.1 Procedure for Scaling for Time and Distance

1. Separately calculate CONDIS and CONTIM for the appropriate distance and time, respectively, from SCOND and TCOND. Perform DITCON diurnal operation on CONTIM if required.

2.

$$\text{TSCON}\ (a_i|b_j) = \sum_{k=1}^{5} \left[\text{CONDIS}\ (a_i|c_k) \cdot \text{CONTIM}\ (c_k|b_j)\right]$$

for a_i from 1 to 5 and b_j from 1 to 5.

3. If the conditionals have been modified for viewed area size, subsitute TSSCON, SCSCON, and SCTCON for TSCON, CONDIS, and CONTIM, respectively.

16.7.2 Example of Scaling for Time and Distance

An example of scaling for time and distance is presented in Table 16.7. At the top of the Table (labeled A) are data scaled according to the procedure demonstrated above. Here the scaling is for 24 hours and 370 km (200 n. mi.) for a sampling area size of 111 km (60 n. mi.). In part B of Table 16.7 the data are scaled for 20 hours, 296 km (160 n. mi.) and for a sampling area size of 111 km (60 n. mi.). In part C of Table 16.7 an example is shown where the time has been scaled to 20 hours. The distance to 296 km (160 n. mi.) and the* sampling area size has also been changed and enlarged to 278 km (150 n. mi.). These matrices can be compared with the unscaled data shown in Tables 16.3 for distance and Table 16.5 for time.

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* Procedures for enlarging the sampling area size are discussed in Section 16.8.

TABLE 16.7 EXAMPLE OF SCALING FOR TIME AND DISTANCE

A - Scaled for Time = 24 Hours, Distance = 370 km (200 n. mi.)
Sampling Area Size = 111 km (60 n. mi.)

0.46	0.07	0.09	0.16	0.22
0.35	0.09	0.10	0.17	0.29
0.27	0.09	0.11	0.23	0.30
0.28	0.08	0.11	0.24	0.29
0.28	0.07	0.11	0.20	0.34

B - Scaled for Time = 20 Hours, Distance = 296 km (160 n. mi.)
Sampling Area Size = 111 km (60 n. mi.)

0.53	0.07	0.07	0.14	0.19
0.31	0.14	0.09	0.16	0.30
0.23	0.11	0.14	0.25	0.27
0.25	0.08	0.10	0.31	0.26
0.24	0.06	0.10	0.19	0.41

C - Scaled for Time = 20 Hours, Distance = 296 km (160 n. mi.)
Sampling Area Size = 278 km (150 n. mi.)

0.15	0.09	0.20	0.24	0.32
0.11	0.10	0.18	0.28	0.33
0.09	0.10	0.17	0.27	0.37
0.07	0.08	0.17	0.29	0.39
0.06	0.08	0.17	0.24	0.45

16. 8 Enlarging the Sample Area Size

Earlier sections have referred to the change in cloud cover distribution resulting from change in the area size over which the cloud cover is defined. It has been pointed out that dramatic changes take place over the very range of sample areas that are to be used in earth-oriented experiments, and thus in simulation. It is required, therefore, that a reasonably effective method be found for generating suitable cloud cover distributions for enlarged sampling areas from already available information — the available cloud statistics. Collection of adequate samples of raw satellite data seems prohibitive, at least until suitable compilations of digitized data become available.

The general features of the change of cloud cover distribution with size of sample area can be readily visualized. The cloud cover over a point can have but two values — clear and overcast. The cloud cover over the entire earth seems to stay reasonably constant at perhaps 40 percent. Intermediate sized areas have cloud distributions which pass from the U shape of small areas to more bell-shaped distributions at rates which depend upon the prevalence of large-scale cloud systems. The temperate zones, in which large cloud systems are the rule, show characteristically U- or J-shaped distributions at the 111 km (60 n. mi.) scale size of the ground observer. Tropical regions may already exhibit bell-shaped distributions at this scale.

The effect of scale size on the distribution can be seen from the examples of Figure 16. 2, which are taken from limited samples of satellite data. A distribution originally bell-shaped at 1 degree area becomes more so at 3 degrees and 5 degrees, at the expense of the already rare clear areas; overcasts also become less probable. A J-shaped distribution tends toward a skewed bell-shape. A U-shaped distribution first becomes binodal, then bell-shaped with increase in sample area scale. In all cases, the probability of clear sky becomes quite small at a 5-degree (556-km) scale.

The effect of increasing the sample area size can be demonstrated by a simple computational exercise of doubling the sampling area.

The cloud distribution in the two areas can be expressed as the joint distribution of the two sets of events. The initial computation will assume independence between events in the two areas. Table 16. 8 outlines the computation of the joint distribution from synthetic data.

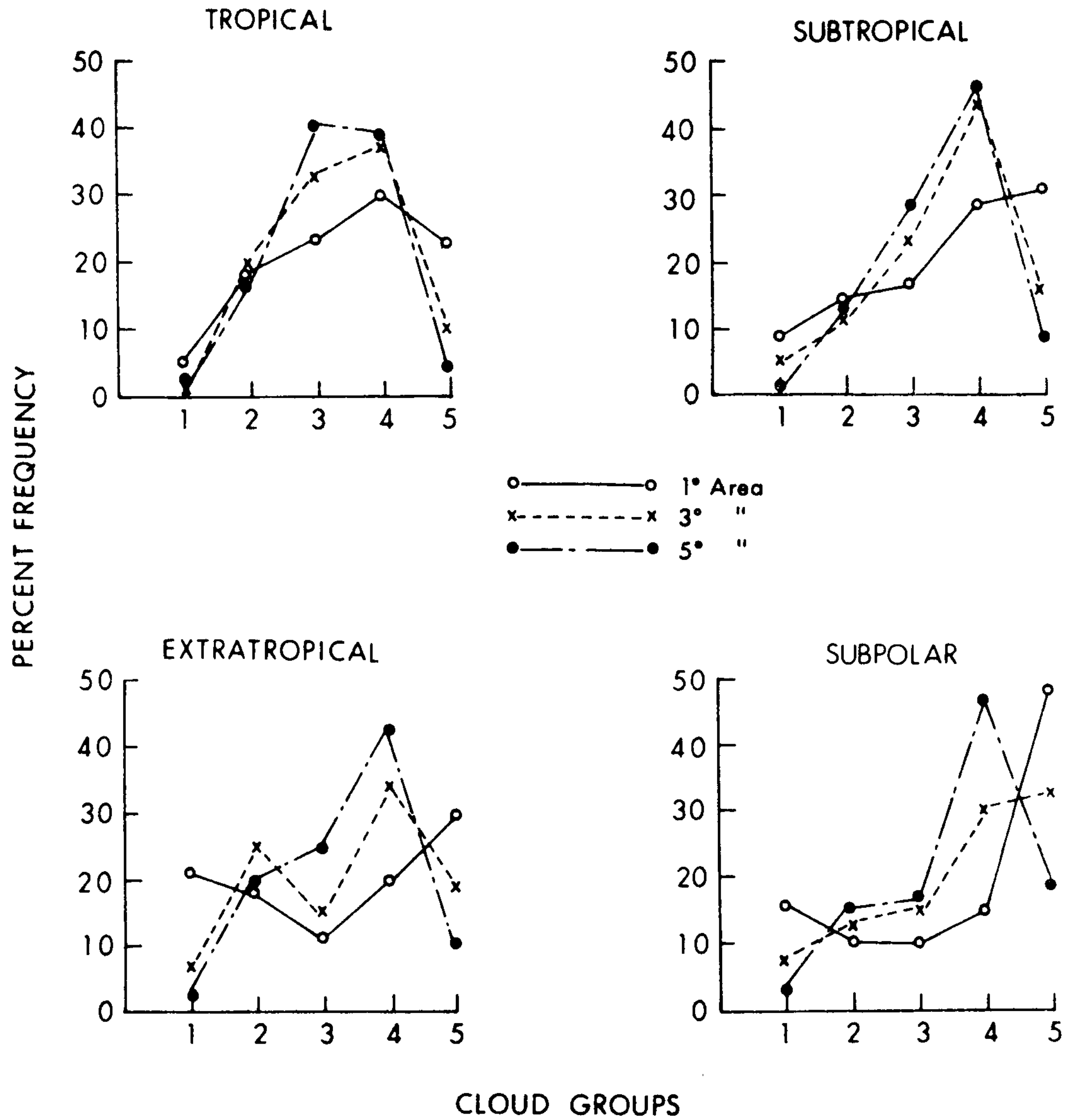

FIGURE 16.2 COMPARISON OF CLOUD COVER DISTRIBUTIONS AS SAMPLING AREA SIZE INCREASES

The joint distribution is defined by:

$$PJOINT\ (a, b) = UNCON\ (a) \cdot UNCON\ (b)$$

TABLE 16.8 COMPUTATION OF JOINT DISTRIBUTION, INDEPENDENT DATA

Cloud Group	UNCON	PJOINT				
		1	2	3	4	5
1	0.3	0.09	0.03	0.03	0.06	0.09
2	0.1	0.03	0.01	0.01	0.02	0.03
3	0.1	0.03	0.01	0.01	0.02	0.03
4	0.2	0.06	0.02	0.02	0.04	0.06
5	0.3	0.09	0.03	0.03	0.06	0.09

Each element of the PJOINT matrix corresponds to an average cloud cover over the doubled area. These cloud covers can be reclassified according to the original cloud cover grouping scheme (Table 16.1). Table 16.9 gives the cloud group assignment of each location in the PJOINT matrix. This location is universally useful in area size computations, and is called KWHERE.

To obtain the cloud cover group values at each location in the KWHERE matrix the cloud amounts of the joint events were averaged. For example, cloud cover 1 for the enlarged area can only result if both areas, used in the average, had cloud cover 1. For all of the upper left to lower right diagonal values in the KWHERE matrix (Table 16.9), the averaged cloud covers remain the same; i.e., cloud cover 2, averaged with 2, results in cloud cover 2, 3 given 3 in 3, etc. The non-diagonal values are derived by averaging the mean cloud amounts from each group; i.e., group 3 with a mean of 3.5 tenths and group 1 with 0 tenths averages to 1.75 tenths. Translated back to cloud groups, this is group 2. Thus, cloud group 2 is shown in the KWHERE matrix at 3 given 1 and 1 given 3; similarly, for all other non-diagonal values.

Conversion of PJOINT to the unconditional distribution scaled for the doubled area size, SUNCON, is achieved by the operation of adding together all elements of PJOINT having the same entry in the matching location of KWHERE. The result, shown in Table 16.10, is rather startling. The previously U-shaped UNCON has become the strongly peaked SUNCON.

TABLE 16.9 CLOUD GROUP LOCATION MATRIX

Cloud Group	KWHERE 1	2	3	4	5
1	1	2	2	3	3
2	2	2	2	3	3
3	2	2	3	4	4
4	3	3	4	4	4
5	3	3	4	4	5

TABLE 16.10 CLOUD COVER DISTRIBUTION FOR DOUBLED AREA, INDEPENDENT EVENTS

Cloud Group	UNCON	SUNCON
1	0.3	0.09
2	0.1	0.15
3	0.1	0.41
4	0.2	0.26
5	0.3	0.09

This extreme change in cloud cover distribution with a relatively small change in area size results from the untenable assumption of independence between cloud events in contiguous areas. Let us repeat the computation, now using a synthetic set of conditional probabilities to describe the dependence of events in the second area on those in the first. Table 16.11 outlines the computation.

$$\text{PJOINT}(a,b) = \text{UNCON}(b) \cdot \text{CONNEW}(a \mid b)$$

is the general case, CONNEW is the spatial conditional distribution appropriately scaled to the distance between centers of the areas.

TABLE 16.11 COMPUTATION OF CLOUD COVER DISTRIBUTION FOR DOUBLED AREA, DEPENDENT EVENTS

Cloud Group	UNCON	CONDIS					PJOINT					SUNCON
		1	2	3	4	5	1	2	3	4	5	
1	0.3	0.5	0.3	0.1	0.1	0	0.15	0.09	0.03	0.03	0	0.15
2	0.1	0.1	0.5	0.2	0.1	0.1	0.01	0.05	0.02	0.02	0.01	0.23
3	0.1	0.1	0.2	0.5	0.1	0.1	0.01	0.02	0.05	0.01	0.01	0.17
4	0.2	0.1	0.1	0.2	0.5	0.1	0.02	0.02	0.04	0.10	0.02	0.30
5	0.3	0	0.1	0.1	0.3	0.5	0	0.03	0.03	0.09	0.15	0.15

Even though CONDIS is only moderately diagonalized, the resulting SUNCON distribution more closely resembles its parent UNCON distribution. Figure 16.3 compares the SUNCON distributions (P_{2A}) with UNCON (P_{1A}).

Let us now consider the more general case of viewed area size several times the area on which the statistical distributions are based.

16.8.1 An Approach to Scaling for Enlarged Sample Area Size

The information at our disposal for the task of enlarging the sampling area size is the unconditional distribution, valid for a sampling area of ≈93 km (50 n. mi.) diameter, and the spatial conditional distribution, defined for areas about 111 km (60 n. mi.) diameter with centers separated by about 370 km (200 n. mi.). A straight line interpolation or extrapolation has been adopted to find conditional distributions at other distances. No information is available to define the conditional dependence of cloud events within an area on more than one of its neighbors.

Let us initially investigate some properties of a straight chain of 129 to 155 km^2 (50 to 60 mi^2) areas, corresponding to a diameter of a larger circle. Let each member of the chain be dependent only on the first member. The straight line approximation to the scaling of the spatial conditional distribution then gives rise to individual PJOINT distributions, the elements of which are linear interpolations between the unit diagonal PJOINT of the first member of the chain, and PJOINT of the last. It can be seen that the distribution of the total cloud cover in this chain can be described by PJOINT of the last element, internally summed as before by reference to the KWHERE locator matrix.

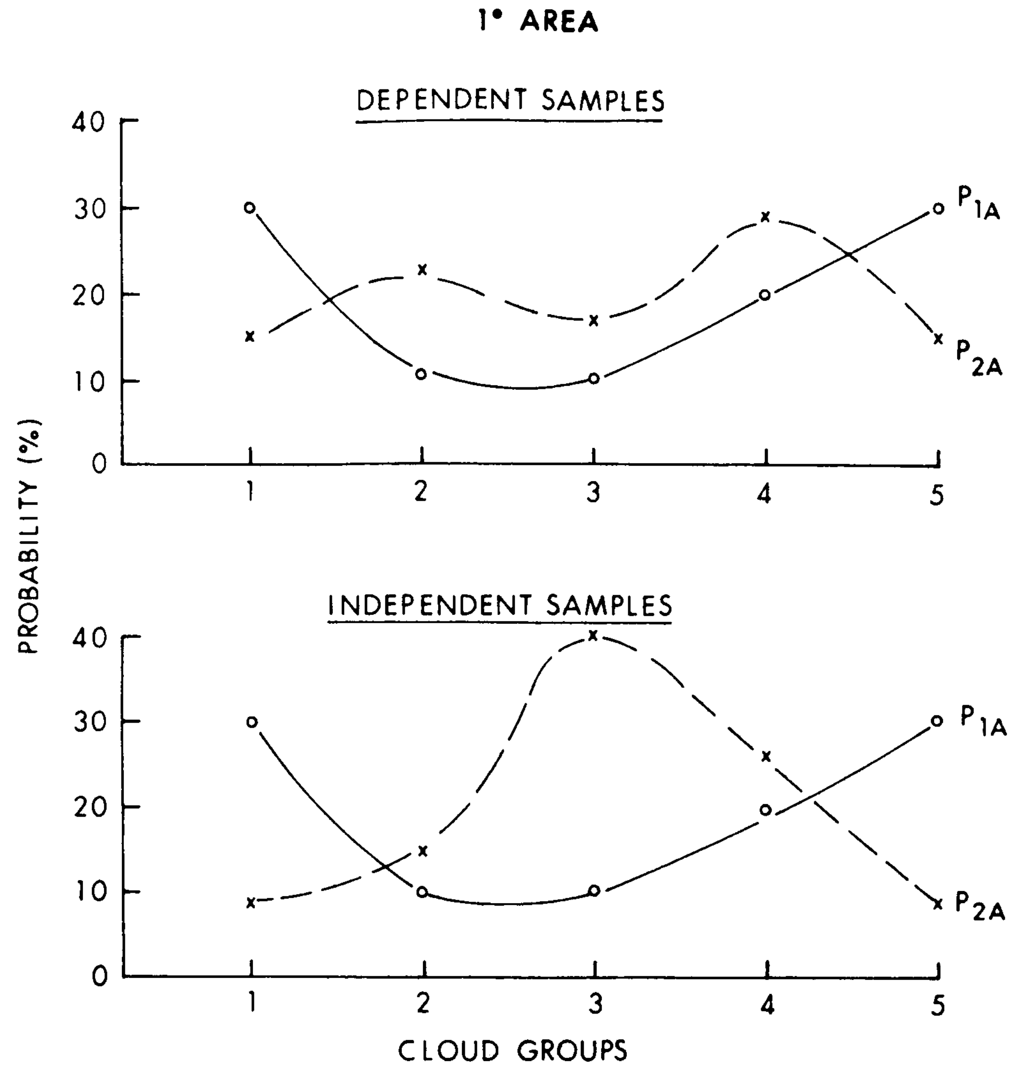

FIGURE 16.3 CHANGE IN SHAPE OF CLOUD COVER AS SAMPLING AREA SIZE DOUBLES

Lacking data for two-way conditionality, we have taken the distribution of cloud cover in the diametric strip as the distribution for the entire circle. Pragmatic success of this procedure has led us to seek the properties of cloud cover that contribute to its success. Cloud systems are usually of larger scale than even the enlarged sampling areas. The cloud cover, rather than being randomly distributed in the sampling area, simply appears as a gradient across the area. This then reduces the calculation of the cloud distribution over the entire area to a one-dimensional linear problem, similar to the procedure we have adopted. We have reasonable verification of the success of the procedure, as outlined in later paragraphs.

16.8.2 Procedure for Computation of Unconditional Distribution Scaled for Sample Area Size

We recapitulate the procedure for finding SUNCON.

1. Tabulate the unconditional and conditional distributions for the required regions, month and time of day.

2. Scale the conditional statistics, using the procedures detailed in Paragraph 16.4 to a distance which corresponds to the diameter of the required enlarged viewed area.

3. The unconditional distribution UNCON is multiplied into the conditional distribution matrix CONNEW.

4. The resultant joint distribution matrix is PJOINT summed using the KWHERE matrix for reference.

5. A new unconditional distribution, SUNCON, applicable to the enlarged viewed area size results.

16.8.3 Computational Procedure for Enlarging the Area Size for Conditional Distributions

The procedure for enlarging sampling area size for conditional distributions is similar to, but more involved than, the procedure for the unconditional distributions.

Referring to Figure 16.4, we are given unconditional distributions for the area represented by "a" and conditional statistics for an area "c" some distance Δ from area "a." What we wish to compute is the conditional probability distribution for new enlarged area B given the unconditional probabilities for new enlarged area A (both areas have been enlarged to the new diameter α). Thus what is required is to first expand area "a" to area A using the techniques described in paragraph 16.8.2. Then, to obtain the new 5 by 5 conditional probability matrix for area B, given A we define:

$P(A,B)$ = joint probability of cloud cover in A and B

16.24
The computational algorithm for accomplishing this multiplication of probabilities is to perform the multiplications indicated in Figure 16.4 where a schematic form for the matrices has been used. In this Figure the designators have the same meaning as defined in Paragraph 16.3, CONNEW is the expanded sampling area space conditionals (SCOND), etc. The joint probability of events in all four areas is:

$$P(abcd) = P(a) \cdot P(b|a) \cdot P(d|b) \cdot P(c|d)$$

where the order of conditionality is somewhat arbitrary.

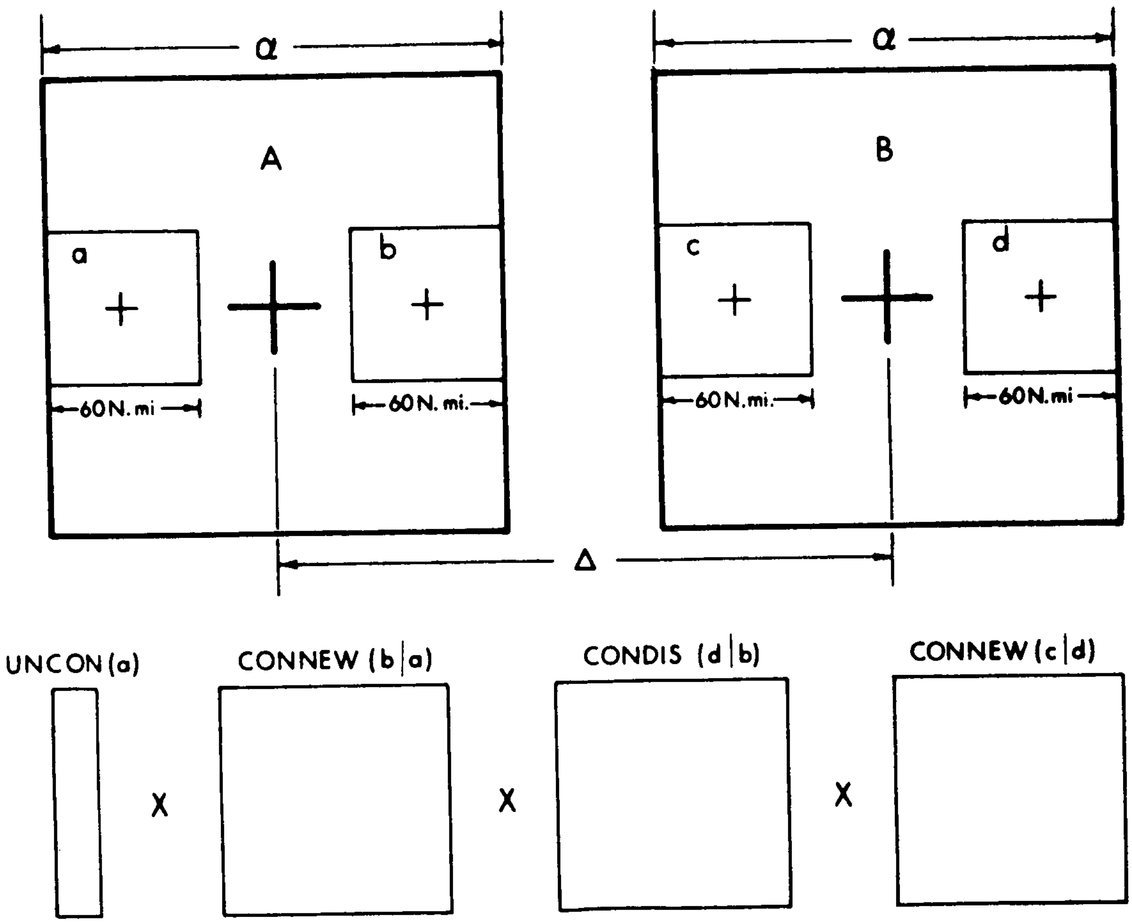

FIGURE 16.4 SCHEME FOR COMPUTATION OF SPATIAL CONDITIONAL DISTRIBUTION OF ENLARGED SAMPLE AREAS

We define the cloud cover in area A to be the average of the cloud cover in a and b while the cloud cover in B is the average cloud cover in c and d. Thus, we can write formally:

$$P(A, B) = P(\overline{ab}, \overline{cd})$$

To find $P(\overline{ab}, \overline{cd})$, the KWHERE locator matrix is used 4-dimensionally. This involves assigning values to $\overline{ab}$ from the a and b locations in the 4-dimensional PJNT matrix, and to $\overline{cd}$ from the c and d locations. The result is the two-dimensional joint probability table P(A, B). This is transformed to the conditional probability by division by the marginal total.

$$P(B|A) = \frac{P(A, B)}{\sum_{B} P(A, B)}$$

The process of finding temporal conditional distributions of enlarged sample areas is identical, with the exception that CONTIM is substituted for CONDIS. CONNEW (c|d) should be computed for the local time of event B, and the DITCON operation (Paragraph 16.6) should be performed in finding CONTIM.

16.8.4 Examples of Conditional Distributions for 333 km (180 n. mi.) Sampling Areas

No suitable data are immediately available for validation of the procedure for computing conditional distributions of enlarged areas, so reliance must be placed on examination of sample calculations for reasonableness.

Examples of conditional and unconditional distributions scaled for time and distance were presented in Paragraphs 16.4 and 16.5. Here we present examples of conditional distributions scaled for larger sampling area size.

Table 16.12 presents unconditional and conditional statistics for a sampling area size of 111 km (60 n. mi.) extracted directly from the tabulated data for Region 19. This data is for 1300 local time for the month of January. Table 16.13 presents the distributions resulting from application of the techniques described in Paragraphs 16.8.2 and 16.8.3 above for an enlarged sampling area of 333 km (180 n. mi.). Note the differences in the two conditional matrices, particularly those values which lie on the diagonal. As might be expected, the middle cloud group, 3, becomes a more probable joint event.

TABLE 16.12 UNCONDITIONAL AND CONDITIONAL DISTRIBUTIONS FOR A 111 km (60 n. mi.) SAMPLING AREA SIZE AT 370 km (200 n. mi.) SEPARATION

Cloud Group	UNCON (60)	SCOND 1	2	3	4	5
1	0.15	0.76	0.05	0.05	0.05	0.09
2	0.12	0.17	0.17	0.08	0.08	0.50
3	0.04	0.13	0.12	0.15	0.30	0.30
4	0.17	0.14	0.09	0.14	0.45	0.18
5	0.52	0.13	0.06	0.12	0.16	0.53

TABLE 16.13 UNCONDITIONAL AND CONDITIONAL DISTRIBUTIONS FOR A 333 km (180n. mi.) SAMPLING AREA SIZE AT 333 km (180 n. mi.) SEPARATION

Cloud Group	SUNCON (180)	SCSCON 1	2	3	4	5
1	0.12	0.34	0.10	0.30	0.13	0.13
2	0.08	0.14	0.12	0.24	0.29	0.21
3	0.21	0.09	0.09	0.21	0.31	0.30
4	0.29	0.03	0.05	0.16	0.44	0.32
5	0.30	0.03	0.07	0.20	0.20	0.50

The SUNCON distribution, found as a by-product, (one of the marginal totals $\sum_A P(A, B)$), has some interesting properties. The probability of clear skies is little changed. The probability of partial cloud almost vanishes in SUNCON, while the slight probability of cloud group 3 in UNCON is replaced with a fairly high probability in SUNCON. Most noteworthy is the drop in the probability of overcast, matched by a distinctly lowered conditional 5|5 in SCSCON. None of these features violate our sense of what may be expected, and thus the new distributions may be accepted as providing more information than no knowledge at all, even if they have not been demonstrated to be "correct."

Some comment is required on the use of these derived distributions in simulation. Each conditional distribution derived for our enlarged sample area represents a 3-step Markhov chain. Two of the steps are formally removed by the averaging process involved, but the variance of elements within the distribution is still at least 3/2 the variance of the elements of the conditional distributions from which it was derived. In the extreme case, if the variance of the distribution entering the computations becomes large, all states of the joint probability matrix become equally probable and the distributions are defined only by the averaging process. Table 16.14 presents the "noise" distribution. The conditional distribution will show no conditionality; thus all rows will be identical to the unconditional. None of the computations we have performed have shown any tendency to revert to this distribution, except for those tropical regions where the parent distribution is already of this form.

TABLE 16.14 DISTRIBUTION RESULTING FROM AVERAGING OF EQUIPROBABLE JOINT EVENTS

Cloud Category	Probability
1	0.04
2	0.28
3	0.36
4	0.28
5	0.04

16.9 Engineering and Simulation Applications

The set of data, techniques, and procedures that have been assembled are intended for a variety of applications in the study and simulation of earth oriented experiments from low orbit. We will list, in no particular order, a number of such applications by category. In most cases the mode of application depends upon the details of the specific problem.

16.9.1 Design of Experiments

Viewed Area Size. Trade-off of entrance aperture of field of view against speed of response and problem of sorting good from cloud-contaminated data. Particularly important for radiometric instruments.

Control Systems. Selection of experiment control system and mode of deployment based on benefit/cost studies over cloudy skies.

Data Volumes. Where film is the medium, it is important to estimate the number of exposures over partly cloudy skies required for mission success. Paragraph 16.9.6 explores this further. The same class of problem may occur with on-board telemetry storage of less capacity than the maximum data-taking rate can use.

Probability of Success. An experiment may be cloud sensitive and require a reasonably coherent chain of observations to achieve a reasonable level of success. An example is infrared observation of apparent diurnal surface temperature changes to estimate the condition of ground cover. Simulation or computation of probability distributions may be desired to ascertain whether the experiment is worth consideration.

Alternate Techniques. The cloud data may be used to evaluate alternate instrumentation for the same general observational purpose. The control system design is one feature of this.

Cost/Benefit. Earth resource satellite system costs and benefits cannot be properly evaluated in the absence of cloud information. While the sophistication of the techniques presented in this report exceeds that of usual techniques for estimating benefits, cloud information at some level is essential.

Orbit Analysis. Each experiment has an orbit inclination, height, precession rate, and time and season of injection into orbit that will give optimum results. It does not follow that an orbit optimized for the experiment without reference to cloud interference will also be the optimum orbit in the presence of cloud. By defining a suitable measure of experiment success, it should be possible, by trial and error if necessary, to find a good, if not optimum, orbit for the experiment over the real cloudy world.

16.9.2 Mission Integration and Design

Mission integration involves assembly of a number of experiments, the spacecraft, its power, control, communication, and, for manned missions, the life support system and the astronauts into a total mission-oriented system. A large number of trade-offs are required. For example, the various candidate experiments may well have divergent requirements for orbit, spacecraft attitude control, etc. From this large set of compromises, a workable physical design must emerge. In addition to the design of the physical system, such features as astronaut skills, the orbit, time in orbit, and time, azimuth, and season of injection must be determined. The object of the integration design activity is to maximize probable mission return as defined by some composite measure of mission success. Constraints of physical realization, economic limits, astronaut safety, range safety, available boosters, etc., limit the degree of freedom.

A major tool for manned mission optimization is a form of mission simulation computer program which can adjust the free parameters of the mission to establish either the most feasible mission, or to select the optimum mission design in the realm of feasibility. To date, these programs have not considered the earth's cloud cover except in the most elementary way. Most unclassified, earth-oriented satellite systems to date have been meteorologically oriented and have not required optimization with respect to the behavior of the earth's cloud cover. Future earth resources systems, manned or unmanned, will doubtlessly require such treatment before the mission can be fully defined.

The mission integration programs generally use various deterministic techniques to arrive at the optimum solutions. The introduction of the earth's cover, which creates a contingency at each possible observation event, requires techniques which have yet to be fully explored. However, data now available from the activity reported here can be used in unsophisticated form to improve the realism of simulation for integration.

16.9.3 Mission Simulation

Given the space system defined by the integration activity, a computer mission simulation can be performed. While this function may be included in the package of integration programs, it can be separately considered. A number of applications can be found for mission simulation programs that embody cloud data in a realistic fashion.

Time Lines. Mission integration will have made up a set of time lines, or rules for finding time lines, of all the various functions on the spacecraft. The time lines are important in establishing control sequences, data acquisition and dump profiles, power profiles, etc. For manned systems they also must involve astronaut sleep-work cycles, skill mixes, etc.

In earth-oriented missions where the attempt at observation by some sensors is contingent on suitable cloud cover or a forecast of cloud cover, time lines become stochastic processes operating within certain constraints. This in turn partially randomizes mission parameters dependent upon the time lines of individual experiments. We are not aware of any attempt to deal with this situation, which can now be effectively simulated through use of cloud data.

Since the concept of only partially constrained random time lines is likely to be abhorrent to the system design engineers as well as to mission controllers, an alternate approach is to seek fixed time lines that maximize the probability of mission success (measured in some suitable way) in the cloudy world. Again, we are not aware of any procedures that go materially beyond a simple assumption of 50 percent success in the performance of an observation.

Probability of Mission Success. The observation mission has a set of *a priori* objectives; the degree of success in meeting these objectives can either be measured quantitatively or be described by a simple success-failure characterization. Having defined the mission, it is of interest to estimate the probability distribution of some measure or measures of success.

Paragraph 16. 9. 6 presents an abridged "simulation" of a photographic mission, in which an estimate is made of the probability that at least p percent of a target area can be photographed in n passes. This also will give the frequency distribution of the number of blind exposures required to give probability P of covering at least p percent of the target area. A slight extension of the example would give the frequency distribution of the number of exposures and the mission length required to give probability P of covering at least p percent of the area if exposure is inhibited when the cloud cover exceeds a value C. This could be traded off against blind photography to ascertain whether the additional complexity of controlled photography is worthwhile.

Mission Performance Analysis. Mission simulation gives the simulator the opportunity to trace the events of the mission, and based on this information, to perform certain adjustments to the mission that are outside the province of the mission integration program. Various statistics can be amassed which will help to better define the characteristics of the mission before flight. Here again, realistic inclusion of cloud cover information will result in a more realistic analysis of the performance of earth-oriented missions.

16.9.4 Experiment Scheduling

The scheduling of experiments both before launch and in real time can be expedited by reference to cloud statistics which can give an assessment of the performance expectation and variance resulting from that schedule. This is similar to time lining, but here refers strictly to the experiments.

16.9.5 Dynamic Programming

During flight, a mission assessment program should keep track of the present status and fractional achievement of the mission to date. It is then possible to simulate future events, based on certain priorities and scheduling rules, out to the end of the mission. The priorities and scheduling rules may be optimized to maximimize mission performance, and the new rules would then be adopted. The accumulated effect of contingencies, both of weather and of the mission, may require further revision of these priorities and rules at a later time. This process, which we feel is essential to expensive missions such as the eventual Apollo Applications system, we call dynamic programming.

19.9.6 A Typical Simulation Problem

Let us suppose we are designing a photographic mission for mapping or for agricultural surveillance. A prime target area of size 556 by 556 km (300 by 300 n. mi.) is contained within one cloud region. The proposed orbit provides coverage of the area with favorable illumination every 3 days. (We make this stipulation to avoid the use of temporal conditional statistics.) If the area is fairly cloudy, we are willing to piece together our map from cloud-free segments of the photographic coverage, although we would, of course, prefer to find the entire area cloudless and complete our mission on a single pass. The questions that may be asked are:

1. How many passes are required to give a probability of 95 percent (or some other level) of at least one clear pass over the area?

2. If the number of passes required to reasonably assure one clear pass is excessive, what is the amount of pieced-together coverage expected in N passes?

3. How many passes are required to give a 90 percent (or some other level) probability that at least 90 percent (or some other fraction) of the area can be photographed?

All of these questions can be answered from a probability distribution of piecewise coverage (which includes total coverage) as a function of the number of passes. To arrive at this distribution, we make the dubious assumption that the clouds in the area are always completely randomly scattered over the whole area, so that the incremental photographic coverage of each pass is:

$$P(i) = (1 - B)(1 - C)$$

where B is the already photographed fraction of the area, and C is the cloud cover encountered on the pass. By induction, the fraction of the area photographed is:

$$B(N) = 1 - \prod^{N} C_n$$

where C_n is the cloud cover encountered on pass number n and N is the total number of passes.

The unconditional cloud distribution for the 556 km (300 n. mi.) square area should be generated from the basic unconditional and spatial conditional data. For ease of computation, we have assumed a distribution which might be typical of a 556 km (300 n. mi.) square area in the southeastern U. S. in summer or spring, at noon, as shown in Table 16.15.

TABLE 16.15 AN ASSUMED DISTRIBUTION

Group	Mean Cloud Cover	Probability
1	0	0.1
2	0.25	0.2
3	0.55	0.3
4	0.75	0.2
5	1.00	0.2

A direct approach to the problem is through elementary combinatory analysis. First, it should be noted that if cloud group 1 occurs at least once in a sequence of N passes, the photographic coverage is 100 percent. Accordingly, the probability of 100 percent coverage is:

$$P_{100\%} = 1 - [1 - P(1)]^N$$

where P(1) is the probability of occurrence of clear sky over the whole area. From this the answer to question 1 for the assumed distribution is that 28 passes must be programmed to provide 95 percent probability of encountering clear skies. Under the postulated conditions, this will take nearly 3 months.

The remaining four cloud groups can occur in any combination, and under our assumption will always give less than 100 percent coverage. The number of combinations, N at a time, of the four cloud groups (see, for example, page 59 of Niven (1965)) is:

$$C(4 + N - 1, N) = \frac{(N+3)!}{3!N!}$$

Table 16.16 shows the number of such combinations.

TABLE 16.16 COMBINATIONS OF FOUR THINGS WITH REPLACEMENT

N	1	2	3	4	5	6	7	8	9	10
C	4	10	20	35	56	84	120	165	220	286

By a systematic listing it is possible to generate all possible combinations.

The various combinations are not equiprobable. The number of ways each combination can occur is:

$$W = \frac{N!}{a!b!c!d!}$$

where a, b, c, d are the number of times cloud groups 2, 3, 4, and 5 occur in the combination. The probability of the event represented by any combination is then W times the joint probability of the individual events of each pass, or

$$W \prod^{N} P(C_n)$$

where $P(C_n)$ is the probability of the cloud group represented by the n^{th} element of the combination.

The next step is to generate cumulative probabilities. Since we are interested in the probability of obtaining at least a certain degree of photographic coverage, we start from a base of the probability in N passes of 100 percent photo coverage, adding the probabilities of combinations with successively smaller area coverage.

Figure 16.5 shows the results of such computations. The curves for N = 2, 3, and 4 were generated by the process described. The curves for N = 5, 6, and 10 are rather gross extrapolations from those curves, using a process similar to that used (properly) for finding the probability of N cloud-free passes. For convenience of display, the curves are plotted on "probability paper." The fact that they are nearly straight shows that the probability distribution of areas photographed in N passes is nearly Gaussian in the range of interest.

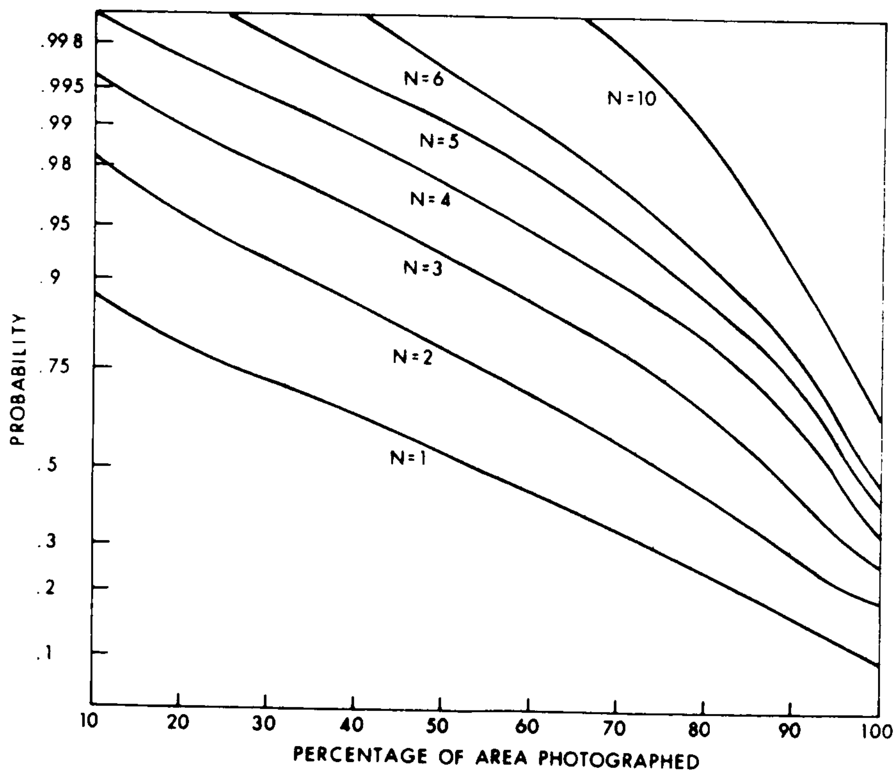

FIGURE 16.5 PROBABILITY OF PHOTOGRAPHING A GIVEN PERCENTAGE OF A TARGET AREA

To the extent that the distributions are Gaussian, the most probable photo coverage can be estimated from the 50 percent level (ignoring the probability spike at 100 percent coverage). Table 16.17 shows the estimate of most probable coverage.

TABLE 16.17 MOST PROBABLE PHOTOGRAPHIC COVERAGE

No. of Passes	1	2	3	4	5	6	7 or more
Coverage, %	55	75	88	94	97	99	100

Exact computation by the combinatory procedures outlined here is feasible on a larger computer up to N = 10 or 12. However, before that point, it is probably more expedient to resort to Monte Carlo procedures.

Use of Monte Carlo permits easy injection of a rather important effect which we have neglected in the combinatorial approach. The assumption was made that partial cloud cover is always sufficiently dissected to make valid an analytic description of the incremental photo coverage of each pass. In truth, the incremental photo coverage has a probability distribution which can be estimated from a consideration of the ways in which the cloud cover might be distributed over the area. One obvious result of a distribution of incremental photo coverage is the appearance of a finite probability of achieving 100 percent photo coverage even though no single pass was clear.

It may be seen, then, that neglect of the distribution of partial cloud cover has resulted in a pessimistic estimate of the probability of total coverage.

A Monte Carlo procedure would facilitate the introduction of temporal conditional probabilities, as would be required if the interval between cases of suitable orbit position and illumination is 24 hours or less. The combinatorial approach also permits use of conditional probabilities, but since the order in which a combination of cloud covers occurs now affects the probability of occurrence, the computation becomes considerably more voluminous.

It may be of interest to explore the development of our first Monte Carlo approach to this problem. The ground rules remain the same, but we removed the restriction on time interval and inserted a provision for a random distribution of incremental photo coverage.

The first order of business was to compute area-scaled tables of unconditional and of temporal conditional cloud cover by the procedures outlined in Paragraphs 16.4, 16.5, 16.7, and 16.8. For sun-synchronous orbits, the temporal conditional table was computed for 24 hours. Orbits of lesser inclination will require several tables of differing intervals. If at all possible, it is desirable to operate from pre-computed tables to avoid additional computer load. All tables are organized as cumulative probabilities in ascending order of cloud cover.

Figure 16.6 is a gross block diagram of the program. Iteration number Q and pass number n are initialized. The first draw is made from the unconditional table by finding which cloud group probability interval contains the random number RAN. If the cloud group is number 1 (clear), 100 percent photo coverage has occurred; there is no need for further photography, and 100 percent is noted in the tabulation for each number of passes.

If the cloud group is other than number 1, a photo coverage is assigned. The pass over the area is initiated. The new cloud cover is now generated from the line in the conditional probability table corresponding to the previous cloud cover. If cloud group 1 occurs, 100 percent cumulative coverage is tabulated for the pass and all subsequent passes. If not, the coverage achieved is tabulated under pass number n. The process is repeated for the N passes of interest. Then the whole process is repeated NOQ times. In similar simulations, we have found NOQ of 100 to 300 give excellent convergence with very short computer times required.

The incremental photo coverage is computed as a stochastic function of existing coverage and the cloud group as follows:

$\Delta B_n = (1 - B_{n-1})(1 - C_n)$ where ΔB_n is the increment of area photographed on pass n. C_n is the cloud cover encountered on pass n.

The amount of area photographed after n passes is

$$B_n = B_{n-1} + (1 - B_{n-1})(1 - C_n) \quad .$$

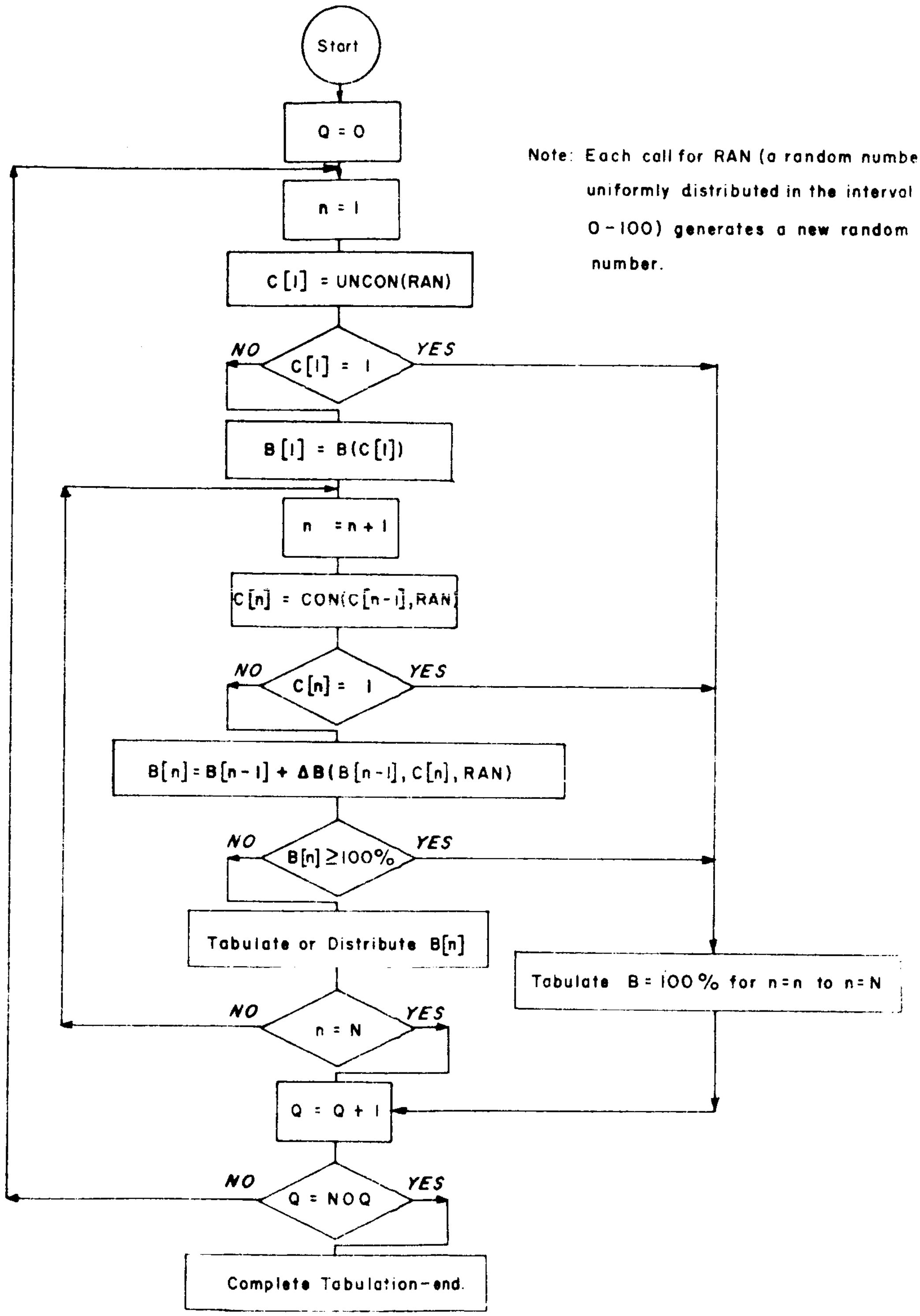

FIGURE 16.6 BLOCK DIAGRAM OF A POSSIBLE MONTE CARLO PROGRAM TO GENERATE PROBABILITY DISTRIBUTION OF PHOTOGRAPHIC COVERAGE

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SECTION XVII. WORLDWIDE SURFACE EXTREMES

BY

Glenn E. Daniels

17.1 Introduction

In the original issue of the "Natural Environment Guidelines" document (Ref. 17.1, 1961), information was needed to fabricate, transport, test, and launch Marshall Space Flight Center space vehicles in limited geographical areas only. It became evident with the development of advanced programs such as the Apollo project that statistical meteorological data are needed from other areas as well. Thus, in a later revision, a section called "Distribution of Surface Extremes in the United States" was included. In the present revision, this brief section on worldwide surface extremes has been prepared. This section will also illustrate the much larger extreme values that occur in some areas and will compare them with those currently used in space vehicle design.

17.2 Sources of Data

A great amount of meteorological data have been collected throughout the world. Various agencies have collected such data in a form that can be used for statistical studies. Kendrew's "Climates of the Continents" (Ref. 17.2) is an excellent summary of mean values of the meteorological parameters, temperature, pressure, and precipitation, and it is also the source of many interesting discussions of local meteorological conditions around the world.

"World Weather Records, 1941-50" (Ref. 17.3), compiled by the Weather Bureau (now part of the Environmental Sciences Services Administration), provides another excellent summary of mean values of meteorological data.

Recently, in revising AR 705-15 (now AR 70-38, Ref. 17.4), the Earth Sciences Laboratory NLABS, U. S. Army Natick Laboratories at Natick, Massachusetts, has collected worldwide data on meteorological extremes. For the revised AR 70-38, the Earth Sciences Laboratory NLABS prepared world maps that show worldwide absolute maximum and absolute minimum temperatures.* These maps are reproduced in this section as

* Absolute is defined as the highest and lowest values of data of record.

Figures 17.1 and 17.2, and due credit is given to the Earth Sciences Laboratory NLABS, U. S. Army Natick Laboratories.

The several climatic atlases for various areas of the world provide other sources of data; those of interest will be referred to in the following sections.

17.3 Worldwide Extremes Over Continents

To present all the geographic extremes properly, many large maps similar to Figures 17.1 and 17.2 would be required; therefore, only worldwide extremes of each parameter will be discussed, and available references on each parameter will be given. Individual geographic extremes will be mentioned when pertinent.

17.3.1 Temperature.

Absolute maximum and absolute minimum world temperature extremes are shown in Figures 17.1 and 17.2. Some geographical extreme air temperatures of record are given in Table 17.1

TABLE 17.1 EXTREME AIR TEMPERATURES OF RECORD

Location	Air Temperatures of Record
Salah, Africa	118°F, mean daily max. for 45 days
	127°F, absolute max.
Azizia, Africa	136°F, absolute max.
Sind, India	123°F, absolute max.
Basra, Iraq	123°F, absolute max.
	78°F, mean daily min. in Aug.
Death Valley, Calif.	134°F, absolute max.
Stuart, Australia	131°F, absolute max.
Verkhoyansk, U.S.S.R.	-94°F, absolute min.
Rogers Pass, Montana	-70°F, absolute min. for U.S.
Snag, Yukon Territory, Canada	-85°F, absolute min. for North America

Temperatures of the ground are normally hotter than the air temperatures during the daytime. In the Sahara Desert of Africa, temperatures of sand as high as 172°F have been measured. At Stuart, Australia, the sand has reached temperatures so hot that matches dropped into it burst into flame.

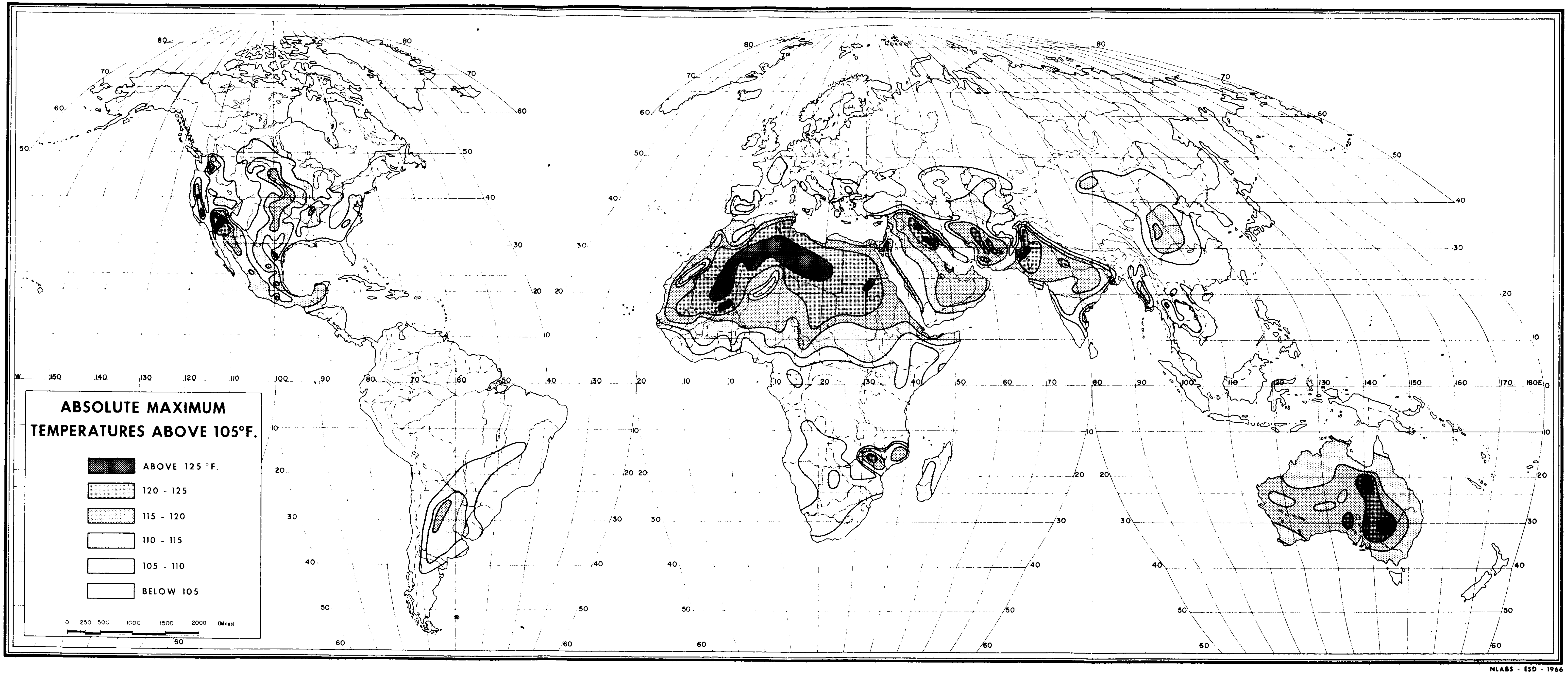

FIGURE 17.1 WORLDWIDE GEOGRAPHIC ABSOLUTE MAXIMUM TEMPERATURES ABOVE 105°F

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

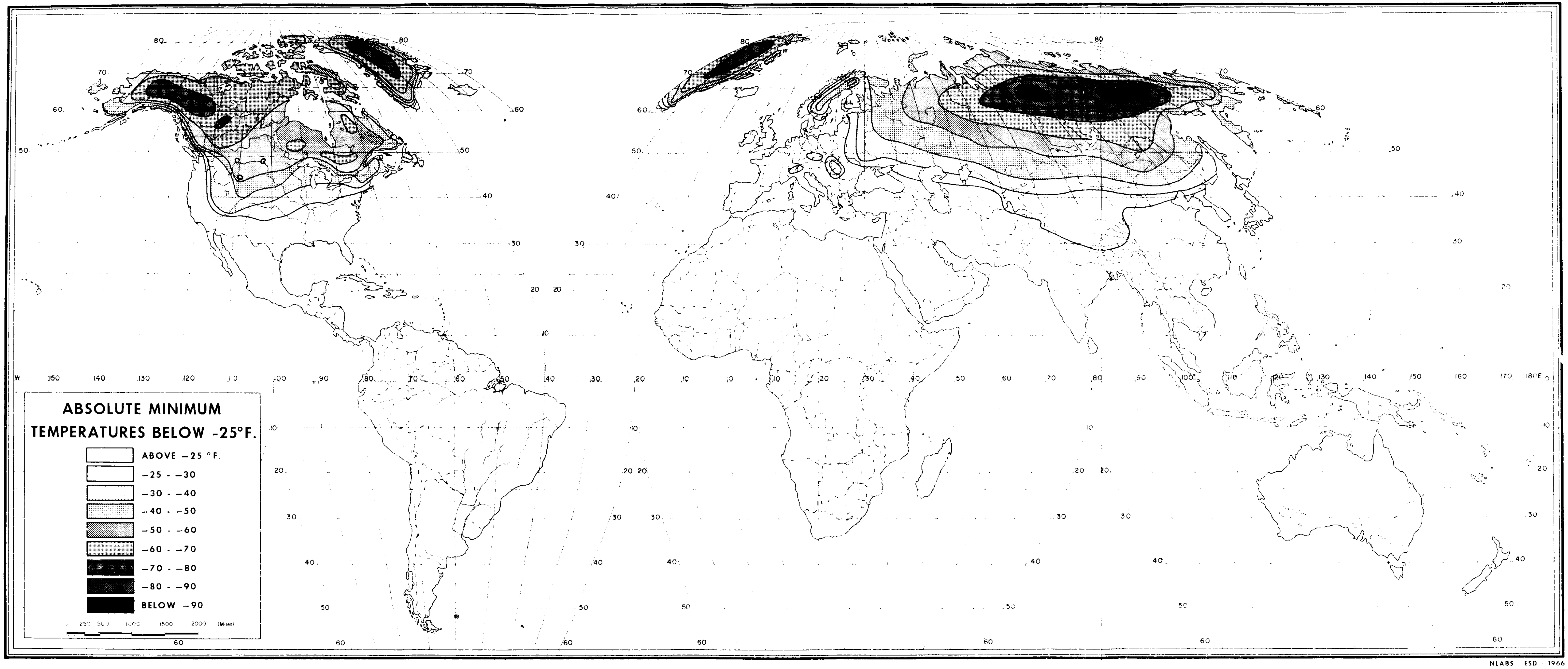

FIGURE 17.2 WORLDWIDE GEOGRAPHIC ABSOLUTE MINIMUM TEMPERATURES BELOW -25°F

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

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In design of equipment for worldwide operations, MIL-STD-210A now uses extreme temperature values of 125°F for a hot temperature and -80°F for a cold temperature. Values outside these limits have been observed. In a study by the Air Force Cambridge Research Laboratories* , June 9, 1969, for Special Assistant for Environmental Service of the Joint Chiefs of Staff, to lower the risk of exposing equipment of MIL-STD-210A, it was recommended that values of 131°F and -87°F would be more realistic for the hot and cold temperatures.

The above recommendation for hot temperature was based upon risk tables, shown in Table 17.2, of extreme high temperatures developed by extreme value theory using 39 extreme annual temperatures at Death Valley, California. Such temperatures persist for one or two hours during a day.

TABLE 17.2 EXTREME HIGH TEMPERATURES WITH RELATION TO RISK AND DESIRED LIFETIME

Risk (%)	Temperatures (°F) Planned Lifetime (years)				
	1	2	5	10	25
1	131	133	134	135	137
10	127	128	130	131	133
25	125	127	128	129	131
50	124	125	127	128	130

The recommendation for cold temperature was based upon risk tables, shown in Table 17.3, of extreme low temperatures, developed by extreme

TABLE 17.3 EXTREME LOW TEMPERATURES WITH RELATION TO RISK AND DESIRED LIFETIME[a]

Risk (%)	Temperature (°F) Planned Lifetime (years)				
	1	2	5	10	25
1	-87	-91	-97	-101	-106
10	-74	-78	-83	- 87	- 92
25	-68	-72	-77	- 81	- 86
50	-63	-67	-73	- 76	- 81

a. Temperatures in Antartica were not considered in the study.

* Norman Sissenwine: "Temperature Extremes Applicable to MIL-STD-210 Area and Risk Considerations." AFCRL, a paper transmitted by a letter dated June 16, 1969, to Chief, Aerospace Environment Division, MSFC.

value theory using 23 annual extreme low temperatures at Snag, Yukon Territory, Canada. The extreme low temperatures will persist for longer periods since they occur during polar darkness.

17.3.2 Dew Point.

High dew points are associated with high temperatures near large bodies of water. Besides being detrimental to equipment, high dew points make living conditions very uncomfortable. Extremely high dew points occur in the following areas, in the vicinity of the water bodies specified:

a. The northern portion of the Arabian Sea in April and May, to 85°F dew point.

b. The Red Sea in July, to 89°F dew point.

c. The Caribbean Sea (includes the western end of Cuba and the Yucatan Penninsula, Mexico) in July, to 81°F dew point.

d. The northern portion of the Gulf of California, to 86°F dew point (data from Puerto Penasco, Mexico, Ref. 17.6).

The Air Force has published the "Atmospheric Humidity Atlas for the Northern Hemisphere" (Ref. 17.5), which shows maps for various percentile levels of dew point for midseason months (January, April, July, and October).

A new report on worldwide humidity is now being published by the U. S. Army Natick Laboratories (Ref. 17.6).

17.3.3 Precipitation.

The worldwide distribution of precipitation is extremely variable; some areas do not receive rain for years, while others receive torrential rain many months of the year. Precipitation is also seasonal; for example, Cherrapunji, India, with its world record total of 905 inches of precipitation in a year, has a mean monthly precipitation of less than one inch in December and January. The heaviest precipitation for long periods (greater than 12 hours) usually occurs in the monsoon type of weather. High rates of rainfall for short periods (less than 12 hours) usually occur in the thunderstorm type of rain and over much smaller areas than the monsoon rain. Some world records for various periods of rainfall are given in Table 17.4 (Ref. 17.2 and 17.7).

TABLE 17.4 WORLD RAINFALL RECORDS

Station	Time Period	Amount (in.)
Unionville, Maryland	1 min	1.23
Plum Point, Jamaica	15 min	8.0
Holt, Missouri	41 min	12.0
D'Hanis, Texas	3 hr	20.0
Baguio, Philippine Islands	1 day	50.0
Cherrapunji, India	30 days	360.0
Cherrapunji, India	1 yr	905.0

Even though the values given in Table 17.4 are considerably higher than the values given in Table 4.2 of Section IV, values in Table 4.2 are considered adequate for most space vehicle design problems within currently expected operational areas.

17.3.4 Pressure.

Surface atmospheric pressure extremes for use in design must be derived from the measured station pressures, not from the computed sea level pressures that are usually published.

Station pressures between stations have great variability because of the difference in altitude of the stations. The lowest station pressures occur at the highest altitudes. The highest station pressures occur at either the lowest elevation stations (below sea level), or in the arctic regions in cold air masses at or near sea level.

Court (Ref. 17.7) has an interesting discussion on worldwide pressure extremes. Some typical high and low pressure values are given in Table 17.5 (Ref. 17.2 and 17.7).

17.3.5 Ground Wind.

Worldwide extreme surface winds have occurred in several types of meteorological conditions: tornadoes, hurricanes or typhoons, mistral winds, and Santa Ana winds. In design, each type of wind needs special consideration. For example, the probability of tornado winds is very low compared with the probability of mistral winds, which may persist for days (see Section 5.2.10).

TABLE 17.5. TYPICAL PRESSURE VALUES OF SELECTED AREAS

Station	Elevation Above Sea Level (ft)	Pressure (mb)	
		Lowest	Highest
Lhasa, Tibet	12 090	645[a]	652[a]
Sedom, Israel	-1 275	—	1081.8
Portland, Maine	61	—	1056
Qutdligssat, Greenland	10	—	1063.4
In a typhoon 400 Miles East of Luzon, Philippine Islands[b]	~0	887	—

a Monthly means.
b Lowest sea level pressure of record.

17.3.5.1 Tornadoes

Tornadoes are rapidly revolving circulations normally associated with a cold front squall line or with warm, humid, unsettled weather; they usually occur in conjunction with a severe thunderstorm. Although a tornado is extremely destructive, the average tornado path is only about a quarter of a mile wide and seldom more than 16 miles long, but there have been a few instances in which tornadoes have caused heavy destruction along paths more than a mile wide and 300 miles long. The probability of any one point being in a tornado path is very small; therefore, design of structures to withstand tornadoes is usually not considered except for special situations where tornado shelters are built underground. Velocities have been estimated to exceed 134 ms^{-1} (260 knots) in tornadoes.

17.3.5.2 Hurricanes (Typhoons).

Hurricanes (also called typhoons, Willy-willies, tropical cyclones, and many other local names) are large tropical storms of considerable intensity. They originate in tropical regions between the equator and 25 degrees latitude. A hurricane may be 1600 kilometers (1000 miles) in diameter with winds in excess of 67 ms^{-1} (130 knots). A tropical storm is defined as a hurricane when winds are equal to or greater than 33 ms^{-1} (64 knots). The winds are frequently associated with heavy rain. Since the hurricanes of the West Indies are as intense as others throughout the world, design winds based upon these hurricanes would be representative for any geographical area. Section 5.2.10 gives hurricane design winds for the area of Cape Kennedy, Florida. Although the highest winds recorded in a hurricane in the area of Cape Kennedy, Florida, were lower than winds from thunderstorms in the same area, the probability still exists that much higher winds could result from hurricanes in the vicinity of Cape Kennedy.

For extremes applicable to equipment, the following Table 17.6 from a study of 39 years of wind data for Taipei, Taiwan (in the Pacific typhoon belt)*, for a height of 10 feet above the natural grade, is representative of all hurricane areas of the world.

TABLE 17.6 EXTREME WINDS IN HURRICANE (typhoon) AREAS WITH RELATION TO RISK AND DESIRED LIFETIME
(3.1-m reference height)

Risk (%)	Extreme Wind Speeds (ms^{-1}) Planned Lifetime (years)				
	1	2	5	10	25
1	38	41	46	49	54
5	30	33	38	41	46
10	26	29	34	38	42
25	21	24	29	33	37
50	16	20	25	28	33

17.3.5.3 Mistral Winds (Ref. 17.2).

The mistral wind is a strong polar current between a large anticyclone and a low pressure center. These winds frequently have temperatures below freezing. The mistral of the Gulf of Lions and the Rhone Valley, France, is the best known of these winds. Although winds of 37 ms^{-1} (83 mph) have been recorded in the area of Marseilles, France, much higher winds have occurred to the west of Marseilles in the more open terrain, where even railway trains have been blown over. Mistrals blow in the Rhone Valley for about 100 days a year. The force of the mistral wind is intensified by its coldness, and the associated greater air density.

* Norman Sissenwine: "Surface Wind Extremes Applicable to MIL-STD-210 Area and Risk Considerations." AFCRL, a paper transmitted by a letter dated June 16, 1969, to Chief, Aerospace Environment Division, MSFC.

17.3.5.4 Santa Ana Winds.

In contrast to the mistrals, the Santa Ana Winds, which occur in Southern California west of the coast range of mountains, are hot and dry and have speeds up to 41 knots. Similar winds, called Föhn winds, occur in the Swiss Alps and in the Andes, but, because of the local topography, they have lower speeds. The destructiveness of these winds it not from their speeds, but from their high temperatures and dryness, which can do considerable damage to blooming tree and vine crops and exposed equipment and instruments whose seals and paint are critical.

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WORLDWIDE EXTREMES

APPROVAL

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TERRESTRIAL ENVIRONMENT (CLIMATIC) CRITERIA GUIDELINES FOR USE IN SPACE VEHICLE DEVELOPMENT, 1969 REVISION

By Glenn E. Daniels, Editor

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

William W. Vaughan

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