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C-734

NASA
SPACE VEHICLE
DESIGN CRITERIA
(ENVIRONMENT)

NASA SP-8021

MODELS OF EARTH'S ATMOSPHERE (120 to 1000 km)

MAY 1969

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

NASA experience has indicated a need for uniform criteria for the design of space vehicles. Accordingly, criteria are being developed in the following areas of technology:

Environment
Structures
Guidance and Control
Chemical Propulsion

Individual components of this work will be issued as separate monographs as soon as they are completed. A list of monographs in this series issued prior to this one can be found on the last page of this monograph.

These monographs are to be regarded as guides and not as NASA requirements, except as may be specified in formal project specifications. It is expected, however, that the criteria sections of these documents, revised as experience may indicate to be desirable, eventually will become uniform design requirements for NASA space vehicles.

This monograph was prepared by the Marshall Space Flight Center under the cognizance of the Goddard Space Flight Center. The principal authors were D. K. Weidner, C. L. Hasseltine*, and R. E. Smith of the Marshall Space Flight Center. S. A. Mills of Goddard Space Flight Center was the Program Coordinator. The comments of scientists and engineers participating in the review cycle were helpful and appreciated.

Comments concerning the technical contents of these monographs will be welcomed by the National Aeronautics and Space Administration, Office of Advanced Research and Technology (Code RVA), Washington, D. C. 20546.

February 1969

*Deceased

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MODELS OF EARTH'S ATMOSPHERE (120 to 1000 km)

1. INTRODUCTION

Atmospheric conditions encountered by a spacecraft in orbit about the Earth are important factors in space vehicle design, mission planning, and mission operations. Density is the primary atmospheric property that affects the spacecraft's orbital altitude, lifetime, and motion in the altitude range of 120 to 1000 km. Near the lower limit of this range where density is greatest, a spacecraft will generally remain in orbit for a very short time; near the upper limit, the density effect on orbital lifetime is almost negligible. Density directly affects the torques which result from aerodynamic interaction between the space vehicle and the atmosphere; such torques must be considered in design of spacecraft attitude control systems. Density scale height is required in heating calculations for space vehicles re-entering the Earth's upper atmosphere. Density as well as chemical composition and temperature are needed in calculating a spacecraft's drag coefficient. Chemical composition and temperature also are required in the design of experiment sensors to be flown in this altitude range.

Because of variability of atmospheric conditions with spatial location and solar condition, invariant models of the Earth's atmosphere (120 to 1000 km) would not be useful for most engineering applications. Therefore, this monograph presents a computerized version of Jacchia's prediction method to provide models of the Earth's atmosphere which vary with solar condition and location. The resulting atmospheric models, which are predicted for particular times and locations, provide atmospheric density, chemical composition, temperature, molecular mass, and density scale height between 120 and 1000 km altitude.

In addition to the computerized method, a quick-look prediction method is given that may be used to obtain an estimate of atmospheric density for any time and spatial location without the use of a computer. A sample problem illustrates this method.

Both methods provide models of mean density and models having reasonable upper extremes for density.

The analytical approaches in both methods are considered to be the best available, but they could be refined considerably by additional data and study.

Information contained in this monograph applies to altitudes between 120 and 1000 km; other design criteria monographs in this series will provide atmospheric information below this altitude region.

2. STATE OF THE ART

Most of the density values for the atmosphere between 120 and 1000 km have been derived from the analysis of changes in the periods of orbiting satellites. These data have been used to establish numerous computer programs that may be used to predict atmospheric density. Temperature and chemical composition may be inferred from the drag determined densities under the assumption of static diffusion. Since mass density, temperature, and chemical composition at these altitudes vary with solar and geomagnetic activity, the level of such activity must be taken into account to estimate these parameters for a given time.

2.1 Variations in Atmospheric Parameters

2.1.1 Chemical Composition

In the Earth's homosphere, extending from the surface to an altitude of near 90 to 100 km, the atmospheric gases mix thoroughly so the constituent gas distribution (chemical composition) does not vary. However, above 90 km and primarily near 105 km, extreme ultraviolet (EUV) solar radiation causes molecular oxygen to dissociate. The resulting atomic oxygen then is transported up and down, changing constituent distribution. Accordingly, the chemical composition above the 90 to 100 km altitude level is a function of the variable amounts of EUV radiation received from the Sun.

2.1.2 Temperature

The temperature lapse rate is influenced by solar radiation. In the lower thermosphere (100 to 300 km), solar radiation in the extreme ultraviolet band (40 to 1000 angstroms) is absorbed and causes the temperature to increase steadily with altitude. Above 300 km, where little or no solar radiation is absorbed, the temperature increases very little with altitude and becomes isothermal as shown in Figure 1. The isothermal temperature which is designated as the "exospheric temperature," varies diurnally, seasonally, and with solar and geomagnetic activity from about 650° to 2100° K.

2.1.3 Density

Variation in density has been found to be related closely to the amount of extreme ultraviolet radiation (EUV) received from the Sun. Although EUV cannot be measured at the Earth's surface, early investigators assumed that there was correlation between EUV and radiation at about 10 cm wavelength which can be measured at the Earth's surface. Data from the first Orbiting Solar Observatory (OSO-1) confirmed this assumption, showing close correlation between EUV and radiation at 10.7 cm (ref. 1). Therefore, the mean daily solar flux at 10.7 cm which is measured by the National Research Council, Ottawa, Canada, has been accepted as an indicator of the amount of EUV radiation that reaches the atmosphere.

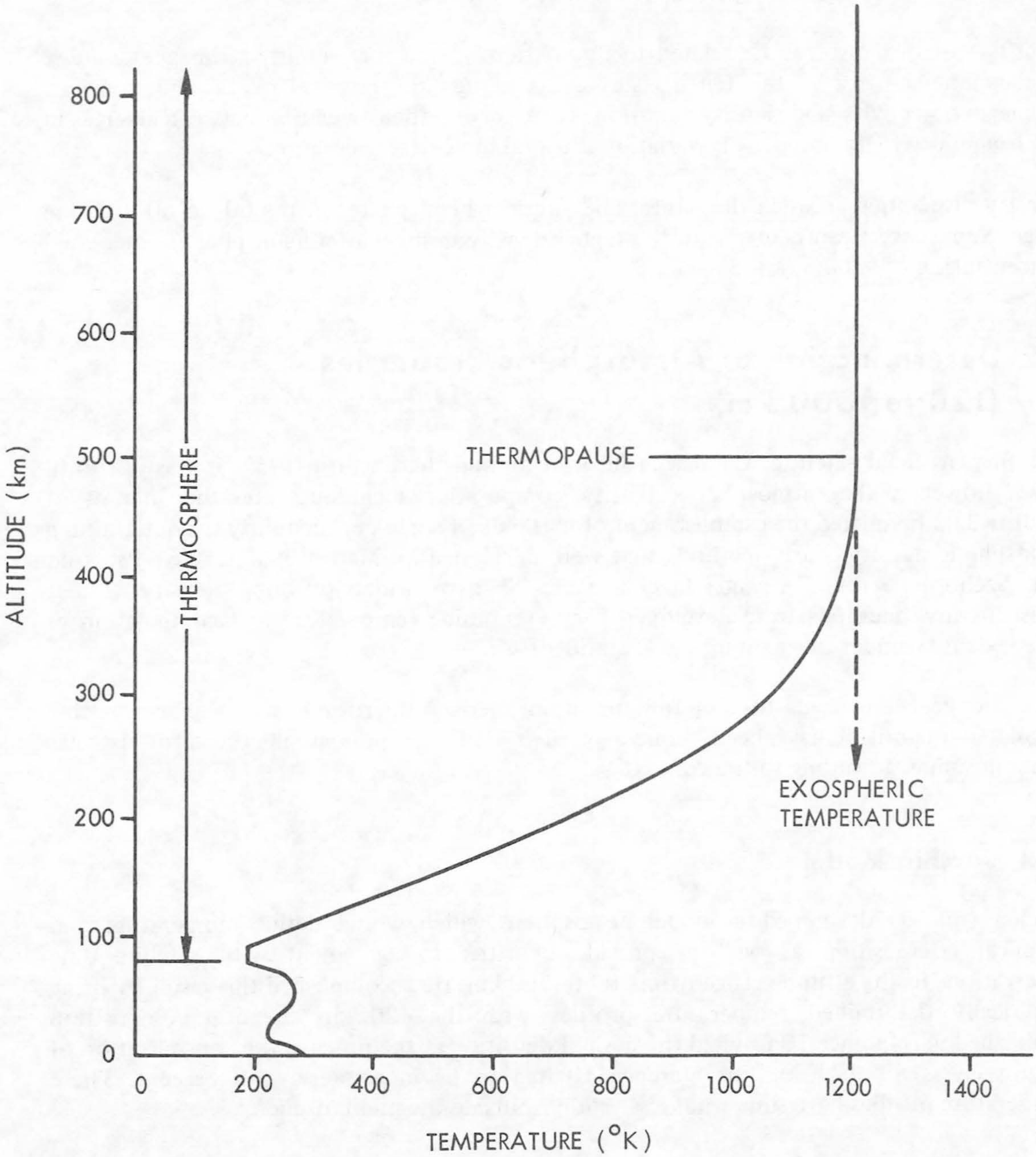

Figure 1. — Typical Plot of Temperature vs Altitude and Exospheric Temperature

The principal periodic variability found in the solar flux at 10.7 cm occurs as a cycle of 27 days, corresponding to the 27-day solar rotation. The same periodicity is reflected in atmospheric density. Density can also be correlated closely with the semi-annual effect, the diurnal effect, and the trend in the 11-year solar cycle as indicated by the 10.7 cm flux averages of successive 81-day periods (refs. 2, 3, 4, and 5).

Density variation also can be related to fluctuations in the three-hourly geomagnetic index of magnetic activity at the Earth's surface. Although the physical relationship between geomagnetic activity and density variation is not known, the correlation between changes in geomagnetic activity and density variation is useful in density prediction.

Density also varies between the winter and summer hemispheres in the 60° to 80° latitude range. Some investigators attribute the higher density in the winter hemisphere to increased concentration of helium (ref. 5).

2.2 Determination of Atmospheric Properties (120 to 1000 km)

The first artificial satellite was placed in orbit around the Earth in 1957. It was not until 1961, however, that atmospheric density computation techniques and the amount of satellite data permitted the establishment of methods of some dependability for determining atmospheric density. Early methods that were developed by Martin et al. (ref. 6), Paetzold and Szchorner (ref. 7), and Jacchia (ref. 8) gave widely-differing density values. Subsequently, methods were developed for determining temperature and composition as well as density under the assumption of static diffusion.

Over the years, methods for determining atmospheric properties as well as the resulting calculated quantities have been termed "models". In this monograph, the term also has either meaning, according to the context.

2.2.1 Jacchia Model

Jacchia (ref. 9) developed a model atmosphere which would define temperature and chemical composition as well as provide densities in agreement with satellite drag observations in the altitude range from 200 to 760 km. He accomplished this result by using empirically determined temperature profiles with the 120 km chemical composition established in reference 10 to yield the desired densities; in the process, the concentration of helium given for 120 km in reference 10 had to be increased by 40 percent. These temperature profiles have somewhat less validity outside the mid-latitudes.

2.2.2. Harris and Priester Model (CIRA 1965)

In another study Harris and Priester (ref. 4) calculated time-dependent profiles of the atmospheric temperature by integrating the heat conduction equation and obtained mass densities by assuming hydrostatic equilibrium and using the chemical composition and temperature at 120 km established by COSPAR Working Group IV (ref. 10). They found, however, that a "second heat source" was needed to make their calculated densities match the satellite drag-determined density data. The satellite drag-determined density data used by Harris and Priester did not range below 200 km altitude. Their model has been taken as the COSPAR International Reference Atmosphere, CIRA 1965 (ref. 10).

The CIRA 1965 density values tend to be high, particularly for molecular nitrogen; and temperature values are also high.

2.2.3 Limitations of the Jacchia Model and CIRA 1965

Jacchia's model with its revised helium concentration and Harris and Priester's model with its "second heat source" are only two of several temperature-chemical composition combinations which might be associated with satellite drag-determined densities. Results of thermosphere rocket experiments (refs. 11, 12, 13, 14, and 15) indicate temperature and chemical composition to be between those given by the Jacchia Model and CIRA 1965.

Atmospheric densities obtained by the Jacchia Model and CIRA 1965 are more representative of atmospheric variations above 250 km than below. This lower altitude limitation results from the assumption in both models that atmospheric temperature and composition are constant at 120 km. (In actuality, both temperature and composition are highly variable at 120 km.)

As mentioned, both models have limitations as to temperature, chemical composition, and density; in addition, CIRA 1965 does not provide for variation in atmospheric parameters with latitude. The Jacchia Model, on the other hand, is representative at any latitude because it contains the density bulge that migrates in latitude with the subsolar point with a lag of about two hours.

The Jacchia Model may be used to obtain atmospheric parameters for any point in time and space and for any predicted solar condition. If CIRA 1965 is used, however, these parameters must be obtained by interpolation between tables given in reference 10 for specific solar flux levels and each two hours of local time.

2.2.4 1967 Modification of Jacchia's Model Atmosphere

A static diffusion model, which is basically a computerized version of Jacchia's model (refs. 16, 5, and 9) was developed at the NASA Marshall Space Flight Center (MSFC) in 1967 and

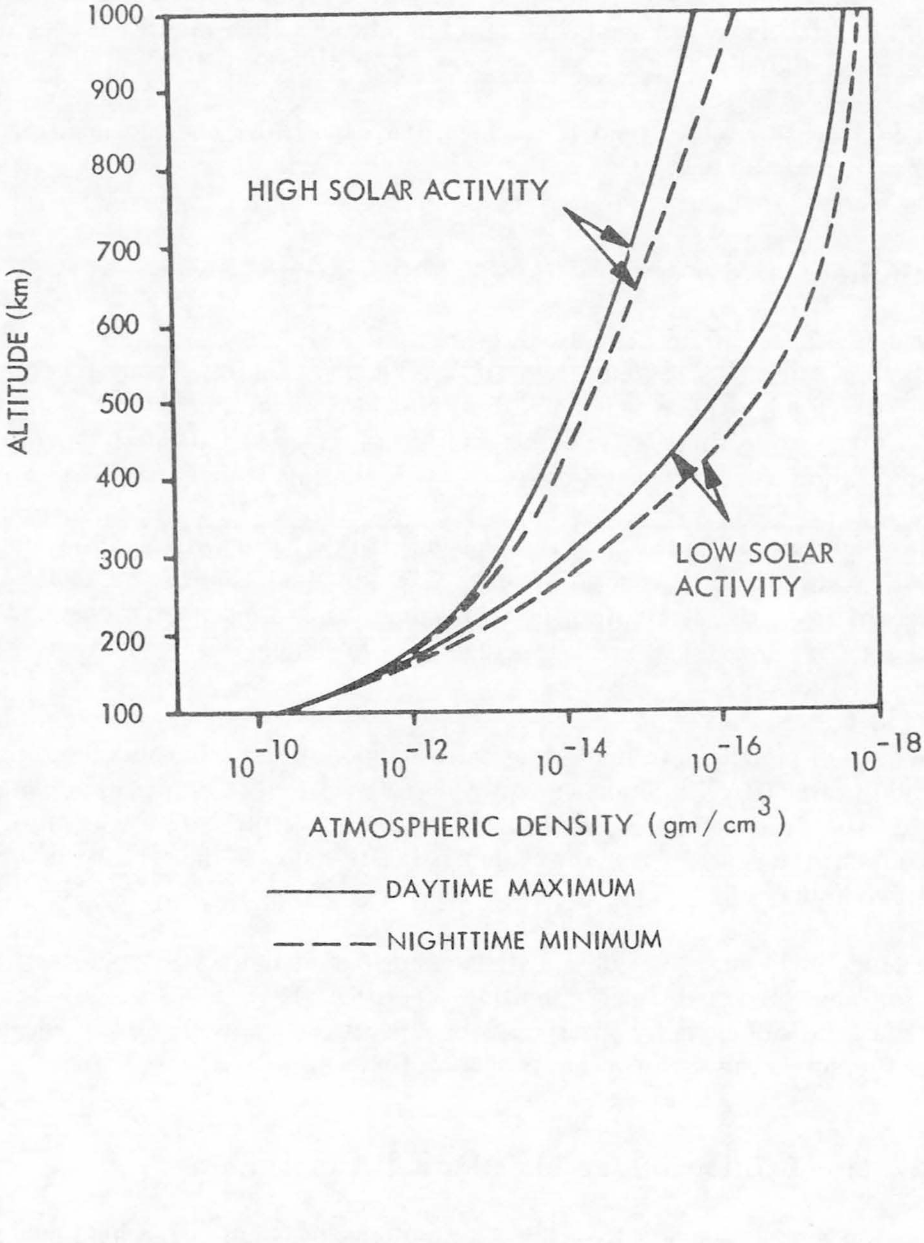

Figure 2. —Typical Daytime Maximum and Nighttime Minimum Atmospheric Density Profiles for High and Low Solar Activity

has been adopted for this monograph. This model can describe the atmosphere from 120 to 1000 km altitude for any time and spatial location.

MSFC used the Jacchia Model as a basis for its model in preference to CIRA 1965 for reasons given in section 2.2.3, but the diffusion equation given by Walker (ref. 17) was used instead of Jacchia's numerical approximation to eliminate the need for table-look-up. A complete description of the computational procedure is given in appendix A. Figure 2 shows four atmospheric density profiles that were calculated by this procedure. These profiles represent typical daytime maximum and nighttime minimum densities for two extremes of solar activity. The density profiles agree very closely with the densities derived from the analyses of satellite orbital decay data above 200 km. Below 200 km, limitations imposed by the assumption of invariant density, temperature, and chemical composition at 120 km cause the density variability to be slightly less than that of the real atmosphere. This is of little significance to most orbital engineering and mission planning applications, however, because of the short time that a spacecraft remains in orbit below 200 km. Recent studies concerning the limitations of currently-used models are given in references 11, 18, and 19.

2.2.5 1967 Quick-Look Density Model

The computerized version of the 1967 Modification of Jacchia's Model discussed in section 2.2.4 gives temperature, chemical composition, and density at orbital altitudes. However, some engineering purposes such as preliminary mission planning, require only an estimate of the expected atmospheric density at the planned orbital altitude. To provide such an estimate, the 1967 Quick-Look Density Model was developed at MSFC and has been adopted for this monograph. The computation procedure given in appendix B for the Quick-Look Model is very similar to that given in reference 20.

The Quick-Look Model is designed to provide an estimate of atmospheric density only. Other atmospheric parameters, however, may be interpolated from the tables given in reference 16, using the exospheric temperature that is calculated from the Quick-Look Model.

3. CRITERIA

Predicted models of the Earth's atmosphere from 120 to 1000 km for use in space vehicle design and mission planning should be obtained in accordance with section 3.1 or 3.2.

Section 3.1 should be used for predictions of density and associated atmospheric parameters, and section 3.2 should be used when a quick estimate of atmospheric density is needed.

Both methods (secs. 3.1 and 3.2) can be used to obtain either mean density models or models having reasonable upper density extremes. Mean density values are obtained if nominal values for predicted solar and geomagnetic activity are used for inputs; upper density values result from using plus 2 σ values for predicted solar and geomagnetic activity. Table I gives sample predicted solar and geomagnetic data.

The upper density model obtained from the plus 2 σ values, however, does not account for short term surges in geomagnetic activity, which are usually of 6 to 12 hours duration. When experiments or subsystems are considered to be sensitive to such short term effects, a geomagnetic index of 400 should be used with the predicted plus 2 σ solar flux values to obtain an upper density model associated with extreme geomagnetic conditions.

3.1 Method for Predicting Earth Atmospheric Parameters (120 to 1000 km)

The 1967 Modification of Jacchia's Model is the method which should be used to predict atmospheric density, temperature, chemical composition, molecular mass, and density scale height for any time and spatial location. Symbols, inputs, and calculation procedures are given in appendix A.

3.2 Method for Predicting Density of Earth's Atmosphere (120 to 1000 km)

The Quick-Look Model Atmosphere (1967) is a method that can be used to obtain an estimate of atmospheric density for any time and spatial location. Although the Quick-Look Model was developed to give density only, other atmospheric parameters may be interpolated from the tables given in reference 16 by using the exospheric temperature that is calculated by the Quick-Look Model.

The computation procedure of the Quick-Look Model is based upon the physical relationships given in appendix A, but all equations have been replaced by tables to eliminate the need for a computer. If interpolations are made with a three decimal accuracy, the density obtained from the Quick-Look method will be within 2 percent of that obtained by appendix A.

Symbols, inputs, and calculation procedures and a sample problem are given in appendix B.

TABLE I

AN EXAMPLE OF NOMINAL AND 2 σ PREDICTIONS OF SUNSPOT NUMBERS, MEAN 10.7 SOLAR FLUX, AND GEOMAGNETIC INDEX*

(Calculation by MSFC Solar Prediction Program in August 1968)

Calendar Year	Sunspots		Mean 10.7 cm flux		Geomagnetic index	
	Nominal	+2	Nominal	+2	Nominal	+2
1968.25	107.30	119.34	153.76	165.40	13	23
1968.50	107.49	130.37	153.96	176.07	13	23
1968.75	107.74	140.40	154.18	185.77	13	23
1969.00	104.78	143.12	151.33	188.40	13	23
1969.25	103.31	147.75	149.90	192.88	13	23
1969.50	102.57	146.09	149.18	191.27	8	23
1969.75	77.64	106.36	125.07	152.85	8	23
1970.00	94.67	139.76	141.55	185.15	8	23
1970.25	90.56	128.30	137.57	174.06	8	23
1970.50	82.42	116.91	129.70	163.05	8	23
1970.75	77.64	106.36	125.07	152.85	8	23
1971.00	70.60	94.61	118.27	141.49	8	23
1971.25	62.48	85.36	111.55	132.54	8	23
1971.50	57.16	80.54	107.15	127.89	8	17
1971.75	51.17	75.38	102.21	122.39	8	17
1972.00	46.04	72.23	97.98	119.84	8	17
1972.25	42.73	70.77	95.25	118.43	8	17
1972.50	38.23	64.62	91.54	113.31	8	17
1972.75	34.02	63.08	88.07	112.04	8	17
1973.00	31.43	61.69	85.93	110.00	8	17
1973.25	27.77	57.58	84.66	107.50	8	17
1973.50	24.91	53.80	82.95	104.39	8	17
1973.75	22.37	50.18	81.42	101.40	8	17
1974.00	18.78	44.82	79.72	96.98	6	17
1974.25	16.19	41.14	77.71	93.94	6	17
1974.50	14.70	33.74	76.82	91.96	6	17
1974.75	12.31	33.04	75.39	87.26	6	17
1975.00	10.94	28.22	74.56	84.93	6	17
1975.25	10.80	24.65	74.49	82.79	6	17
1975.50	10.36	21.66	74.22	81.00	6	17
1975.75	11.76	26.13	75.06	83.68	6	17
1976.00	13.96	33.64	76.38	87.75	6	17
1976.25	17.38	44.03	78.43	96.33	6	17
1976.50	23.24	62.04	81.95	111.18	8	17
1976.75	30.81	83.81	85.42	131.05	8	23
1977.00	39.26	105.91	92.39	152.41	8	23
1977.25	48.44	123.83	99.97	169.74	8	23
1977.50	55.66	135.55	105.92	181.08	8	23
1977.75	63.86	149.23	112.68	194.30	8	23
1978.00	73.32	165.80	120.90	210.33	8	23
1978.25	81.35	178.53	128.66	222.64	8	23
1978.50	88.94	187.01	136.01	230.84	13	23
1978.75	90.88	186.67	137.88	230.51	13	23
1979.00	91.12	189.24	138.11	232.99	13	23

*These data are inferred from predicted mean sunspot numbers by linear regression techniques (ref. 21) which were modified to make quarterly predictions (ref. 22).

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APPENDIX A

1967 Modification of Jacchia's Model Atmosphere

The computational procedure for obtaining predicted models of the Earth's atmosphere for any time and spatial location is given below. A computer program that has been developed for this procedure is on file at the Computation Laboratory of the NASA Marshall Space Flight Center.

Predictions of the 10.7 cm solar flux and geomagnetic activity for the desired future time are required as inputs. Such data for each quarter, 10 years into the future, are issued monthly and should be obtained from the NASA Marshall Space Flight Center, Mail Code S & E-AERO-Y, Huntsville, Alabama 35812. Table I is an example of such data. The geomagnetic index should be used as the input for the three-hourly geomagnetic index; and the mean solar flux should be used twice, as inputs for the daily and 81-day solar flux (F and $\bar{F}$).*

* In obtaining models of the Earth's atmosphere for any time in the past, observed daily and calculated 81-day mean solar flux values are used for F and $\bar{F}$.

SYMBOLS

a_p	three-hourly geomagnetic index (input), unitless
B	computed parameter used in number density calculation (equation A-21), unitless
DATE	date (input), month/day/year
DD	day number after Jan. 1 (input), days
DS	declination of Sun (equation A-6), deg
F	daily 10.7 cm solar flux (input), unitless
$\bar{F}$	81-day mean of F, ending on date atmospheric property desired (input), unitless
GP	Greenwich meridian position (equation A-3), deg
g_i	acceleration of gravity at geometric altitude, i (equation A-30), km/sec^2
HRA	hour angle of Sun (equation A-8), deg
i	denotes a level of geometric altitude
J	Julian date (equation A-1), days
J*	computed parameter used in computing GP (equation A-2), years $\times$ 100
LAT	latitude of computation point (input), deg
LNG	longitude of computation point (input), deg
LS	celestial longitude (equation A-5), radians
MM	Greenwich Mean Time from 0000 GMT (input), minutes
MW	atmospheric molecular mass (equation A-29), unitless
M(X)	molecular mass of constituent "X" (input constant), unitless
N(H)	number density of hydrogen (equation A-24), cm^{-3}
$N(H)_{500}$	number density of hydrogen at 500 km geometric altitude (equation A-23), cm^{-3}
N(HE)	number density of helium (equation A-25), cm^{-3}

N(TOT) total atmospheric number density (equation A-27), cm^{-3}

N(U) number density of constituent "U" (equation A-26), cm^{-3}

$N(U)_{120}$ number density of constituent "U"' at 120 km geometric altitude (input constant), cm^{-3}

P computed parameter used in number density calculations (equation A-20)

Q computed parameter used in number density calculations (equation A-19), mole/gm

RAP right ascension of computation point (equation A-4), deg

RAS right ascension of Sun (equation A-7), deg

S computed parameter used in temperature and number density computations (equation A-16), km^{-1}

SH atmospheric density scale height (equation A-30), km

TAU angle between computation point and density bulge (equation A-9), deg

T(1) exospheric temperature corrected for mean solar activity (equation A-10), °K

T(2) T(1) corrected for daily solar activity (equation 11-A), °K

T(3) T(2) corrected for semi-annual variations (equation A-12),°K

T(4) T(3) corrected for diurnal variations (equation A-13), °K

T(5) exospheric temperature with all corrections (equation A-14), °K

T(6) atmospheric temperature (equation A-18), °K

TD(X) thermal diffusion factor for constituent "X". (zero for N_2, O_2, and O; -0.37 for H_e; equation A-22 for H), unitless

U denotes constituent N_2, O_2, or O

W(X) mass of constituent "X" per mole (input constant), gm

X denoted constituent N_2, O_2, O, H_e, or H

YR year (input), years

z	geometric altitude (input), km
ΔH	height difference between geometric altitude of computation and 120 km (equation A-17), km
ρ	mass density (equation A-28), gm/cm^{-3}

INPUT

DATE	date, month/day/year
YR	year
DD	day number since Jan. 1, days
MM	Greenwich Mean Time from 0000 GMT, minutes
LAT	latitude of computation point, north (+), south (-), deg
LNG	longitude of computation point, east (+), west (-), deg
z	geometric altitude, km
F	daily 10.7 cm solar flux, unitless
$\bar{F}$	81-day mean of F, ending on date atmospheric properties desired, unitless
a_p	three hourly geomagnetic index, unitless

PROCEDURE

I. SUN'S DECLINATION AND HOUR ANGLE

A. Julian date (days)

$$J = 2439856.0 + (YR - 1968)\,365 + DD \qquad \text{(A-1)}$$

where

YR = year (input)
DD = day number after Jan. 1 (input)

B. J* parameter, (years × 100)

$$J^* = \frac{J - 2415020.0}{36525} \qquad \text{(A-2)}$$

C. Greenwich meridian position (deg)

$$GP = 99.6909833 + 36000.76854(J^*) + 0.00038708(J^*)^2 + (MM)\ 0.25068447 \qquad (A\text{-}3)$$

where

MM = Greenwich Mean Time in minutes (input) and
GP must be between 0 and 360 deg

D. Right ascension of computation point (deg)

$$RAP = GP + LNG \qquad (A\text{-}4)$$

where

LNG = longitude of computation point (input) and
RAP must be between 0 and 360 degrees

E. Celestial longitude (radians)

$$LS = 0.017203\,(J - 2435839) + 0.0335 \sin\,[0.017203\,(J\text{-}2435839)] - 1.410 \qquad (A\text{-}5)$$

F. Declination of Sun (deg)

$$DS = \arcsin\,[\sin(LS)\sin(23.45^\circ)] \qquad (A\text{-}6)$$

G. Right ascension of Sun (deg)

$$RAS = \arcsin\left[\frac{\tan(DS)}{\tan(23.45^\circ)}\right] \qquad (A\text{-}7)$$

H. LS must be converted to degrees

I. Put (RAS) in quadrant of LS

J. Compute hour angle (deg)

$$HRA = (RAP) - (RAS) \qquad (A\text{-}8)$$

II. TEMPERATURE COMPUTATION

A. Exospheric temperature

1. Angle between bulge and computation point (deg)

$$TAU = HRA - 45^\circ + 12^\circ \sin(HRA + 45^\circ) \qquad (A\text{–}9)$$

where

TAU must be placed between +180 and −180 degrees

2. Mean solar activity correction (°K)

$$T(1) = 362 + 3.60\,(\bar{F}) \qquad \text{(A-10)}$$

where $\bar{F}$ = 81-day mean solar flux (input)

3. Daily solar activity correction (°K)

$$T(2) = T(1) + 1.8\,(F - \bar{F}) \qquad \text{(A-11)}$$

where F = daily solar flux (input)

4. Semi-annual correction (°K)

$$T(3) = T(2) + [f(DD)]\,\bar{F} \qquad \text{(A-12)}$$

where

$$f(DD) = \left[0.37 + 0.14 \sin 2\pi \left(\frac{DD - 151}{365}\right)\right] \sin 4\pi \left(\frac{DD - 59}{365}\right)$$

and DD = day number (input)

5. Diurnal correction (°K)

$$T(4) = T(3)\ [1 + 0.28 \sin^{2.5} \theta]\ [1 + A \cos^{2.5} (TAU/2)] \qquad \text{(A-13)}$$

where

$$A = 0.28 \left[\frac{\cos^{2.5} W - \sin^{2.5} \theta}{1 + 0.28 \sin^{2.5} \theta}\right]$$

$$W = 1/2\ (LAT - DS)$$

$$\theta = |1/2\ (LAT + DS)|$$

LAT = latitude of computation point (input), deg
DS = Sun's declination (equation A-6), deg

6. Geomagnetic activity correction for exospheric temperature, T(5), (°K)

$$T(5) = T(4) + A_p + 100\,[1 - \exp(-0.08\, a_p)] \qquad \text{(A-14)}$$

where

a_p = three hourly geomagnetic index (input)

B. Temperature at geometric altitude levels

1. "X" parameter (unitless)

$$X = \frac{[T(5) - 800]}{750 + 1.722 \times 10^{-4} \ [T(5) - 800]^2} \qquad \text{(A-15)}$$

where T(5) = exospheric temperature (equation A-14), °K

2. "S" parameter, (km^{-1})

$$S = 1.5 \times 10^{-4} + [0.0291 \ \exp(-X^2/2)] \qquad \text{(A-16)}$$

3. Height difference between level i and 120 km, (km)

$$\Delta H = \frac{(z_i - 120)\ (6476.77)}{6356.77 + z_i} \qquad \text{(A-17)}$$

where

z = geometric altitude, km
i denotes a level of geometric altitude

4. Temperature, T(6), for geometric altitude level i, (°K)

$$T(6)_i = T(5) - [T(5) - 355]\ [\exp - (S(\Delta H)_i)] \qquad \text{(A-18)}$$

where

T(5) = exospheric temperature (equation A-14), °K
ΔH = height difference between level i and 120 km (equation A-17), km
S = curve fit parameter (equation A-16), km^{-1}

III. NUMBER DENSITY COMPUTATIONS

A. Hydrogen

1. "Q" parameter (mole/gm)

$$Q = \frac{1.13619033}{T(5)\ S} \qquad \text{(A-19)}$$

2. "P" parameter (unitless)

$$P = \frac{T(5) - 355}{T(5)} \qquad \text{(A-20)}$$

3. "B" parameter (unitless)

$$B = \frac{1 - P}{1 - P \exp[(-S)(\Delta H)]} \tag{A-21}$$

4. Thermal diffusion factor for hydrogen (unitless)

$$\begin{aligned} TD(H) = & -10.48947029 + 2.844291123 \times 10^{-2} [T(5)] \\ & -3.62095821 \times 10^{-5} [T(5)]^2 + 2.341193059 \\ & \times 10^{-8} [T(5)]^3 - 7.577509214 \times 10^{-12} [T(5)]^4 \\ & + 9.753963073 \times 10^{-16} [T(5)]^5 \end{aligned} \tag{A-22}$$

5. Hydrogen number density at 500 km altitude, (cm^{-3})

$$N(H)_{500} = \text{anti log} \left[73.13 - 39.4 \log T(5) + 5.5 [\log T(5)]^2 \right] \tag{A-23}$$

("log" denotes common logarithm)

6. Hydrogen number density for geometric altitude i, ($i > 500$ km), (cm^{-3})

$$N(H)_i = [N(H)_{500}] [B]^{[1 + TD(H) + (1.008) Q]} \left[\exp[(-S)(\Delta H)(Q)(1.008)] \right] \tag{A-24}$$

B. Helium number density, (cm^{-3})

$$N(HE)_i = [3.4 \times 10^7] [B]^{[0.63 + (4.002) Q]} \left[\exp[(-S)(\Delta H)(Q) 4.002] \right] \tag{A-25}$$

C. Number density for molecular nitrogen and molecular and atomic oxygen, (cm^{-3})

$$N(U)_i = [N(U)_{120}] [B]^{[1 + (Q) M(U)]} \left[\exp[(-S)(\Delta H)(Q) M(U)] \right] \tag{A-26}$$

where

U denotes N_2, O_2 or O

and input constants are

$N(N2)_{120} = 4.0 \times 10^{11}, cm^{-3}$

$N(O2)_{120} = 7.5 \times 10^{10}, cm^{-3}$

$N(O)_{120} = 7.6 \times 10^{10}, cm^{-3}$

M(N2) = 28.0134, unitless

M(O2) = 31.9988, unitless

M(O) = 15.9990, unitless

D. Total number density, (cm^{-3})

$$N(TOT)_i = N(H)_i + N(HE)_i + N(N2)_i + N(O2)_i + N(O)_i \qquad (A\text{-}27)$$

IV. MASS DENSITY (gm/cm^3)

$$\rho_i = N(H)_i \; W(H) + N(HE)_i \; W(HE) + N(N2)_i \; W(N2) + N(02)_i \; W(02) + N(O)_i \; W(O) \qquad (A\text{-}28)$$

where input constants in grams/mole

$W(H) = 1.6731 \times 10^{-24}$

$W(HE) = 6.6435 \times 10^{-24}$

$W(N2) = 4.6496 \times 10^{-23}$

$W(O2) = 5.3104 \times 10^{-23}$

$W(O) = 2.6552 \times 10^{-23}$

V. MOLECULAR MASS (Unitless)

$$(MW)_i = \frac{N(H)_i M(H) + N(HE)_i M(HE) + N(N2)_i M(N) + N(O2)_i M(O2) + N(O)_i M(O)}{N(TOT)_i} \qquad (A\text{-}29)$$

VI. DENSITY SCALE HEIGHT, (km)

$$SH = \frac{8.31432 \times 10^{-3} \; [T(6)]_i}{(MW)_i \; g_i} \qquad (A\text{-}30)$$

where

$$g_i = 9.80665 \times 10^{-3} \left(1 + \frac{z_i}{6356.77}\right)^{-2}$$

OUTPUT

Temperature, °K
Number density of N_2, O_2, O, H_e, and H, cm^{-3}
Total number density, cm^{-3}
Mass density, gm/cm^3
Molecular mass, unitless
Density scale height, km

APPENDIX B

1967 Quick-Look Density Model with Sample Problem

The computational procedure for obtaining an estimate of atmospheric density for any time and spatial location is given below. Required inputs for this procedure include predictions of the 10.7 cm solar flux and geomagnetic activity for the future time desired. Such data are issued monthly and current predictions should be obtained from the NASA Marshall Space Center, Code S & E-AERO-Y, Huntsville, Alabama 35812. Table I is a sample of such data.

A sample problem shows the step-by-step procedure used in obtaining an estimate of the mean atmospheric density for July 1, 1971, 1600 hours local time at an altitude of 300 km and latitude of 30°N. From the sample data in table I, the predicted nominal geomagnetic and mean solar flux indices are found to be 8 and 107.15, respectively. The geomagnetic index from table I is used as the three-hourly geomagnetic index; and the mean solar flux is used twice, as the daily and 81-day mean solar flux (F and $\bar{F}$).* It should be noted, however, that table I is only a sample; the most recent predictions of the 10.7 cm solar flux and geomagnetic activity should be obtained for predicting atmospheric density.

SYMBOLS

a_p	three-hourly geomagnetic index (input), unitless
DD	date (input), month/day/year
DCL	declination of Sun (Fig. B-1), deg
F	daily 10.7 cm solar flux (input), unitless
$\bar{F}$	81-day mean of F, ending on date for which density desired (input), unitless
K	parameter used in computing T(3) (table B-1), unitless
LAT	latitude of computation point (input), deg
LCT	local time (input), hours
P	parameter given in table B-2 used in computing T(4) for LCT 1000 to 2400 hours, unitless

*In obtaining estimates of atmospheric density for any time in the past, observed daily and calculated 81-day mean solar flux values for F and $\bar{F}$ should be used.

Q parameter given in table B-3 used in computing T(4) for LCT 0000 to 1000 hours, unitless

T(2) exospheric temperature corrected for solar activity (equation B-1), °K

T(3) T(2) corrected for semi-annual variations (equation B-2), °K

T(4) T(3) corrected for diurnal effect (equation B-5 or B-6), °K

T(5) exospheric temperature with all corrections (equation B-7), °K

z geometric altitude (input), km

δT temperature correction for geomagnetic index variations given in table B-4, °K

$(\delta D)_B$ angle of declination between computation point and density bulge center, (equation B-3), deg

$(\delta D)_A$ angle of declination between computation point and anti-bulge center (equation B-4), deg

INPUT*

DD date (July 1, 1971)

F daily 10.7 cm solar flux (107.15)

$\bar{F}$ 81-day mean solar flux (107.15)

a_p three-hourly geomagnetic index (8)

LAT latitude (30°N)

LCT local time (1600)

z altitude (300 km)

*Inputs for sample problem in parenthesis

PROCEDURE*

I. EXOSPHERIC TEMPERATURE COMPUTATION

A. Variation with solar activity

$$T(2) = 362 + 1.8\,(\bar{F} + F) \qquad \text{(B-1)}$$
$$= 362 + 1.8\,(107.15 + 107.15) = 747.74$$

B. Semi-annual correction
(From table B-1 by interpolation, K = -0.383

$$T(3) = T(2) + K(F) \qquad \text{(B-2)}$$
$$= 747.74 + (-0.383)\,(107.15) = 696.80$$

C. Diurnal Correction

1. Angle of declination between computation point and density bulge for 1000-2400 hours (LCT) (from figure B-1, DCL = +23.0°)

$$(\delta D)_B = LAT - DCL \qquad \text{(B-3)}$$
$$= 30.0 - (23.0) = 7.0$$

2. Angle of declination between computation point and anti-bulge for 0000-1000 hours (LCT)

$$(\delta D)_A = LAT + DCL \qquad \text{(B-4)}$$

3. Diurnal correction for 1000 to 2400 hours (LCT) (From table B-2), by interpolation, P = 1.260

$$T(4) = T(3)\,P \qquad \text{(B-5)}$$
$$= 696.80\,(1.260) = 878.0$$

4. Diurnal correction for 0000 to 1000 hours (LCT)

$$T(4) = T(3)\,Q \qquad \text{(B-6)}$$

where Q is obtained from table B-3 using $(\delta D)_A$ and LCT

D. Variation with geomagnetic activity (From table B-4); by interpolation, $\delta T = 61$

$$T(5) = T(4) + \delta T \qquad \text{(B-7)}$$
$$= 878.0 + 61 = 939.0$$

*Calculations for sample problem follow each equation

TABLE B-1

EXOSPHERIC TEMPERATURE CORRECTION FACTOR
FOR SEMI-ANNUAL EFFECT

	°K		°K		°K		°K
Jan 1	-0.267	Apr 1	+0.218	Jul 1	-0.383	Oct 1	+0.434
11	-0.276	11	+0.259	11	-0.453	11	+0.472
21	-0.255	21	+0.275	21	-0.469	21	+0.451
Feb 1	-0.203	May 1	+0.258	Aug 1	-0.418	Nov 1	+0.366
11	-0.138	11	+0.200	11	-0.312	11	+0.250
21	-0.063	21	+0.119	21	-0.163	21	+0.117
Mar 1	0.000	Jun 1	-0.010	Sep 1	+0.026	Dec 1	-0.016
11	+0.078	11	-0.143	11	+0.196	11	-0.130
21	+0.151	21	-0.273	21	+0.338	21	-0.215

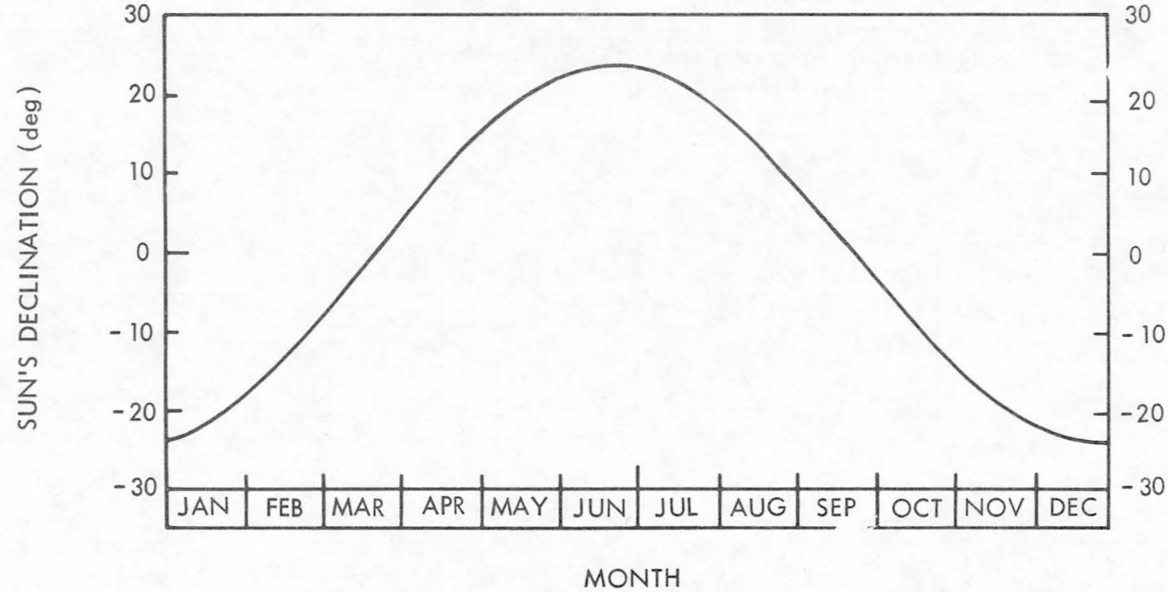

Figure B-1. —Declination of Sun.

TABLE B-2

EXOSPHERIC TEMPERATURE CORRECTION FACTOR, (PARAMETER P), FOR DIURNAL EFFECT FOR 1000-2400 HOURS (LCT)

Latitude (deg)	Local Time (hours)														
	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
90	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166
75	1.171	1.182	1.190	1.196	1.198	1.197	1.194	1.188	1.182	1.175	1.167	1.160	1.153	1.147	1.142
80	1.174	1.194	1.210	1.221	1.226	1.224	1.217	1.207	1.194	1.181	1.166	1.152	1.139	1.127	1.116
45	1.174	1.203	1.227	1.242	1.248	1.246	1.237	1.222	1.204	1.184	1.163	1.143	1.124	1.106	1.091
30	1.172	1.208	1.238	1.258	1.266	1.263	1.251	1.232	1.209	1.184	1.159	1.133	1.109	1.087	1.068
15	1.168	1.210	1.245	1.267	1.276	1.273	1.259	1.238	1.212	1.183	1.153	1.124	1.096	1.071	1.049
0	1.165	1.210	1.246	1.270	1.280	1.276	1.262	1.239	1.211	1.180	1.149	1.118	1.088	1.061	1.038
-15	1.168	1.210	1.245	1.267	1.276	1.273	1.259	1.238	1.212	1.183	1.153	1.124	1.096	1.071	1.049
-30	1.172	1.208	1.238	1.258	1.266	1.263	1.251	1.232	1.209	1.184	1.159	1.133	1.109	1.087	1.068
-45	1.174	1.203	1.227	1.242	1.248	1.246	1.237	1.222	1.204	1.184	1.163	1.143	1.124	1.106	1.091
-60	1.174	1.194	1.210	1.221	1.226	1.224	1.217	1.207	1.194	1.181	1.166	1.152	1.139	1.127	1.116
-75	1.171	1.182	1.190	1.196	1.198	1.197	1.194	1.188	1.182	1.175	1.167	1.160	1.153	1.147	1.142
-90	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166

TABLE B-3

EXOSPHERIC TEMPERATURE CORRECTION FACTOR, (PARAMETER Q), FOR DIURNAL EFFECT FOR 0000-1000 HOURS (LCT)

Latitude (deg)	Local Time (LCT)										
	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000
90	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166
75	1.142	1.138	1.135	1.133	1.133	1.134	1.137	1.142	1.150	1.160	1.171
60	1.116	1.108	1.102	1.099	1.099	1.101	1.106	1.117	1.132	1.152	1.174
45	1.091	1.079	1.071	1.067	1.066	1.068	1.076	1.092	1.114	1.143	1.174
30	1.068	1.053	1.043	1.038	1.037	1.040	1.049	1.069	1.097	1,133	1.172
15	1.049	1.032	1.020	1.014	1.013	1.016	1.028	1.050	1.083	1.124	1.168
0	1.038	1.020	1.007	1.001	1.000	1.003	1.015	1.039	1.074	1.118	1.165
-15	1.049	1.032	1.020	1.014	1.013	1.016	1.028	1.050	1.083	1.124	1.168
-30	1.068	1.053	1.043	1.038	1.037	1.040	1.049	1.069	1.097	1.133	1.172
-45	1.091	1.079	1.071	1.067	1.066	1.068	1.076	1.092	1.114	1.143	1.174
-60	1.116	1.108	1.102	1.099	1.099	1.101	1.106	1.117	1.132	1.152	1.174
-75	1.142	1.138	1.135	1.133	1.133	1.134	1.137	1.142	1.150	1.160	1.171
-90	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166	1.166

TABLE B-4

EXOSPHERIC TEMPERATURE CORRECTION FOR GEOMAGNETIC ACTIVITY

Geomagnetic Activity Index (a_p)	δT (°K)	Geomagnetic Activity Index (a_p)	δT (°K)
0	0	39	134
2	9	48	145
3	19	56	156
4	28	67	167
5	37	80	180
6	47	94	194
7	56	111	210
9	66	132	229
12	75	154	251
15	85	179	279
18	94	207	313
22	104	236	358
27	114	300	417
32	124	400	495

II. ATMOSPHERIC DENSITY INTERPOLATIONS

T(5), which is the final exospheric temperature, should be used to enter table B-5 to obtain the atmospheric density at any desired altitude. Using the T(5) value of 939.0°K found in the numerical example, the density at 300 km interpolated to be 2.0003×10^{-14} gm/cm^3.

TABLE B-5

DENSITY (gm/cc) AS A FUNCTION OF EXOSPHERIC TEMPERATURE AND GEOMETRIC ALTITUDE

Geometric Alt (km)	Exospheric Temperature* (°K)			
	650° K	700° K	800° K	900° K
120	2.4595-11	2.4595-11	2.4595-11	2.4595-11
130	9.2172-12	9.0565-12	8.7590-12	8.4994-12
140	4.1902-12	4.1549-12	4.0825-12	4.0107-12
150	2.1388-12	2.1620-12	2.1950-12	2.2121-12
200	1.6926-13	1.9256-13	2.3843-13	2.8074-13
250	2.5629-14	3.1967-14	4.6365-14	6.2190-14
300	5.3550-15	7.1879-15	1.1782-14	1.7477-14
350	1.3274-15	1.9146-15	3.5202-15	5.7073-15
400	3.6376-16	5.6280-16	1.1613-15	2.0571-15
450	1.0943-16	1.7876-16	4.0964-16	7.9196-16
500	3.8699-17	6.3021-17	1.5372-16	3.2076-16
550	1.6706-17	2.5609-17	6.2168-17	1.3647-16
600	9.0800-18	1.2559-17	2.7900-17	6.1655-17
650	5.8935-18	7.4073-18	1.4306-17	3.0141-17
700	4.2434-18	4.9997-18	8.4449-18	1.6266-17
800	2.5266-18	2.7906-18	4.0560-18	6.5087-18
900	1.6384-18	1.7360-18	2.4119-18	3.5627-18
1000	1.1251-18	1.1369-18	1.5471-18	2.2574-18

*The two-digit number (preceded by a minus sign) following each entry indicates the minus power of ten by which that entry should be multiplied.

TABLE B-5 (CONTINUED)

DENSITY (gm/cc) AS A FUNCTION OF EXOSPHERIC TEMPERATURE
AND GEOMETRIC ALTITUDE

Geometric Alt	Exospheric Temperature* (°K)					
(km)	1000°K	1100°K	1200°K	1300°K	1400°K	1500°K
120	2.4595-11	2.4595-11	2.4595-11	2.4595-11	2.4595-11	2.4595-11
130	8.2819-12	8.1075-12	7.9742-12	7.8775-12	7.8118-12	7.7702-12
140	3.9431-12	3.8823-12	3.8300-12	3.7869-12	3.7527-12	3.7265-12
150	2.2166-12	2.2120-12	2.2016-12	2.1880-12	2.1732-12	2.1588-12
200	3.1719-13	3.4651-13	3.6844-13	3.8354-13	3.9289-13	3.9782-13
250	7.8237-14	9.3345-14	1.0661-13	1.1749-13	1.2587-13	1.3193-13
300	2.3955-14	3.0780-14	3.7479-14	4.3641-14	4.8985-14	5.3391-14
350	8.4160-15	1.1513-14	1.4813-14	1.8112-14	2.1227-14	2.4032-14
400	3.2535-15	4.7160-15	6.3766-15	8.1454-15	9.9271-15	1.1639-14
450	1.3439-15	2.0627-15	2.9259-15	3.8950-15	4.9229-15	5.9629-15
500	5.8249-16	9.4642-16	1.4080-15	1.9518-15	2.5552-15	3.1927-15
550	2.6285-16	4.5076-16	7.0269-16	1.0140-15	1.3744-15	1.7702-15
600	1.2359-16	2.2198-16	3.6150-16	5.4233-16	7.6055-16	1.0094-15
650	6.1027-17	1.1319-16	1.9132-16	2.9752-16	4.3109-16	5.8906-16
700	3.2060-17	6.0124-17	1.0434-16	1.6728-16	2.4972-16	3.5081-16
800	1.1210-17	1.9902-17	3.4649-17	5.7387-17	8.9522-17	1.3174-16
900	5.4116-18	8.5662-18	1.3943-17	2.2612-17	3.5601-17	5.3717-17
1000	3.2528-18	4.7109-18	6.9936-18	1.0616-17	1.6174-17	2.4248-17

*The two-digit number (preceded by a minus sign) following each entry indicates the minus power of ten by which that entry should be multiplied.

TABLE B-5 (CONTINUED)

DENSITY AS A FUNCTION OF EXOSPHERIC TEMPERATURE
AND GEOMETRIC ALTITUDE

Geometric Alt (km)	Exospheric Temperature* (°K)					
	1600° K	1700° K	1800° K	1900° K	2000° K	2100° K
120	2.4595-11	2.4595-11	2.4595-11	2.4595-11	2.4595-11	2.4595-11
130	7.7461-12	7.7331-12	7.7258-12	7.7196-12	7.7108-12	7.6969-12
140	3.7067-12	3.6916-12	3.6797-12	3.6693-12	3.6592-12	3.6483-12
150	2.1454-12	2.1335-12	2.1229-12	2.1137-12	2.1056-12	2.0982-12
200	3.9968-13	3.9967-13	3.9879-13	3.9779-13	3.9722-13	3.9744-13
250	1.3609-13	1.8896-13	1.4076-13	1.4225-13	1.4370-13	1.4540-13
300	5.6892-14	5.9632-14	6.1819-14	6.3674-14	6.5404-14	6.7183-14
350	2.6469-14	2.8549-14	3.0336-14	3.1924-14	3.3416-14	3.4912-14
400	1.3227-14	1.4669-14	1.5976-14	1.7183-14	1.8338-14	1.9495-14
450	6.9773-15	7.9442-15	8.8585-15	9.7313-15	1.0584-14	1.1446-14
500	3.8411-15	4.4840-15	5.1139-15	5.7328-15	6.3504-15	6.9817-15
550	2.1880-15	2.6165-15	3.0495-15	3.4859-15	3.9301-15	4.3901-15
600	1.2810-15	1.5685-15	1.8671-15	2.1752-15	2.4947-15	2.8301-15
650	7.6724-16	9.6141-16	1.1684-15	1.3868-15	1.6174-15	1.8627-15
700	4.6853-16	6.0051-16	7.4476-16	9.0029-16	1.0674-15	1.2477-15
800	1.8404-16	2.4599-16	3.1706-16	3.9696-16	4.8586-16	5.8456-16
900	7.7468-17	1.0710-16	1.4270-16	1.8438-16	2.3241-16	2.8731-16
1000	3.5330-17	4.9797-17	6.7937-17	9.0008-17	1.1632-16	1.4728-16

*The two-digit number (preceded by a minus sign) following each entry indicates the minus power of ten by which that entry should be multiplied.

APPENDIX C

Glossary

Atmospheric Density.– Same as **Mass Density.**

Celestial Longitude.—The arc of the ecliptic between the vernal equinox and the point at which the celestial longitude is given. It is always measured eastward from the vernal equinox, completely around the ecliptic, from 0° to 360°.

Daily 10.7 cm Flux.—Assumed to be the same as radio flux. A measured indicator for the amount of EUV solar radiation received by the Earth. See **Radio Flux.**

Declination.—In the geocentric coordinate system, it is the angular distance along the meridian of a point of body from the equator. Declination is analogous to latitude on Earth. It is taken positive north of the equator and negative south of the equator.

Density.—Same as **Mass Density.**

Density Bulge.—A slight bulge in the daylight portion of the atmosphere that is caused by atmospheric heating. The center of the bulge follows the Sun, lagging by two hours, and also migrates north and south with the sub-solar point. A slight depression in the dark portion of the atmosphere (anti-bulge), which is a product of the bulge, is centered ten hours earlier at 0400 local time. At any given height above 120 km, the maximum density occurs at the center of the density bulge.

Density Scale Height.—The scale height of a point in the atmosphere is a numerical quantity that represents the altitude above the point at which the mass density would decrease by a factor of 1/e (the exponential log e) from the density at the point. See equation A-30.

Diffusive Equilibrium.—The steady state resulting from the diffusive process in which the constituent gases of the atmosphere are distributed independently of one another. In sucn a state, the number density of the heavier constituents decreases more rapidly with altitude than the lighter.

Diurnal Effect.—The day-to-night variation in nearly all atmospheric parameters that is caused by the rotation of the Earth. See **Density Bulge.**

Ecliptic.—The apparent path of the sun about the Earth during a year. Strictly, it is the projection of the plane of the Earth's orbit on the celestial sphere.

81-Day Mean Solar Flux.–The arithmetic average of the daily 10.7 cm solar flux values for the 81 days preceding the day for which the 81-day mean is given.

Electromagnetic Radiation.–Energy that is propagated through space, primarily from the Sun, in the form of an advancing disturbance in electric and magnetic fields (often called radiation).

Exospheric Temperature.–The value that the atmospheric temperature reaches near 500 km altitude. Above this altitude, temperature is considered to be isothermal (lapse rate of zero) and to range from 650° to 2100°K.

Geomagnetic Index.–See **Three-hourly Geomagnetic Index.**

Hour Angle.–The angular distance measured eastward or westward along the celestial equator to the longitude of the point for which the hour angle refers. Morning hour angles are negative and afternoon are positive.

Julian Date (also Julian day).–Number of days measured from January 1 (noon), 4713 B.C.

Lapse Rate.–The change in temperature with increasing altitude.

Magnetic Field.–A region wherein any magnetic dipole would experience a magnetic force or torque.

Mass Density.–The ratio of the mass of any substance to the volume occupied by it (usually expressed in gm/cm^3).

Mixing.–A random exchange of atmospheric constituents caused primarily by non-homogeneous pressure forces.

Modified Julian Day.–Number of days measured from November 17, 1858 (midnight).

Number Density.–The numerical count of molecules of a particular constituent for a given volume (usually given as $number/cm^3$).

Radio Flux ($F_{10.7}$).–The radio flux density at 10.7 cm is a useful indicator of solar activity as it exhibits both 11-year and 27-day periodicities. Its high correlation with the solar radiation which is absorbed in the upper atmosphere makes it a desirable weighting function for representing the effects of this absorption in a model atmosphere. The standard data source is Ottawa, Canada, although it is measured at several observatories. The solar flux is actually measured over a complete bandwidth to increase the faithfulness of the radio energy input as it passes through the receiver and therefore must be divided by the width of the band. The 10.7 cm solar flux has units of 10^{-22} watts/sq m/sec/bandwidth but should be considered as a unitless quantity for the equations herein.

Right Ascension.–The angular distance measured from the vernal equinox eastward along the celestial equator to the longitude of the point to which the right ascension refers.

Semi-annual Effect.–A systematic variation of upper atmospheric density that in brief is caused by the interaction between the solar wind and magnetic field, modulated by the orbital motion of the Earth. The semi-annual effect causes the atmospheric density above 200 km altitude to decrease to a deep minimum in July, then increase to a high maximum in October or November. These are followed by a secondary minimum in January and a secondary maximum in April.

Solar Radiation.–The total electromagnetic radiation and corpuscular radiation emitted by the Sun.

Solar Wind.–The steady flux of plasma from the Sun.

Static Diffusion.–Same as **Diffusive Equilibrium.**

Sunspot Number.–A solar index which has been compiled back to 1600 A.D. The sunspot number takes into account the number of sunspot groups as well as the number of individual spots.

where

$$R = K\,(10g + s)$$

R = sunspot number

g = number of groups

s = number of spots

K = a constant, roughly equal to 1

K is used to adjust individual R numbers to account for some observatories having better observing conditions than others.

Three-Hourly Geomagnetic Index.–A measurement of the most active component of the magnetic field made by surface magnetic observatories (an average of 12 selected stations) at three-hour intervals. The measurement is made in the units of gauss or gamma (1 gauss = 10^5 gammas), but observations are reported in terms of a unitless quantity (a_p) which varies from 0 to 400.

Thermosphere.–The region of the atmosphere extending upward from about 85 km to outer space. In this region the temperature increases with altitude to about 500 km and then is constant with increasing altitude. See figure 1.

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