THE NASA MARSHALL ENGINEERING THERMOSPHERE MODEL

(NASA-CR-179359) THE NASA MARSHALL ENGINEERING THERMOSPHERE MODEL
(Universities Space Research Association)
40 p

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Interim Report

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This document contains a description of the NASA Marshall Engineering Thermosphere (MET) Model, which is a modified version of the MSFC/J70 Orbital Atmospheric Density Model as currently used in the J70MM program at MSFC. The modifications to the MSFC/J70 model required for the MET model are described, graphical and numerical examples of the models are included, as is a listing of the MET model computer program. Major differences between the numerical output from the MET model and the MSFC/J70 model are discussed.
This work was performed under NASA Contract NAS8-36400 under the technical monitorship of Messrs. Claude E. Green and Dale L. Johnson. Qualified requestors may obtain copies of the computer program for this NASA Marshall Engineering Thermosphere model upon request to the Chief, Earth Science and Applications Division, Structures and Dynamics Laboratory, NASA, Marshall Space Flight Center, Alabama 35812.
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INTRODUCTION

The model currently used at NASA/Marshall Space Flight Center to describe the properties of the neutral atmosphere between 90 and 2500 km altitude is the MSFC/J70 model [1,2], as described in [3]. In the Earth Science and Applications Division of the Structures and Dynamics Laboratory the computer program used to output data from the MSFC/J70 model is the J70MM. This program, which runs on an HP-1000 computer, outputs data in a latitude/longitude matrix grid (for a fixed time, altitude and solar and geomagnetic indices) which can then be printed on a line printer. A listing of this program, which is written in Fortran IV, can be found in [3].

For many purposes it is more convenient to have any computer generated output plotted rather than simply tabulated, and with several different input parameters used in the model (solar and geomagnetic indices, latitude, longitude, altitude and time) it was decided that the computer code should be substantially modified and streamlined. This was implemented on a VAX 11/780 computer by the use of more subroutines and by writing the code in Fortran 77. Some other modifications were also performed which relate to the calculation of ephemeris data and to the calculation of helium number densities in the upper thermosphere. Some additional atmospheric thermodynamic parameters are now also calculated in the model.

In the course of producing global contour plots from the data produced by the new streamlined model, it was found that occasionally density discontinuities were present over certain regions of the globe. On further investigation, it was discovered that these discontinuities were associated with an occasional problem in the integration routine used in the model. More details concerning the nature of this problem and its solution are given in this report.

The final version of this model has been named the NASA Marshall Engineering Thermosphere (MET) Model. It consists of a number of subroutines which are driven by a very simple driving program, as given in the appendix. To produce plots, all one needs to do is modify the driving program. This has been done in an accompanying report [4], the details of which will not appear here.
A schematic representation of the MET model is given in Figure 1. The driving program calls the control subroutine ATMOSPHERES, which then makes decisions based upon the values of the four switches which have been set in the driver. In the basic model presented here, only one calculation is performed (i.e. calculations are performed for one altitude, latitude, longitude and time and for one set of solar and geomagnetic conditions) so that all of the switches have been set to a character value of "Y". The development of a driving program suitable for the generation of data files to be used for creating plots would require the execution of multiple calculations, and hence would require one of the switches being set to a character value of "N" in the driver program for an x-y line plot, or would require at least one or two of the switches being set to a character value of "N" in the driver program for a contour plot. The subject of multiple executions is not discussed any further here, but is discussed in [4].

Once the subroutine ATMOSPHERES has been called, it successively calls the subroutines TIME, SOLSET, J70 and J70SUP. Here, in this most basic setup, TIME and SOLSET are called once only. Each of these subroutines prompt the user for the time (year, month, day, hour and minute) and the solar and geomagnetic indices (AP, F10.7 and F10.7), respectively, as discussed in [3]. In the MET model the user, not given a choice of using the KP index, could easily edit SOLSET should the KP index be preferred over the use of the AP index.

Subroutine J70 calculates most of the atmospheric parameters which the MSFC/J70 model did, but it contains several modifications which will be discussed shortly. J70 successively calls the subroutines TME, TINF, JAC, SLV and SLVH. Apart from changing the code from Fortran IV to Fortran 77, TINF, SLV and SLVH are basically very similar to their old versions appearing in the MSFC/J70 model. Some constants have been changed in TME, while JAC has been extensively re-written in an attempt to make it intelligible to the reader! An intermittent problem within JAC has also been corrected, and this will be discussed in more detail shortly. Between altitudes of 440 and 500 km J70 also calls a new subroutine called FAIR5, which we will discuss shortly.

Once calculations in J70 are finished, J70SUP is called. This subroutine calculates additional atmospheric thermodynamic parameters which will also be described shortly.
Figure 1. The MET Model*

*Sequential numerical operation is down and to the right
SUBROUTINE TME

A number of relatively minor changes have been made to some of the ephemeris constants, as described in [5]. These changes, listed in Table 1, lead to improvements in the calculated values of the solar declination and solar hour angles, as given in [5]. However, the associated changes in the total density are typically fractions of a percent.

TABLE 1

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>OLD VALUE</th>
<th>NEW VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>36000.76854</td>
<td>36000.76892</td>
</tr>
<tr>
<td>A4</td>
<td>0.2506847</td>
<td>0.25068477</td>
</tr>
<tr>
<td>B1</td>
<td>0.017203</td>
<td>0.0172028</td>
</tr>
<tr>
<td>B3</td>
<td>1.410</td>
<td>1.407</td>
</tr>
<tr>
<td>FMJD</td>
<td>XMJD-2435839</td>
<td>XMJD-2435839+GMT/1440.</td>
</tr>
<tr>
<td>XJ</td>
<td>(XMJD-2415020.0)/36525.0</td>
<td>(XMJD-2415020.5)/36525.0</td>
</tr>
<tr>
<td>XLS</td>
<td>AMOD(Y1+B2*SIN(Y1)-B3,TPI)</td>
<td>AMOD(Y1+B2*SIN(Y2)-B3,TPI)</td>
</tr>
<tr>
<td></td>
<td>where Y2=0.017202*(FMJD-3.)</td>
<td></td>
</tr>
<tr>
<td>B4</td>
<td>(TPI/360.)*23.45</td>
<td>(TPI/360.)<em>(23.4523-0.013</em>XJ)</td>
</tr>
</tbody>
</table>

SUBROUTINE JAC

This subroutine has been extensively streamlined and improved by the introduction of a function statement (GRAVITY), two function subprograms (TEMP and MOL_WT) and a subroutine (INTEGRATE). Section 1 of JAC is used for altitudes between 90 and 105 km, while Section 2 is used only for altitudes greater than 105 km. Section 3 is used only for the calculation of hydrogen number densities which below 500 km altitude are set equal to $10^6 m^{-3}$.

The function subprogram MOL_WT only calculates the molecular weight at and below altitudes of 105 km using the sixth-degree polynomial given in [1]. Given this molecular weight and the temperature, the total mass density is computed by integrating the barometric equation. For altitudes above 105 km the number density of each individual specie is calculated by integrating the diffusion equation upwards from 105 km. Thus, above 105 km altitude the molecular weight is not known (it is calculated later from the number densities of all of the species) nor is it needed. Thus, the subprogram MOL_WT simply sets the molecular weight to unity above 105 km altitude.
Between 90 and 105 km altitude the atmosphere is well mixed, but as a result of the dissociation of O₂ to 0 the mean molecular mass in the model varies in such a manner that the ratio \( n(0)/n(O_2) = 1.5 \) at 120 km [1]. Above 105 km each individual species is in a state of diffusive equilibrium. The only exception to this is hydrogen, which in the model exists above 500 km in a state of diffusive equilibrium. Thus, between 90 and 105 km the density is computed by integrating the barometric equation while above 105 km it is computed by integrating the diffusion equation. This integration is performed in the subroutine INTEGRATE using Simpson’s Rule.

Integration is performed between the altitudes A and D where at these altitudes the integrand has values of \( FA \) and \( FD \), respectively. At and below 105 km altitude \( gM/T \) is integrated (\( g \) is the gravitational acceleration, \( M \) is the mean molecular weight and \( T \) is temperature), while above 105 km altitude \( g/T \) is integrated. Integration is performed using Simpson’s Rule quadrature, and the value of the integral of either \( gM/T \) or \( g/T \) between altitudes A and D is set equal to \( R(N) \), where the number of sub-intervals used to evaluate the integral in the interval A to D is given by \( 2^{N-1} \). Integration is said to have converged when the solution obtained by doubling the number of subintervals is "equal" to the previous solution within some specified tolerance, \( \epsilon \). Mathematically, this is stated as:

\[
\epsilon |R(N)| > |R(N)-R(N-1)|
\]  

If equation (1) is satisfied, then convergence is said to have been achieved, the result (RR) is set to \( R(N) \), and execution returns to the calling program (in this case subroutine JAC). This method is the same as that used in the original J70MM program, but the code has been substantially re-written.

While there is nothing wrong with this basic method, the implementation of it in J70MM contained a major flaw which appears to be intermittent in nature. Figure 2(a) is a contour plot of total mass density over a portion of the globe at 230 km altitude. The input conditions required to generate this plot are:-
Indices: $F_{10.7} = 230$, $F_{10.7} = 230$, $A_p = 0$
Altitude: 230 km

This plot was not generated with the MET model, but with a modified form of the original J70MM program. The important feature of this plot is not the actual magnitudes of the densities, but the discontinuous nature of these densities as a function of both latitude and longitude, as revealed by the several "saw-toothed curves" which are clearly evident in the plot. It is important to note, however, that all of the empirical equations upon which the model is based are continuous functions of both latitude and longitude [1]. Also, each individual data point used in Figure 2(a) is independent of all of the other data points which are used. Hence, any error in the model which has produced the discontinuities in this figure are peculiar to the calculations made for each individual data point which is in error. Due to the fact that a contour plot of mass density at 200 km altitude, (with all other input parameters identical to those used in Figure 2(a)) appeared to be perfectly continuous over latitude and longitude, a discontinuity in density as a function of altitude was sought.

Figure 2(b) shows mass density as a function of altitude for the same time and solar and geomagnetic indices as previously used in Figure 2(a), and for a latitude of $-62.1^\circ$ and a longitude of $295^\circ$. [This geographic position was chosen because it corresponds to a region of discontinuity in Figure 2(a). Also, only a small altitude range centered about 230 km was considered. Had a large altitude range been chosen, any small discontinuities may have been hidden on the plot by the scaling required to display the rapid exponential decrease of density which occurs over increasing altitude.] Immediately evident in this figure is a density discontinuity centered at approximately 229.8 km altitude with a vertical extent of approximately 1 km and a magnitude of about 1.2%. This discontinuity is a direct result of the convergence criterion used in the integration procedure, and although a detailed description of this problem is beyond the scope of this report, a brief description of the problem and its solution follows.

As already stated, integration is performed using Simpson's Rule quadrature. The form of this procedure, as used here, is an iterative one, and is such that unnecessary re-evaluation of the integrand is not required at the "old" subinterval end- and mid-points when the number of subintervals is doubled. Specifically, if the number of subintervals is $2^J$, then the area $A(J)$ is given by

$$A(J) = \frac{1}{3} \ (\text{SOME})_J + \frac{4}{3}h_J \ (\text{STOW})_J$$

(2)
Figure 2(a) Contour plot of J70MM model mass density

Figure 2(b) Altitude plot of J70MM model mass density
where $h_J$ is the subinterval length (equal to $(D-A) \cdot 2^{-J}$ in subroutine INTEGRATE) and where $S\mathrm{ONE}$ and $S\mathrm{TO\ W}$ are functions of the integrand evaluated at subinterval end- and mid-points (the exact functional forms of $S\mathrm{ONE}$ and $S\mathrm{TO\ W}$ are not required here, but can be found in subroutine INTEGRATE). If the number of subintervals is now doubled (i.e. $2^{J+1}$), then the area calculated with this new number of subintervals ($A(J+1)$) in terms of $A(J)$ is

\[
A(J+1) = \frac{1}{2} A(J) - \frac{2}{3} h_{J+1} (S\mathrm{TO\ W})_J + \frac{4}{3} h_{J+1} (S\mathrm{TO\ W})_{J+1} \tag{3}
\]

Evaluation of $A(J+1)$ simply requires the evaluation of $(S\mathrm{TO\ W})_{J+1}$, because $A(J)$ and $(S\mathrm{TO\ W})_J$ are already known. Evaluation of $(S\mathrm{TO\ W})_{J+1}$ requires calculating the integrand at every point lying halfway between every "old" subinterval (2 of them) end- and mid-point.

Examination of equation (3) reveals that if

\[
\frac{4}{3} h_{J+1} (S\mathrm{TO\ W})_{J+1} - \frac{2}{3} h_{J+1} (S\mathrm{TO\ W})_J \approx \frac{1}{2} A(J) \tag{4}
\]

then iterative convergence, as defined in equation (1), may be achieved if the equality in equation (4) is "sufficiently close" (this will, of course, depend on the value of $\epsilon$). That equation (4), and hence that equation (1), could be satisfied by fluke is not beyond the realm of possibility, and in fact as it transpires, the discontinuities in Figures 2(a) and 2(b) are directly attributable to this fluke convergence. For altitudes below about 229.3 km and above about 230.3 km the integration procedure required that at least $2^5$ (i.e. 32) subintervals be used to ensure convergence. Between these two altitudes only $2^3$ (i.e. 8) subintervals were required for equation (1) to be satisfied, meaning that no significant increase in accuracy was achieved by increasing the number of subintervals from 4 to 8. However, a re-calculation using 16 subintervals showed that convergence had not been achieved. In fact, 32 subintervals were required to ensure convergence.

The remedy to this problem, which was implemented in, and subsequently incorporated into INTEGRATE, is a very simple one but may not be guaranteed under all conditions. Quite simply, above 180 km altitude, the number of subintervals used must be at least 16 (i.e. $2^4$) before convergence is tested using equation (1). Up until the present time this has always been successful, but any future encounters with problems related to this should be reported to either the author or to the Branch Chief, ED44, NASA/MSFC, Huntsville, Alabama 35812.

The results of using the new MET model, which incorporates these
modifications, are shown in figures 3(a) and 3(b). The input parameters used to generate these results are identical to those used for the corresponding results (using a modified J70MM program) shown in Figure 2. The MET model shows no sign of any discontinuities.

SUBROUTINE FAIR5

In the MET model, as in the J70MM model, the helium number density (and concomitantly the total mass density) above 500 km altitude is modified by seasonal-latitudinal variations according to the equations of Jacchia [2]. This seasonal-latitudinal variation of helium is calculated in subroutine SLVH. (This should not be confused with the seasonal-latitudinal variation of density which is calculated for altitudes between 90 and 170 km in subroutine SLV). In the J70MM model the inclusion of seasonal-latitudinal variations at altitudes above 500 km led to a discontinuity in the helium number densities (and also, therefore, in the total mass density) across the 500 km level. This undesirable feature of the J70MM model has been eliminated in the MET model by the use of subroutine FAIR5 [7]. FAIR5 is invoked between 440 and 500 km altitude, while SLVH is now invoked at all altitudes above 440 km (instead of 500 km). Using a spline routine, FAIR5 adds progressively more and more of the seasonal-latitudinal variation to the helium number densities as one progresses from 440 to 500 km altitude, so that no effect of SLVH is included at 440 km altitude, but the full affect of SLVH is included at 500 km altitude. While FAIR5 now corrects the density discontinuity problem at 500 km altitude, it does not in any way significantly effect the total mass density between the altitudes of 440 and 500 km, because helium is still a minor species in this altitude range.

SUBROUTINE J70SUP.

This subroutine calculates supplementary atmospheric parameters which are not directly calculated in J70. The input parameters for J70SUP are altitude and the entire OUTDATA array from J70. The output parameters calculated by J70SUP are \( g \) (gravitational acceleration), \( H \) (pressure scale-height), \( C_p \) (specific heat at constant pressure), \( C_v \) (specific heat at constant volume) and \( \gamma \) (ratio \( C_p/C_v \)).

For consistency \( g \) is calculated as in [1], given by

\[
g = 9.80665 \left(1 + \frac{Z}{R_e}\right)^{-2} \text{ms}^{-2}
\]

where \( Z \) is altitude (in km) and the Earth's radius \( R_e = 6.356766 \times 10^3 \text{ km} \). The equation for the pressure scale-height, \( H \), can be found in most standard texts (eg.[6]) and in a hydrostatic and
Figure 3(a) Contour plot of MET model mass density

Figure 3(b) Altitude plot of MET model mass density
Isothermal atmosphere is given by

\[ H = \frac{p}{\rho g} \]  

(6)

where \( p \) is pressure and \( \rho \) is mass density. The value of \( \gamma \) is then calculated from the weighted mean of all diatomic and monatomic gases by assuming that all diatomic gases have \( \gamma = 1.4 \) and all monatomic gases have \( \gamma = 1.67 \). By using equation (6), the equation of state and the fact that \( R = c_p - c_v \) (\( R \) is the gas constant) one obtains

\[ c_v = \frac{gH}{(\gamma-1)T} \]

(7)

where \( T \) is temperature.

**TEST CASE**

The following is a test case for the MET model. For the following input:

- Time: 1987, October 27, 1400 hrs
- Indices: \( F_{10.7} = 230 \), \( F_{10.7} = 230 \), \( AP = 400 \)
- Altitude = 200 km, Latitude = Longitude = 0°

The following output should obtain:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exospheric temperature</td>
<td>2105.903 K</td>
</tr>
<tr>
<td>Local temperature</td>
<td>1495.590 K</td>
</tr>
<tr>
<td>( N_2 ) number density</td>
<td>( 6.378800 \times 10^{15} ) m(^{-3} )</td>
</tr>
<tr>
<td>( O_2 ) number density</td>
<td>( 7.158251 \times 10^{14} ) m(^{-3} )</td>
</tr>
<tr>
<td>( O ) number density</td>
<td>( 4.897181 \times 10^{15} ) m(^{-3} )</td>
</tr>
<tr>
<td>( A ) number density</td>
<td>( 1.146983 \times 10^{13} ) m(^{-3} )</td>
</tr>
<tr>
<td>( H_2 ) number density</td>
<td>( 9.737494 \times 10^{12} ) m(^{-3} )</td>
</tr>
<tr>
<td>( H ) number density</td>
<td>( 1.000000 \times 10^6 ) m(^{-3} )</td>
</tr>
<tr>
<td>Average molecular weight</td>
<td>23.34522</td>
</tr>
<tr>
<td>Total mass density</td>
<td>( 4.656589 \times 10^{-10} ) kgm(^{-3} )</td>
</tr>
<tr>
<td>( \log_{10} ) (mass density)</td>
<td>-12.33193</td>
</tr>
<tr>
<td>Total pressure</td>
<td>( 2.480329 \times 10^{-4} ) Pa</td>
</tr>
<tr>
<td>Local gravitational acceleration</td>
<td>9.217513</td>
</tr>
<tr>
<td>Ratio of specific heats</td>
<td>1.510544</td>
</tr>
<tr>
<td>Pressure scale-height</td>
<td>57786.66</td>
</tr>
<tr>
<td>Specific heat at constant pressure</td>
<td>1053.729 m(^2s(^{-2}K(^{-1} )</td>
</tr>
<tr>
<td>Specific heat at constant volume</td>
<td>697.5829 m(^2s(^{-2}K(^{-1} )</td>
</tr>
</tbody>
</table>

For the same input conditions the original J70MM model produced an exospheric temperature of 2105.775K, a local temperature of 1495.539K and a mass density of \( 4.656528 \times 10^{-10} \) kgm\(^{-3} \) (the en-
tire output from J70MM is not given here). Therefore, for this particular case the differences between results from the MET model and the J70MM model are typically less than 0.01%. One must remember, however, that occasionally results from the two models will differ by more than 1% (eg. Figure 2).

CONCLUSIONS AND RECOMMENDATIONS

This report has described how the MSFC/J0 model was modified in order to produce the NASA/MET model. Although this report has been primarily concerned with the several modifications which directly affect the numerical output of the MET model, most of the modifications to the MSFC/J70 model entailed extensive rewriting of the FORTRAN code with the result that the MET model, written in FORTRAN 77, is easy to follow and easy to tailor to suit ones individual needs. The MET model computer program, listed in the Appendix, should be compared with the J70MM model computer program, which is listed in [3].

Most of the numerical differences between the output of the two models is generally small, and typically fractions of a percent. Occasionally, however, differences can be about one percent (in total mass density), and these are associated with the intermittent integration error in the MSFC/J70 model. The MET model outputs several parameters which the MSFC/J70 (or J70MM) model did not. These extra parameters may be useful to some users.

The MET model is currently available to users who have access to the NASA/GSFC ENVIRONET network. In the present report, it is recommended that the MET model replace the MSFC/J70 and J70MM models for all studies relating to all design, building and operations of NASA space vehicles.
References


APPENDIX

The Marshall Space Flight Center

Marshall Engineering Thermosphere Model

written by

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This program is a driving program for the following subroutines :-

ATMOSPHERES

SOLSET

TIME

J70

The atmospheric model is a modified Jacchia 1970 model and is given in
the subroutine J70. All of the other subroutines were designed to
allow flexible use of this model so that various input parameters could
be varied within a driving program with very little software development.
Thus, for example, driving routines can be written quite easily to
facilitate the plotting of output as line or contour plots. Control is
achieved by setting the values of four switches in the driving program,
as described in subroutine ATMOSPHERES.

REAL*4 INDATA (12) , OUTDATA (12) , AUXDATA (5)

CHARACTER*1 SWITCH (4)

CALL LIB$INIT TIMER

C Set all switches to 'Y' so that only one particular calculation is performed

SWITCH (1) = 'Y'

SWITCH (2) = 'Y'

SWITCH (3) = 'Y'

SWITCH (4) = 'Y'

CALL ATMOSPHERES ( INDATA, OUTDATA, AUXDATA, SWITCH )

C Now type output data

Type *, ' All output in MKS units'

Type *, ' Exospheric temperature = ', OUTDATA (1), ' K'

Type *, ' Temperature = ', OUTDATA (2), ' K'

Type *, ' N2 number density = ', OUTDATA (3), '/m3'

Type *, ' O2 number density = ', OUTDATA (4), '/m3'

Type *, ' O number density = ', OUTDATA (5), '/m3'

Type *, ' A number density = ', OUTDATA (6), '/m3'

Type *, ' He number density = ', OUTDATA (7), '/m3'

Type *, ' H number density = ', OUTDATA (8), '/m3'

Type *, ' Average molecular wt. = ', OUTDATA (9)

Type *, ' Total mass density = ', OUTDATA (10), ' kg/m3'

Type *, ' Log10 mass density = ', OUTDATA (11)

Type *, ' Total pressure = ', OUTDATA (12), ' Pa'

Type *, ' Local grav. acceln. = ', AUXDATA (1), ' m/sec'

Type *, ' Ratio specific heats = ', AUXDATA (2)

Type *, ' Pressure scale-height = ', AUXDATA (3), ' m'

Type *, ' Specific heat cons. p = ', AUXDATA (4), ' m2.sec-2.K-1'

PRECEDING PAGE BLANK NOT FILMED
Type *; Specific heat cons. \( v = ' \), AUXDATA (5),\' m2.sec\(^{-2}\).K\(^{-1}\) Type *; '*

CALL LIB$SHOW_TIMER
STOP
END
SUBROUTINE ATMOSPHERES ( INDATA, OUTDATA, AUXDATA, SWITCH )

DESCRIPTION:

Calculate atmospheric data in single precision using subroutine J70 and J70SUP.

SUBRoutines:

TIME, SOLSET, GMC, J70 and J70SUP

INPUT:

all single precision, either through subroutines or from main driver program.

INDATA (1) — altitude = Z
(2) — latitude = XLAT
(3) — longitude = XLNG
(4) — year (yy) = IYR
(5) — month (mm) = MN
(6) — day (dd) = IDA
(7) — hour (hh) = IHR
(8) — mins (mm) = MIN
(9) — geomagnetic index = IGEO_IND
(10) — solar radio noise flux F10
(11) — 162-day average F10 = F10B
(12) — geomagnetic activity index = GI=AP

OUTPUT:

NOTE: All output in MKS units

OUTDATA (1) — exospheric temperature (K)
(2) — temperature at altitude Z
(3) — N2 number density (per meter-cubed)
(4) — O2 number density
(5) — O number density
(6) — A number density
(7) — He number density
(8) — H number density
(9) — average molecular weight
(10) — total density
(11) — log10 (total density)
(12) — total pressure (Pa)

AUXDATA (1) — gravitational acceleration (m/s-s)
(2) — ratio of specific heats
(3) — pressure scale-height (m)
(4) — specific heat at constant pressure
(5) — specific heat at constant volume

COMMENTS:

SWITCH(1) — if Y(es), date and time are input from terminal through subroutine TIME once only
SWITCH(2) — if Y(es), solar/magnetic activity are input from terminal through subroutine SOLSET once only
SWITCH(3) — if Y(es), only ONE altitude value is input from terminal through main calling program
SWITCH(4) — if Y(es), only ONE latitude AND longitude are input from terminal through main calling program
EXTERNAL TIME

DIMENSION AUXDATA (5)

INTEGER HR

REAL*4 LAT, LON, INDATA (12), OUTDATA (12)

CHARACTER*1 SWITCH (4)

PARAMETER PI = 3.14159265

This next section is only executed on the first call to ATMOSPHERES

DO WHILE ( CALL. EQ. 0.0 )

SECTION A:

IF ( SWITCH(1). EQ. 'Y' ) THEN

CALL TIME ( IYR, MON, IDA, HR, MIN, SWITCH(1) )

INDATA (4) = FLOATJ (IYR)

INDATA (5) = FLOATJ (MON)

INDATA (6) = FLOATJ (IDA)

INDATA (7) = FLOATJ (HR)

INDATA (8) = FLOATJ (MIN)

END IF

SECTION B:

IF ( SWITCH(2). EQ. 'Y' ) THEN

CALL SOLSET ( IGEO_IND, F10, FI0B, GI, SWITCH(2) )

INDATA (9) = FLOATJ (IGEO_IND)

INDATA (10) = F10

INDATA (11) = FI0B

INDATA (12) = GI

END IF

SECTION C:

IF ( SWITCH(3). EQ. 'Y' ) THEN

TYPE *, ' Input altitude, km'

ACCEPT *, INDATA (1)

Z = INDATA (1)

END IF

SECTION D:

IF ( SWITCH(4). EQ. 'Y' ) THEN

TYPE *, ' Input latitude and longitude, degrees'

ACCEPT *, ( INDATA(1), I= 2,3 )

LAT = INDATA (2)

LON = INDATA (3)

RLT = INDATA (2) * PI / 180.  ! geographic latitude, radians
CALL = 1.0
END DO

C End of first executable section
C
C The following depend on the values of the switches
C****
C* SECTION 1:-
    IF ( SWITCH(1). NE. 'Y' ) THEN
        IYR = JINT ( INDATA (4) )
        MON = JINT ( INDATA (5) )
        IDA = JINT ( INDATA (6) )
        HR = JINT ( INDATA (7) )
        MIN = JINT ( INDATA (8) )
        CALL TIME ( IYR, MON, IDA, HR, MIN, SWITCH(1) )
    END IF
C*****
C* SECTION 2:-
    IF ( SWITCH(2). NE. 'Y' ) THEN
        IGEO_IND = JINT ( INDATA (9) )
        F10 = INDATA (10)
        F10B = INDATA (11)
        GI = INDATA (12)
        CALL SOLSET ( IGEO_IND, F10, F10B, GI, SWITCH(2) )
    END IF
C*****
C* SECTION 3:-
    IF ( SWITCH(3). NE. 'Y' ) THEN
        Z = INDATA (1)
    END IF
C*****
C* SECTION 4:-
    IF ( SWITCH(4). NE. 'Y' ) THEN
        LAT = INDATA (2)
        LON = INDATA (3)
        RLT = INDATA (2) * PI / 180.  ! geographic latitude, radians
    END IF
C All setting-up complete.
    CALL J70 ( INDATA, OUTDATA )
    CALL J70SUP ( Z, OUTDATA, AUXDATA )
RETURN
ENTRY ATMOS_ENT ( DUMMY )
CALL = DUMMY
RETURN
END
SUBROUTINE TIME ( IYR, MON, IDA, HR, MIN, SWITCH )

This subroutine sets up time of year and day

INPUTS/OUTPUTS:

IYR = year (2 digits)
MON = month
IDA = day of month
HR = hour of day
MIN = minutes

Written by Mike Hickey, USRA

DIMENSION IDAY (12)
INTEGER HR
CHARACTER*1 SWITCH

DATA IDAY / 31, 28, 31, 30, 31, 30, 31, 30, 31, 30, 31, 30, 31 /

PARAMETER PI = 3.14159265

C If SWITCH = Y(es) then input data and time from terminal

IF ( SWITCH.EQ.'Y'. OR. SWITCH.EQ.'y' ) THEN

TYPE *, 'Input date and time of date? (yy,mm,dd,hh,mm)' ACCEPT *, IYR, MON, IDA, HR, MIN

END IF

IF ( JMOD (IYR,4) .EQ. 0 ) THEN

IF ( JMOD (IYR,100) .NE. 0 ) IDAY (2) = 29
ELSE

IDAY (2) = 28
ENDIF

DAYTOT = 0.0

DO 1 I = 1, 12

DAYTOT = DAYTOT + FLOATJ ( IDAY (I) )

CONTINUE

IF ( MON. GT. 1 ) THEN

KE = MON - 1
ID = 0

DO 2 I = 1, KE

ID = ID + IDAY (I)

CONTINUE

ID = ID + IDA

DD = IDA

ELSE

RETURN

END
SUBROUTINE SOLSET ( IGEO_IND, F10, F10B, GI, SWITCH )

C**************************************************************************
C*
C* This subroutine simply calls for a setup of the solar-activity and auroral
C* activity indices.
C*
C**************************************************************************

C**** INPUTS/OUTPUTS: 
C****
C**** IGEO_IND = geomagnetic index 
C**** F10 = solar radio noise flux 
C**** F10B = 162-day average F10 
C**** GI = geomagnetic activity index 
C**** Written by Mike Hickey, USRA

CHARACTER*1 SWITCH

IGEO_IND = 2

IF ( SWITCH.EQ.'Y'. OR. SWITCH.EQ.'y' ) THEN
    TYPE *, ' Input geomagnetic index ( l-KP, 2-AP ) '
    ACCEPT *, IGEO_IND
    TYPE *, ' Input solar radio noise flux ( F10 = 0-400 ) '
    ACCEPT *, F10
    TYPE *, ' Input 162-day average F10 ( F10B = 0-250 ) '
    ACCEPT *, F10B
    IF ( IGEO_IND . EQ. 2 ) THEN
        TYPE *, ' Input geomagnetic activity index ( GI = 0-400 ) '
    ELSE
        TYPE *, ' Input geomagnetic activity index ( GI = 0-9 ) '
    END IF
    TYPE *, ' Input AP index ( AP = 0 - 400 ) '
    ACCEPT *, GI
END IF

RETURN
END
SUBROUTINE J70SUP ( Z, OUTDATA, AUXDATA )

C* DESCRIPTION:--
C* J70SUP calculates auxiliary variables which are output in array
C* AUXDATA, given data input from J70 which are contained in array OUTDATA.
C* INPUT DATA:--
C* Z — altitude (km)
C* TZZ — temperature at altitude z = OUTDATA (2)
C* N2 — N2 number density = .. (3)
C* O2 — O2 number density = .. (4)
C* A — A number density = .. (5)
C* He — He number density = .. (7)
C* EM — average molecular weight = .. (9)
C* DENS — total density = .. (10)
C* P — total pressure = .. (12)
C* OUTPUT DATA:--
C* G — gravitational acceleration = AUXDATA (1)
C* GAM — ratio of specific heats = AUXDATA (2)
C* H — pressure scale-height = AUXDATA (3)
C* CP — specific heat at constant pressure = AUXDATA (4)
C* CV — specific heat at constant volume = AUXDATA (5)
C* Written by Mike Hickey, USRA

REAL*4 OUTDATA (12), AUXDATA (5), H
G = 9.80665 / ( ( 1. + Z / 6.356766E3 )**2 )
H = OUTDATA (12) / ( G * OUTDATA (10) )
SUM1 = OUTDATA (3) + OUTDATA (4)
SUM2 = 0.8
DO 1 I = 5, 8
   SUM2 = SUM2 + OUTDATA (I)
   CONTINUE
GAM = ( 1.4 * SUM1 + 1.67 * SUM2 ) / ( SUM1 + SUM2 )
CV = G * H / ( ( GAM - 1.0 ) * OUTDATA (2) )
CP = GAM * CV
AUXDATA (1) = G
AUXDATA (2) = GAM
AUXDATA (3) = H
AUXDATA (4) = CP
AUXDATA (5) = CV
RETURN
END
SUBROUTINE J70 (INDATA, OUTDATA)

C******************************************************************************
C** ++
C** J70 developed from J70AM by
C** Mike P. Hickey
C** Universities Space Research Association
C** at
C** NASA / Marshall Space Flight Center, ED44,
C** Huntsville, Alabama, 35812, USA.
C** Tel. (205) 544-5692
C**
C** INPUTS: through the subroutine calling list
C** OUTPUTS: through the subroutine calling list
C**

C******************************************************************************
C**
C** INPUT DATA:
C**
Z — altitude = INDATA (1)
XLAT — latitude = INDATA (2)
XLNG — longitude = INDATA (3)
IYR — year (yy) = INDATA (4)
MN — month (mm) = INDATA (5)
IDA — day (dd) = INDATA (6)
IHR — hour (hh) = INDATA (7)
MIN = mins (mm) = INDATA (8)
I1 — geomagnetic index = INDATA (9)
F10 — solar radio noise flux = INDATA (10)
F10B — 162-day average F10 — INDATA (11)
GI — geomagnetic activity index = INDATA (12)
C**
C**
C** OUTPUT DATA:
C**
T — exospheric temperature = OUTDATA (1)
TZZ — temperature at altitude Z = OUTDATA (2)
A(1) — N2 number density = OUTDATA (3)
A(2) — O2 number density = OUTDATA (4)
A(3) — O number density = OUTDATA (5)
A(4) — A number density = OUTDATA (6)
A(5) — He number density = OUTDATA (7)
A(6) — H number density = OUTDATA (8)
EM — average molecular weight = OUTDATA (9)
DENS — total density = OUTDATA (10)
DL — log10 (total density) = OUTDATA (11)
P — total pressure = OUTDATA (12)
C**
C**
C** NB. Input through array 'INDATA'
C** Output through array 'OUTDATA'
C******************************************************************************

DIMENSION A (6)
REAL*4 INDATA (12), OUTDATA (12)
PARAMETER RGAS = 8.31432E3
PARAMETER BFH = 440.0

C Calculations performed for only one latitude, one longitude
C and one altitude

C
C** Set parameters to INDATA values
C
Z = INDATA (1)
XLAT = INDATA (2)
XLNG = INDATA (3)
IYR = JINT (INDATA (4)) + 1900
MN = JINT (INDATA (5))
IDA = JINT (INDATA (6))
IHR = JINT (INDATA (7))
MIN = JINT (INDATA (8))
I1 = JINT (INDATA (9))
F10 = INDATA (10)
CALL TME (MN, IDA, IYR, IHR, MIN, XLAT, XLANG, SDA,
         SHA, DD, DY)
CALL TINF (F10, F10B, GI, XLAT, SDA, SHA, DY, I1, TE)
CALL JAC (Z, TE, TZ, A(1), A(2), A(3), A(4), A(5), A(6),
          EM, DENS, DL )

DENLG = 0.
DUMMY = DL
DEN = DL

IF (Z.LE.170.) THEN
   CALL SLV (DUMMY, Z, XLAT, DD)
   DENLG = DUMMY
END IF

C
C** 'Fair' helium number density between base fairing height (BFH) and 500 km
C

IF (Z.GT.500.) THEN
   CALL SLVH (DEN, A(5), XLAT, SDA)
   DL = DEN
ELSE IF (Z.GT.BFH) THEN
   DHEL1 = A(5)
   DHEL2 = A(5)
   DLG1 = DL
   DLG2 = DL
   CALL SLVH (DLG2, DHEL2, XLAT, SDA)
   IH = Z
   CALL FAIR5 (DHEL1, DHEL2, DLG1, DLG2, IH, FDHEL, FDLG)
   DL = FDLG
   A(5) = FDHEL
END IF

DL = DL + DENLG
DENS = 10.**DL
XLAT = XLAT * 57.29577951

C Fill OUTDATA array
OUTDATA (1) = TE
OUTDATA (2) = TZ

DO 80 I = 1, 6
OUTDATA (I+2) = 1.E6 * (10.**A(I))
80 CONTINUE

OUTDATA (9) = EM
OUTDATA (10) = DENS * 1000.
OUTDATA (11) = DL
P = OUTDATA (10) * RGAS * TZ / EM
OUTDATA (12) = P

RETURN
END
SUBROUTINE TME (MN, IDA, IYR, IHR, MIN, XLAT, XLNG, SDA, SHA, DD, DY)

C******************************************************************************
C** Subroutine 'TME' performs the calculations of the solar declination angle and solar hour angle.
C**
C** INPUTS:
C**     MN = month
C**     IDA = day
C**     IYR = year
C**     IHR = hour
C**     MIN = minute
C**     XMJD= mean Julian date
C**     XLAT= latitude (input-geocentric latitude )
C**     XLNG= longitude (input-geocentric longitude, -180,+180)
C**
C** OUTPUTS:
C**     SDA = solar declination angle (rad)
C**     SHA = solar hour angle (rad)
C**     DD = day number from 1 JAN.
C**     DY = DD / tropical year
C**     Modified by Mike Hickey, USRA
C******************************************************************************

DIMENSION IDAY(12)

DATA IDAY / 31,28,31,30,31,30,31,31,30,31,30,31 /
PARAMETER YEAR = 365.2422
PARAMETER A1 = 99.0719833, A2 = 36000.76892
PARAMETER A3 = 0.00038799, A4 = 0.250684477
PARAMETER B1 = 0.0172028, B2 = 0.00335, B3 = 1.407
PARAMETER PI = 3.14159265, TPI = 6.28318531
PARAMETER PI2 = 1.57079633, PI32 = 4.71238898
PARAMETER RAD-DEG = 0.017453293

XLAT = XLAT / 57.29577951
YR = IYR

IF ( JMOD(IYR, 4) .EQ. 0 ) THEN
  IF ( JMOD(IYR, 100) .NE. 0 ) IDAY(2) = 29 1 Century not a leap year
ELSE
  IDAY(2) = 28
END IF

IF ( MN.GT. 1 ) THEN
  ID = 0
  DO 20 I = 1, MN-1
    ID = ID + IDAY(I)
  END DO
  CONTINUE
END IF

ID = ID + IDA
DD = ID
DY = DD/YEAR

C** Compute mean Julian date
C
XMJD = 2415020. + 365. * ( YR - 1900.) + DD
  + FLOATJ ( ( IYR - 1901 ) / 4 )

C** Compute Greenwich mean time in minutes GMT
C
XHR = IHR
XMIN = MIN
GMT = 60 * XHR + XMIN
FMJD = XMJD - 2435839. + GMT / 1440.

C** Compute Greenwich mean position - GP (in rad)
C
XJ = ( XMJD - 2415020.5 ) / ( 36525.0 )
GP = AMOD ( A1 + A2 * XJ + A3 * XJ * XJ + A4 * GMT, 360. )

C** Compute right ascension point - RAP (in rad)
C
C** 1st convert geocentric longitude to deg longitude - west neg, + east
IF ( XLNG .GT. 180. ) XLNG = XLNG - 360.

RAP = AMOD ( GP + XLNG, 360. )

C
C** Compute celestial longitude - XLS ( in rad ) -- zero to 2PI
C
Y1 = B1 * FMJD
Y2 = 0.017202 * ( FMJD - 3. )
XLS = AMOD ( Y1 + B2 * SIN(Y2) - B3, TPI )

C
C** Compute solar declination angle - SDA ( in rad )
C
B4 = RAD_DEG * ( 23.4523 - 0.013 * XJ )
SDA = ASIN ( SIN ( XLS ) * SIN ( B4 ) )

C
C** Compute right ascension of Sun - RAS ( in rad ) -- zero to 2PI
C
RAS = ASIN ( TAN ( SDA ) / TAN ( B4 ) )

C
C** Put RAS in same quadrant as XLS
C
RAS = ABS ( RAS )
TEMP = ABS ( XLS )
IF ( TEMP.LE.PI .AND. TEMP.GT.PI2 ) THEN
   RAS = PI - RAS
ELSE IF ( TEMP.LE.PI32 .AND. TEMP.GT.PI ) THEN
   RAS = PI + RAS
ELSE IF ( TEMP.GT.PI32 ) THEN
   RAS = TPI - RAS
END IF
   IF ( XLS.LT.0. ) RAS = -RAS

C
C** Compute solar hour angle - SHA ( in deg ) --
C
SHA = RAP * RAD_DEG - RAS
IF ( SHA.GT.PI ) SHA = SHA - TPI
IF ( SHA.LT.-PI ) SHA = SHA + TPI

RETURN
END
SUBROUTINE TINF ( F1O, F10B, GI, XLAT, SDA, SHA, DY, I1, TE )

C*****************************************************************************
C**** Subroutine 'TINF' calculates the exospheric temperature according to **
C**** L. Jacchia SAO 313, 1970 **
C*****************************************************************************

PARAMETER PI = 3.14159265 , TPI = 6.28318531
PARAMETER XM = 2.5 , XNN = 3.0

C** Ci are solar activity variation variables
PARAMETER C1 = 383.0 , C2 = 3.32 , C3 = 1.80

C** Di are geomagnetic variation variables
PARAMETER D1 = 28.0 , D2 = 0.03 , D3 = 1.0 , D4 = 100.0 , D5 = -0.08

C** Ei are semiannual variation variables
PARAMETER E1 = 2.41 , E2 = 0.349 , E3 = 0.206 , E4 = 6.28318531
PARAMETER E5 = 3.9531708 , E6 = 12.5663706 , E7 = 4.3214352
PARAMETER E8 = 0.1145 , E9 = 0.5 , E10 = 6.28318531
PARAMETER E11 = 5.9742620 , E12 = 2.16

PARAMETER BETA = -0.6457718 , GAMMA = 0.7504916 , P = 0.1047198
PARAMETER RE = 0.31

C** solar activity variation
TC = C1 + C2 * F10B + C3 * ( F1O - F10B )

C** diurnal variation
ETA = 0.5 * ABS ( XLAT - SDA )
THETA = 0.5 * ABS ( XLAT + SDA )
TAU = SHA + BETA + P * SIN ( SHA + GAMMA )

IF ( TAU. GT. PI ) TAU = TAU - TPI
IF ( TAU. LT.41 ) TAU = TAU + TPI

A1 = ( SIN ( THETA ) )**XM
A2 = ( COS ( ETA ) )**XM
A3 = ( COS ( TAU / 2. ) )**XNN
B1 = 1.0 + RE * A1
B2 = ( A2 - A1 ) / B1
TV = B1 * ( 1. + RE * B2 * A3 )
TL = TC * TV

C** geomagnetic variation
IF ( I1.EQ.1 ) THEN
TG = D1 * GI + D2 * EXP(GI)
ELSE
TG = D3 * GI + D4 * ( 1 - EXP ( D5 * GI ) )
END IF

C
C** semiannual variation
C
   G3 = 0.5 * ( 1.0 + SIN ( E10 * DY + E11 ) )
   G3 = G3 ** E12
   TAU1 = DY + E8 * ( G3 - E9 )
   G1 = E2 + E3 * ( SIN ( E4 * TAU1 + E5 ) )
   G2 = SIN ( E6 * TAU1 + E7 )
   TS = E1 + F10B * G1 * G2
C
C** exospheric temperature
C
   TE = TL + TG + TS
RETURN
END
SUBROUTINE JAC ( Z , T , TZ , AN , A02 , AO , AA , AH , EM , DENS , DL )

C******************************************************************************
C** **
C** Subroutine 'JAC' calculates the temperature TZ , the total density DENS **
C** and its logarithm DL, the mean molecular weight EM, the individual **
C** specie number densities for N, O2, O, A, HE and H ( each preceded with **
C** an 'A' ) at altitude Z given the exospheric temperature T. **
C** This subroutine uses the subroutine 'INTEGRATE' and the function **
C** subprograms 'TEMP' and 'MOL_WT'. **
C** Rewritten by Mike Hickey, USRA **
C******************************************************************************

DIMENSION ALPHA(6) , EI(6) , DI(6) , DIT(6)
REAL*4 MOL_WT
PARAMETER AV = 6.02257E23
PARAMETER QN = .78110
PARAMETER QO2 = .20955
PARAMETER QA = .009343
PARAMETER QHE = 1.289E-05
PARAMETER RGAS = 8.31432
PARAMETER PI = 3.14159265
PARAMETER TO = 183.
GRAVITY ( ALTITUDE ) = 9.80665 / ( ( 1. + ALTITUDE / 6.356766E3 )**2 )

DATA ALPHA / 0.0 , 0.0 , 0.0 , 0.0 , -.380 , 0.0 /
DATA EI / 28.0134 , 31.9988 , 15.9994 , 39.948 , 4.0026 , 1.00797 /

TX = 444.3807 + .02385 * T - 392.8292 * EXP ( -.0021357 * T )
A2 = 2. * (T-TX) / PI
TX-T0 = TX - T0
T1 = 1.9 * TX-T0 / 35.
T3 = -1.7 * TX-T0 / ( 35.*3 )
T4 = -0.8 * TX-T0 / ( 35.*4 )
TZ = TEMP (2, TX, T1 , T3, T4, A2)

A = 90.
D = AMIN1 ( Z , 105. )

FA = MOL_WT ( A ) * GRAVITY ( A ) / TEMP ( A , TX , T1 , T3 , T4 , A2 )
GD = GRAVITY ( D )
TD = TEMP ( D , TX , T1 , T3 , T4 , A2 )
EM = MOL_WT ( D )
FD = EM * GD / TD

C Integrate gM/T from 90 to minimum of Z or 105 km :-
CALL INTEGRATE ( A , D , FA , FD , R , TX , T1 , T3 , T4 , A2 )

C The number 2.1926E-8 = density x temperature/mean molecular weight at 90 km.
DENS = 2.1926E-8 * EM * EXP( -R / RGAS ) / TD
FACTOR = AV * DENS
PAR = FACTOR / EM
FACTOR = FACTOR / 28.96

C For altitudes below and at 105 km calculate the individual specie number C densities from the mean molecular weight and total density.

IF ( Z .LE. 105 ) THEN

DL = ALOG10 ( DENS )
AN = ALOG10 ( QN * FACTOR )
AA = ALOG10 ( QA * FACTOR )
AHE = ALOG10 ( QHE * FACTOR )
AO = ALOG10 ( 2. * PAR * ( 1.-EM / 28.96 ) )
AO2 = ALOG10 ( PAR * ( EM * ( 1.+Q02 ) / 28.96-1. ) )
A0 = ALOG10 ( 2. * PAR * ( 1.-EM / 28.96 ) )
A02 = ALOG10 ( PAR * ( EM * ( 1.+Q02 ) / 28.96-1. ) )
AH = 0.

C** Return to calling program
C
RETURN

END IF

C** SECTION 2 : This section is only performed for altitudes above 105 km
C

C Note that having reached this section means that D in section 1 is 105 km.
C

C Calculate individual specie number densities from the total density and mean
C molecular weight at 105 km altitude.

DI(1) = QN * FACTOR
DI(2) = PAR * ( EM * ( 1.+Q02 ) / 28.96-1. )
DI(3) = 2. * PAR * ( 1.-EM / 28.96 )
DI(4) = QA * FACTOR
DI(5) = QHE * FACTOR
FA1 = GD / TD
FD1 = GRAVITY ( Z ) / TZ

CALL INTEGRATE ( D , Z , FA1 , FD1 , R , TX , T1 , T3 , T4 , A2 )

DO 41 I = 1 , 5
DIT(I) = DI(I) * ( TD / TZ ) **(1.+ALPHA(I)) * EXP ( -EI(I) * R / RGAS)
IF ( DIT(I) .LE. 0. ) DIT(I) = 1.E-6
CONTINUE

C** This section calculates atomic hydrogen densities above 500 km altitude.
C** Below this altitude, H densities are set to 10**-6.
C** SECTION 3
C

IF ( Z .GT. 500. ) THEN
    A1 = 500.
    S = TEMP ( A1 , TX , T1 , T3 , T4 , A2 )
    DI(6) = 10.** ( 73.13 - 39.4 * ALOG10 ( S ) + 5.5 * ALOG10 ( S ) * ALOG10 ( S ) )
    FA1 = GRAVITY ( A1 ) / S
    CALL INTEGRATE ( A1 , Z , FA1 , FD1 , R , TX , T1 , T3 , T4 , A2 )
    DIT(6) = DI(6) * ( S/TZ ) * EXP ( -EI(6) * R / RGAS )
ELSE
    DIT(6) = 1.0
ENDIF

30
C For altitudes greater than 185 km, calculate total density and mean
C molecular weight from individual specie number densities.

DENS=0
DO 42 I = 1 , 6
   DENS = DENS + EI(I) * DIT(I) / AV
42 CONTINUE

EM = DENS * AV / ( DIT(1)+DIT(2)+DIT(3)+DIT(4)+DIT(5)+DIT(6) )
DL = ALOG10 (DENS)

AN = ALOG10(DIT(1))
A02 = ALOG10(DIT(2))
AO = ALOG10(DIT(3))
AA = ALOG10(DIT(4))
AHE = ALOG10(DIT(5))
AH = ALOG10(DIT(6))

RETURN
END
FUNCTION TEMP ( ALT, TX, T1, T3, T4, A2 )

C******************************************************************************
C* Function subprogram 'TEMP' calculates the temperature at altitude ALT **
C* using equation (10) for altitudes between 90 and 125 km and equation **
C* (13) for altitudes greater than 125 km, from SAO Report 313. **
C******************************************************************************
C* Written by Mike Hickey, USRA **
C******************************************************************************

PARAMETER BB = 4.5E-6

REAL FUNCTION MOLWT4 ( A )

C******************************************************************************
C* Subroutine 'MOLWT' calculates the molecular weight for altitudes **
C* between 90 and 105 km according to equation (1) of SAO report 313. **
C* Otherwise, MOLWT is set to unity. **
C* Written by Mike Hickey, USRA **
C******************************************************************************

DIMENSION B (7)

DATA B / 28.15204, -0.005586, 1.284E-4, -1.0056E-5, -1.021E-5, -1.821E-5, 1.5044E-6, 9.9826E-8 /

IF ( A .GT. 105. ) THEN
   MOLWT = 1.
ELSE
   U = A - 100.
   MOLWT = B (1)
   DO 1 I = 2, 7
   MOLWT = MOLWT + B (I) * U ** ( I-1 )
1 CONTINUE
ENDIF
SUBROUTINE INTEGRATE ( A, D, FA, FD, RR, TX, T1, T3, T4, A2 )

C******************************************************************************
C Subroutine 'INTEGRATE' performs the Simpson's Rule quadrature (SRQ4) *
C implemented by G. F. Kuncir.
C******************************************************************************
C A = lower limit of integration
C D = upper limit of integration
C EPS = relative error convergence criterion
C M = maximum number of integrations
C RR = result of integration
C N = number of integrations required to find R
C******************************************************************************
C Written by Mike Hickey, USRA
C******************************************************************************

DIMENSION B (7)
REAL*4 MOLWT, R (0:10)

GRAVITY (ALTITUDE) = 9.80665 / ((1. + ALTITUDE / 6.356766E3)**2)

M = 10
EPS = .0001
SONE = (D - A) * (FA + FD) / 0.5
R (0) = 0.0

DO 2 N = 1, M
NINT = 2 ** N
STOW = 0.
DEL = (D - A) / FLOAT(NINT)

DO 1 111.N = 1, NINT, 2
X = A + DEL * FLOAT(I)
FX = MOLWT(X) * GRAVITY(X) / TEMP(X, TX, T1, T3, T4, A2)
STOW = STOW + FX
1 CONTINUE


C For altitudes greater than 180 km N usually reaches 5 or 6 before
C convergence is achieved. Quite occasionally, R can appear to reach
C convergence for N=3 at altitudes above 200 km. This anomalous and erroneous
C result can be avoided by forcing N to go to values greater than 3 before
C checking for convergence at altitudes greater than 180 km :

IF ((D.GE.180. .AND. N.GE.4) .OR. D.LT.180.) THEN
  IF (EPS*ABS(R(N)).GE.ABS(R(N) - R(N-1))) THEN
    RR = R(N)
    RETURN
  END IF
END IF

SONE = 0.25 * (SONE + 3. * R(N))

D IF (N.EQ.M) TYPE *,'WARNING : Convergence not achieved'

2 CONTINUE

RETURN
END
SUBROUTINE SLV ( DEN , ALT , XLAT , DAY )

C** Subroutine 'SLV' computes the seasonal-latitudinal variation of density **
C** in the lower thermosphere in accordance with L. Jacchia, SAO 332, 1971. **
C** This affects the densities between 90 and 170 km. This subroutine need **
C** not be called for densities above 170 km, because no effect is observed. **
C**
C** The variation should be computed after the calculation of density due to **
C** temperature variations and the density ( DEN ) must be in the form of a **
C** base 10 log. No adjustments are made to the temperature or constituent **
C** number densities in the region affected by this variation. **
C**
C** initialize density (DEN) = 0.0
C
DEN = 0.0
C
C** check if altitude exceeds 170 km
C
IF ( ALT . GT. 170. ) RETURN
C
C** compute density change in lower thermosphere
C
Z = ALT - 90.
X = -0.0013 * Z * Z
Y = 0.0172 * DAY + 1.72
P = SIN (Y)
SP = ( SIN (XLAT) ) **2
S = 0.014 * Z * EXP (X)
D = S * P * SP

C** check to compute absolute value of 'XLAT'
C
IF ( XLAT . LT. 0. ) D = -D
DEN = D

RETURN
END
SUBROUTINE SLVH ( DEN , DENHE , XLAT , SDA )

C********************************************************************
C** Subroutine 'SLVH' computes the seasonal-latitudinal variation of the
C** helium number density according to L. Jacchia, SAO 332, 1971. This
C** correction is not important below about 500 km.
C**
C** DEN = density (log10)
C** DENHE = helium number density (log10)
C** XLAT = latitude (rad)
C** SDA = solar declination angle (rad)
C********************************************************************

D0 = 10. ** DENHE
A = ABS ( 0.65 * ( SDA / 0.40909079 ) )
B = 0.5 * XLAT

C*+ Check to compute absolute value of 'B'
C
IF ( SDA. LT. 0. ) B = -B

C*+ compute X, Y, DHE and DENHE
C
X = 0.7854 - B
Y = ( SIN (X) ) ** 3
DHE = A * ( Y - 0.35356 )
DENHE = DENHE + DHE

C*+ compute helium number density change
C
D1 = 10. ** DENHE
DEL = D1 - D0
RHO = 10. ** DEN
DRHO = ( 6.846E-24 ) * DEL
RHO = RHO + DRHO
DEN = ALOG10 (RHO)

RETURN
END
SUBROUTINE FAIR5 ( DHEL1 , DHEL2 , DLG1 , DLG2 , IH , FDHEL , FDLG )

C******************************************************************************
C This subroutine fairs between the region above 500 km, which invokes the
C seasonal-latitudinal variation of the helium number density ( subroutine
C SLVH ), and the region below, which does not invoke any seasonal-
C latitudinal variation at all.
C******************************************************************************
C** INPUTS:  DHEL1 - helium number density before invoking SLVH
C**        DHEL2 - helium number density after invoking SLVH
C**        DLG1 - total density before invoking SLVH
C**        DLG2 - total density after invoking SLVH
C**        IH  - height ( km ) — INTEGER
C**        IBFH - base fairing height ( km ) — INTEGER
C** OUTPUTS: FDHEL - faired helium number density
C**        FDLG - faired total density
C** Written by Bill Jeffries, CSC, Huntsville, AL.
C** ph. (205) 830-1000, x311
C******************************************************************************

DIMENSION CZ ( 6 )
PARAMETER IBFH = 440

C Height index
I = ( IH - IBFH ) /10 + 1
C Non-SLVH fairing coefficient
CZI = CZ ( I )
C SLVH fairing coefficient
SIZ = 1.0 - CZI
C Faired density
FDLG = ( DLG1 * CZI ) + ( DLG2 * SIZ )
C Faired helium number density
FDHEL = ( DHEL1 * CZI ) + ( DHEL2 * SIZ )

RETURN
END