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Operation of the Computer Model for Direct Atomic Oxygen Exposure of Earth Satellites

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For FLUXAVG, version 2.0.

BOEING DEFENSE & SPACE GROUP

OPERATION OF FLUXAVG, THE COMPUTER MODEL FOR DIRECT ATOMIC OXYGEN EXPOSURE OF EARTH SATELLITES

FOREWORD

This report describes the operation of the computer model FLUXAVG, which was developed to predict direct atomic oxygen exposure to satellite surfaces. Boeing Defense & Space Group's activities were supported by the following NASA Langley Research Center (LaRC) contracts: "LDEF Special Investigation Group Support" contracts NAS1-18224, Tasks 12 and 15 (October 1989 through January 1991), NAS1-19247 Tasks 1 & 2 (May 1991 through October 1992), and NAS1-19247 Task 8 (initiated October 1992). Sponsorship for these programs was provided by National Aeronautics and Space Administration, Langley Research Center, Hampton, VA, and The Strategic Defense Initiative Organization, Key Technologies Office, Washington, D.C.

Mr. Lou Teichman, NASA LaRC, was the initial NASA Task Technical Monitor. Following Mr. Teichman's retirement, Ms. Joan Funk, NASA LaRC, became the Task Technical Monitor. The Materials & Processes Technology organization of the Boeing Defense & Space Group performed the five contract tasks with the following Boeing personnel providing critical support throughout the program:

Sylvester Hill	Task Manager
Roger Bourassa	Modeling
Dr. James R. Gillis	Scientific Computing
Dr. Peter Gruenbaum	User Interface Programming
Dr. Gary Pippin	Project Coordination

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CONTENTS

Changes in this manual

This version differs from the September 24, 1993 version of the manual in the following ways:

1. An appendix has been added that describes how to obtain solar and geomagnetic data.
2. An appendix has been added that describes the library of orbits now included with the software.
3. Minor clarifications have been made.

This version differs from the January 26, 1994 version of the manual in the following ways:

1. The newest version of FLUXPLOT (version 1.1) is described.
2. Minor clarifications have been made.

Changes in the software

There have been no changes in FLUXAVG.

FLUXPLOT has been updated from version 1.0 to version 1.1. Version 1.1 puts the surface name in the header rather than the incidence angle for fluence vs. time plots, and produces better files for reading by TECPLOT.

This manual applies to FLUXAVG version 2.0 and FLUXPLOT version 1.1.

TABLES

FIGURES

SYMBOLS

$<c>$	Average molecular speed, cm/sec
c	Molecular speed, cm/sec
F	Atomic oxygen flux, atoms/cm^2-sec
G	Maxwell's speed distribution function
H	Solid angle distribution function
M	Molecular weight, g/g-mole
N	Number density, molecules/cm^3
R	Universal gas constant, ergs/g-mole-°K
t_n	time at event n
T	Absolute temperature, °K
u	Absolute value of the component of relative velocity of a molecule perpendicular to n exposed surface, cm/sec
U	Normalized speed of advance, dimensionless
v	Spacecraft orbital speed, cm/sec
α	Angle between the normal to an exposed surface and the spacecraft ram vector
β	Angle between the velocity vector of a molecule and the normal to an exposed surface
γ	rotation angle about the z axis
δ	rotation angle about the y axis
Δ	time interval of ASAP calculation
ε	rotation angle about the x axis
θ	Spherical coordinate angle measured from the x axis towards the y axis (figure 5)
π	Value of pi, 3.14 . . .
ϕ	Spherical coordinate angle measured from the z axis (figure 5)
Φ	Atomic oxygen fluence at time t (atoms/cm^2)
ω	Solid angle, steradians
Ω	Earth rotation rate (radians/sec)

1.0 INTRODUCTION

1.1 BACKGROUND

One of the primary causes of material degradation in low Earth orbit (LEO) is exposure to atomic oxygen. When atomic oxygen molecules collide with an orbiting spacecraft, the relative velocity is 7 to 8 km/sec and the collision energy is 4 to 5 eV per atom. Under these conditions, atomic oxygen may initiate a number of chemical and physical reactions with exposed materials. These reactions contribute to material degradation, surface erosion, and contamination. Interpretation of these effects on materials and the design of space hardware to withstand on-orbit conditions requires quantitative knowledge of the atomic oxygen exposure environment.

Atomic oxygen flux is a function of orbit altitude, the orientation of the orbit plane to the Sun, solar and geomagnetic activity, and the angle between exposed surfaces and the spacecraft heading. We have developed a computer model to predict the atomic oxygen exposure of spacecraft in low Earth orbit. The application of this computer model is discussed in this document.

1.2 OBJECTIVE

The goal of this report is to provide directions for operation of the Computer Model for Direct Atomic Oxygen Exposure for Earth Satellites and to describe the technical features of the program.

1.3 SCOPE

The computer model discussed herein (designated FLUXAVG) handles the prediction of direct atomic oxygen fluence to planar surfaces of an Earth satellite. The surfaces may be oriented at any angle to the satellite velocity vector. The calculation is valid for any orbital path or duration of exposure. The program does not treat shadowing of one surface by another interfering surface or reflection of atomic oxygen between exposed surfaces. Shadowing and reflection can be important for curved and irregular-shaped surfaces and for interfering planar surfaces. The effects of shadowing and reflection are treated by another model (designated SHADOW) which will be discussed in separate documentation.

A companion program, FLUXPLOT, has also been developed to take the output of FLUXAVG and create files that can be imported easily into plotting applications for a PC or Macintosh.

An additional model has been developed for predicting solar exposure of Earth satellites. The model, designated SOLSHAD, is similar to SHADOW. Documentation for the solar model is also being developed.

2.0 PROGRAM OPERATION

2.1 DESCRIPTION OF COMPUTER MODEL FOR DIRECT ATOMIC OXYGEN EXPOSURE

2.1.1 Description of Program Modules

Direct Atomic Oxygen Exposure Program. FLUXAVG is a FORTRAN computer program which calculates atomic oxygen fluxes and fluences on unshielded surfaces of satellites in low Earth orbit. Figure 1 is a conceptual block diagram of FLUXAVG which shows some elements of the program operation. A more detailed description of the algorithms used and the operation of FLUXAVG is given in section 3.0.

FLUXAVG assumes that the satellite surfaces maintain a constant orientation with respect to orbital heading and zenith directions. The initial user description of surface normal directions is transformed from the user coordinate system to the program internal coordinate system based on the user's designation of coordinates to use for heading and zenith directions. If the designated coordinates do not align exactly with the orbital heading and zenith directions, then yaw, pitch, and roll may be applied.

The orbit propagation routines LOP and ASAP (refs. 1 and 2) calculate the position and velocity of the satellite over user-selected intervals. These routines are accurate orbit predictors which include the effects of zonal harmonics to order 4, lunar and solar gravity, and atmospheric drag. The orbit routines have been modified to call the MSIS-86 atmospheric model (ref. 3) which accounts for the effects of solar and geomagnetic activity, date, and position of satellite on atomic oxygen density, total density, and temperature of the atmosphere.

The Earth's atmosphere rotates with the Earth; hence, the velocity of the satellite with respect to the atmosphere varies with the position of the satellite in its orbit. The angle between the velocity vector relative to the atmosphere and each surface normal is calculated at each point on orbit. The flux on each surface at each orbit point is calculated by a kinetics routine, which accounts for the angle, atmospheric temperature, the Maxwell thermal molecular speed distribution, and atomic oxygen density. These fluxes are averaged and multiplied by the time interval between calculations to accumulate fluences on the surfaces.

Application File Generator/Plotting Interface. FLUXAVG puts its output data into a file called the mission file. We have created a program called FLUXPLOT which takes the data from the mission file and generates files that can be imported into plotting software for making graphs. FLUXPLOT is designed to create files that can be easily imported into spreadsheets, Cricket Graph (by Computer Associates for Macintoshs), and TECPLOT (by Amtec for PCs).

There are four types of application files created by FLUXPLOT: (1) data for graphs of fluence versus time; (2) data for graphs of other variables versus time (atomic oxygen density, altitude, temperature, and speed); (3) data for graphs of fluence versus incidence angle at a given time; and (4) tables of fluence versus incidence angle for all the dates in the mission.

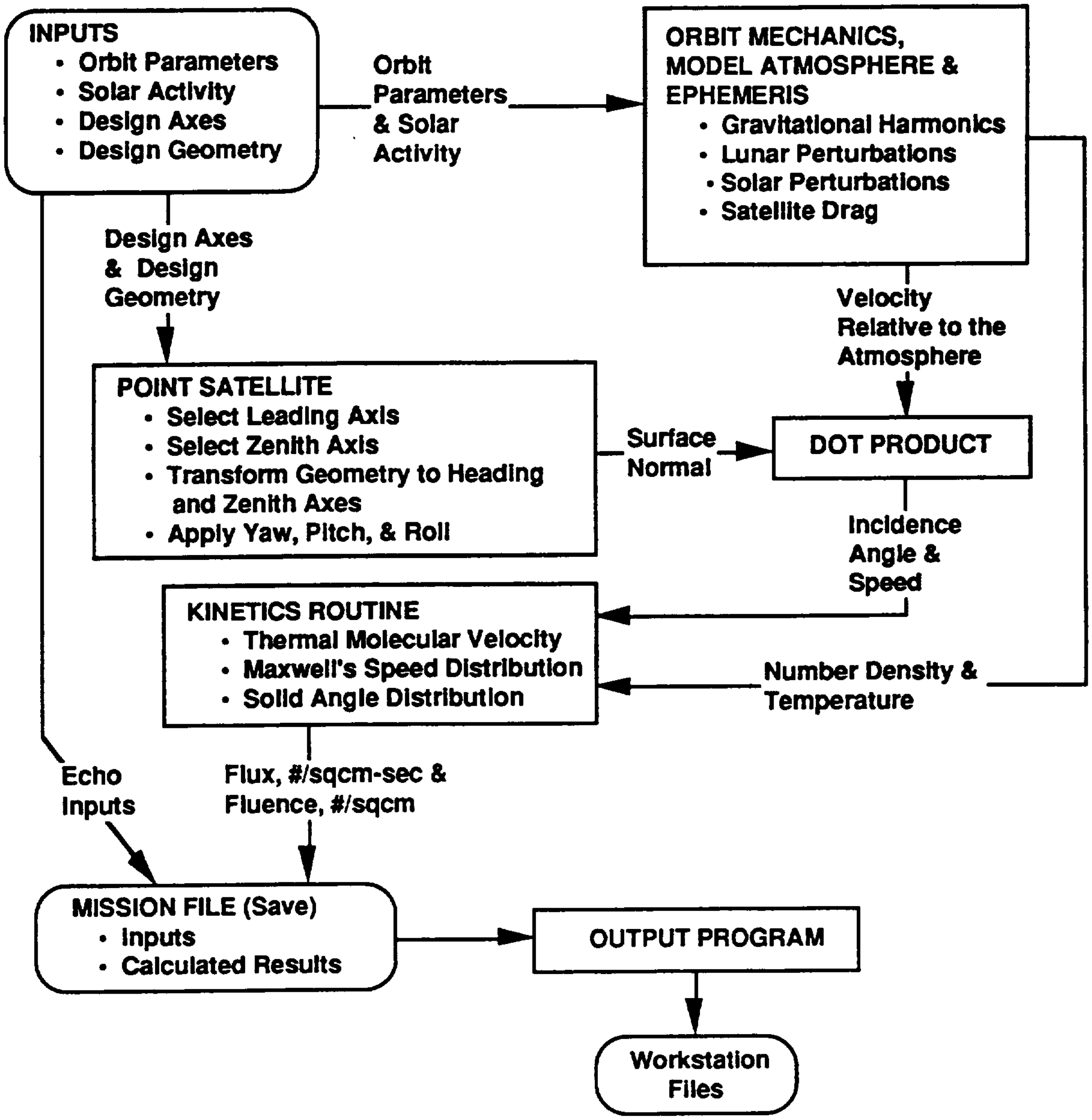


Figure 1. Elements of the Computer Model

2.1.2 Mainframe and Workstation Platforms

FLUXAVG and its companion program FLUXPLOT operate on two platforms: a mainframe and a PC or Macintosh workstation. FLUXAVG was developed on a CONVEX C2 supercomputer. It generates a mission file which is then transferred to a PC or Macintosh. FLUXPLOT then takes the mission file and generates "application files" that can be imported into plotting packages on the PC or Macintosh.

2.1.3 Input Files

FLUXAVG requires three files for input: the program control file, the solar/geomagnetic file, and the orbit file. The program control file contains general information on the mission. This includes (1) the names of the mission file, solar/geomagnetic file, and orbit parameter file; (2) the mission start and end dates; (3) the satellite surface names and the angles of their normals; and (4) information on transforming the satellite coordinate system to the program's internal system.

The solar/geomagnetic file contains solar and geomagnetic data used by the MSIS-86 atmospheric model that is called by the orbit routines. It consists of a list of dates and corresponding values for the 90-day average solar flux, daily average solar flux, and geomagnetic index.

The orbit file contains orbital elements and satellite parameters. It consists of a series of repeated blocks, where each block contains an epoch date. For each date, the file contains the drag area of the satellite, the drag coefficient of the satellite, the satellite mass, a flag indicating mean orbital or osculating orbital elements, the time steps used in the calculation by LOP, the semimajor axis, the eccentricity, the inclination of orbit, the longitude of ascending node, the argument of perigee, the mean anomaly, and time steps for the ASAP routine. Some of these variables are required by the orbit routine for exact position of the satellite as a function of time, but they do not have to be known exactly for the orbit-averaged atomic oxygen calculations.

2.1.4 Mission File and Output File

FLUXAVG generates two files: a mission file, which contains all the data in a format that is mostly easily read by the application file generator, and a standard output file, which contains the same data in an easier-to-read format. Both of these files contain all of the input data and all of the calculated flux and fluence results for the mission. Each mission file is identified by a software version number and a program-generated file name to distinguish it from all other mission files that may have been generated. The mission file name consists of a prefix that is specified with the inputs, followed by the date and a serial number from 1 to 99.

The main section of the mission file contains the following information calculated as a function of time:

a. Average, minimum and maximum of atomic oxygen density, temperature, altitude, absolute speed, and relative speed. (Relative velocity is the vehicle velocity minus the velocity of the atmosphere.)

b. A listing of surfaces making up the exposed geometry of the satellite, their average incidence angles, and calculated atomic oxygen fluxes and fluences for these surfaces as functions of time.

The mission file is the source of data for preparation of files for plots and tables using the application file generator, FLUXPLOT. The concept allows for convenient modification of report formats generated by workstation application software without the need to modify or rerun the mainframe program.

2.1.5 Application File Generator

A program called FLUXPLOT has been created to take this mission file and convert it into several smaller files that can be imported into spreadsheets or plotting programs. This program generates files to produce graphs of any calculated value versus time, as well as any calculated value versus angle at a given point in time. It also has an option to generate a series of tables that show the fluence versus angle at all the dates in the mission file.

FLUXPLOT creates ASCII files with tab-separated data. Three options are available for the data header: (1) generic for spreadsheets, (2) specific headers for Cricket Graph, and (3) specific headers for the TECPLOT plotting program. If another plotting program is preferable, changing the header with a text editor is a straightforward task.

The mission file name is written into the header of the application files generated by FLUXPLOT. Samples of the application files are shown in Appendix A.

2.2 INPUT FILE CONSTRUCTION

FLUXAVG requires three files for input: the program control file, the solar and geomagnetic data file, and the orbit parameter file. These files may be generated with any text editor. All files are ASCII text files, with line lengths of 78 characters or less.

This section gives instructions on how to create these three files. In general, most of the changes from run to run will be made in the program control file; the solar/geomagnetic and orbit parameter files will tend to remain unchanged. Each file consists of several records. The values to be entered into each record are described below, along with the character columns to be used for entry, the variable type, and the variable name that is used in the FORTRAN code. The variable name is only needed for users who are working with the code directly. The specific FORTRAN format that is used for input is also described.

2.2.1 Constructing the Program Control File

The program control file must be directed to standard input when running FLUXAVG. The program control file consists of 12 records as described below. Figure 2 shows an example of a program control file.

Record A1 Format (A78)

Entry	Columns	Type	Variable
The root name of the mission file to be created by this run. FLUXAVG will append the date and a serial number to this root.	1-78	character	MISFIL

Record A2 Format (A78)

Entry	Columns	Type	Variable
Name of this FLUXAVG input file.	1-78	character	INPNAM

Record A3 Format (A78)

Entry	Columns	Type	Variable
This record contains user-supplied commentary of as many lines as the user supplies. The commentary must be terminated by a card with a $ in column 1.	1-78	character	LINE

Record A4 Free format

Entry	Type	Variable
This entry is normally set to zero. If not set to 0, then extensive satellite velocity information is printed to standard output. Normally this output is desired only for debugging.	integer	IVEL

Record A5 Free format

Entry	Type	Variable
A six-element array giving the mission start date and time (UTC) in the following format: YYYY MM DD HH MM SS.SS.	5 integers, 1 real	STTIME

Record A6 Free format

Entry	Type	Variable
A six-element array giving the mission end date and time (UTC) in the following format: YYYY MM DD HH MM SS.SS.	5 integers, 1 real	QTIME

Record A7 Format (A78)

Entry	Columns	Type	Variable
Name of the file containing solar and geomagnetic data.	1-78	character	SOLNAM

Record A8 Free format

Entry	Type	Variable
The number of satellite surface normals to be read in. The maximum number set in the code is 98. If more surface normals are needed, code parameter MGEO must be changed.	integer	NAZEL

Record A9 Format (A25,2F10.0)

Entry	Columns	Type	Variable
Name of the surface.	1-25	character	ROWLAB
Surface normal direction angle phi (degrees) measured from the user defined Z-axis.	26-35	real	SATEL
Surface normal direction angle theta (degrees) measured from the user defined X axis toward the user-defined Y axis.	36-45	real	SATAZ

Record A9 entries are repeated once for each surface. The number of surfaces (NAZEL) is specified by record A8 above. Note that if you plan to use FLUXPLOT to create 2D graphs to be viewed using the TECPLOT commercial plotting program, it is useful to choose surface names that can be distinguished using only their first five letters, since TECPLOT often only displays these first five letters in its menus.

The user shall define a Cartesian, right-handed coordinate system for the satellite (satellite body coordinates X, Y, and Z) from which the surface normal directions will be defined. The same body coordinate system must be used to specify the orientation of all surfaces on the satellite. The choice of directions for the reference coordinates is arbitrary, but the system must be right-handed and orthogonal.

Record A10 Format: (A2, 1X, A2)

Entry	Columns	Type	Variable
Axis which is closest to the satellite heading direction: +X, +Y, +Z, -X, -Y, or -Z.	1-2	character	THDG
Axis which is closest to the orbital zenith direction: +X, +Y, +Z, -X, -Y, or -Z.	4-5	character	TZEN

The user designates satellite axes nearest to the orbital heading and zenith directions in record A10. There are six possible choices for the heading axis. Either the positive or negative direction of any of the three coordinates defined in record A9 may be designated as the heading axis, however, the selected axis should parallel the satellite velocity vector as nearly as possible. After selection of the heading axis, there are four possible choices that may be made for the zenith axis. The positive or negative direction of either of the two remaining satellite coordinates may be directed toward the zenith, however, the selected axis should parallel to the Earth zenith vector as nearly as possible. Either the positive or the negative direction of the unused coordinate automatically becomes the (right-hand) side axis of the satellite.

Record A11 Free format

Entry	Type	Variable
Roll, the rotation angle (degrees) about the orbital heading direction. Right-handed rotation is positive.	real	ROLL
Pitch, the rotation angle (degrees) about the resulting side axis. Right-hand rotation is positive.	real	PITCH
Yaw, rotation angle (degrees) about the resulting zenith axis. Right-hand rotation is positive.	real	YAW

Roll, pitch, and yaw specify the orientation of the axes that the user has designated nearest the orbital heading and zenith directions defined in record A10 relative to the actual orbital heading and zenith directions. If these two sets of axes coincide, roll, pitch, and yaw are all zero.

Roll, pitch, and yaw rotations are not commutative operations. They must be performed in proper order, first roll, then pitch, and lastly yaw.

Record A12 Format (A78)

Entry	Columns	Type	Variable
The name of the file containing orbit parameters.	1-78	character	ONAME

Example:

<u>Record</u>

```
A1  fluxavg.mission_example
A2  fluxavg.cont_example
A3  This is an example program control file for FLUXAVG.
A3  This is for the start of the Space Station Freedom mission,
A3  with only 5 surfaces instead of 37.
A3               Described in Mission Profile Grumman
A3               Memo P SH-314-M092-038
A3               date Sept 8, 1991
A3  The second set of orbit elements is set to calculate fluxes and fluences
A3  at the orbit elements epoch date and at 7 and 14 days after.  The other
A3  sets of orbit elements calculate fluxes and fluences only on the
A3  epoch date.
A3  $
A4  0                                 IVEL FLAG FOR VELOCITY INFORMATION
A5  1995 11 30 13 55 21.80            MISSION START DATE
A6  1996 02 03 03 51 45.3             MISSION END DATE
A7  solgeo.sample
A8  5                                 NAZEL NUMBER OF SURFACES
A9  SIDE 1                    0.         90.         PHI, THETA
A9  SIDE 2                    5.         90.
A9  SIDE 3                    10.        90.
A9  SIDE 4                    15.        90.
A9  SIDE 5                    20.        90.
A10 +Z +X
A11  0.0      0.0       0.0           yaw,pitch,roll
A12 orbinp.example
```

Figure 2. Example of a Program Control File

2.2.2 Solar and Geomagnetic Data File

This is the file named in record A7 (variable SOLNAME) of the program control file (sec. 2.2.1). It contains solar and geomagnetic data used by the MSIS-86 atmospheric model called by the orbit routine. For this file, it is necessary to know the 10.7 cm radio flux (90 day average and daily average) and the geomagnetic index A_p for dates during the mission. Appendix C describes how to obtain this data from NASA Goddard and NASA Marshall.

Figure 3 shows an example of a solar and geomagnetic data file.

Record B1 contains a line of header information which is not used by FLUXAVG. The following header is used in the example files.

Record B1 Format (A78)

Entry	Columns
Header line in the following format:	
YR	3-4
MO	7-8
DA	11-12
3 MO AV F10.7	15-27
WK AV F10.7	32-42
WK AP	53-57

Record B2 Format (3I4, 3F15.0)

Entry	Columns	Type	Variable
Four-digit year. This may be abbreviated as a two-digit year. If so, 1900 is added to the year if it is between 50 and 99, and 2000 is added to the year if it is less than 50.	1-4	integer	IY
Two digit month.	5-8	integer	IM
Day of the month	9-12	integer	ID
90-day average solar 10.7 cm radio flux (10^4 Jansky)	13-27	real	FA3
Daily average solar 10.7 cm radio flux (10^4 Jansky)	28-42	real	FA
Geomagnetic index, A_p	43-57	real	AP

Record B2 is repeated for as many dates as needed. The file must contain data starting at or before the mission start date. If the data end before the end of mission, the data are assumed to repeat starting from the first date in the file. This means, for example, that if one has a long mission spanning several solar cycles, only data for the first solar cycle must be entered. Data beyond the end of the mission are ignored.

Example:

```
Record
B1     YR   MO   DA   3 MO AV F10.7      WK AV F10.7          WK AP
B2   1995   11   30            92.0             92.0             17
B2   1995   12    1            92.0             92.0             17
B2   1995   12   31            91.8             91.8             17
B2   1996    1    1            91.8             91.8             17
B2   1996    1   31            91.4             91.4             17
B2   1996    2   29            90.8             90.8             17
```

Figure 3. Example of the Solar and Geomagnetic Data File

2.2.3 Constructing the Orbit Parameter File

The orbit parameter file is the file named in record A12 (variable ONAME) of the program control file (sec. 2.2.1). The orbit parameter file contains (1) satellite size and shape factors, (2) orbital elements as functions of date, and (3) parameters that control the size and number of time steps to be taken in the calculation. The orbital elements file allows great flexibility in modeling satellite orbits. Reboosts, altered satellite mass, drag area, and drag coefficient are all handled by entering a new set of orbital elements and satellite parameters at the event time. Orbital decay may be modeled by appropriate choice of satellite mass, drag area, and drag coefficient.

Six records make up the orbit parameter file. Records C1 through C6 are repeated for each set of parameters and orbital elements required to define the mission. The epoch date for the first set of entries must start on or before the mission start date and time named in record A5 (STTIME) of the program control file (sec. 2.2.1). The dates of the sets do not need to extend to the end of the mission. In this case, the last set of satellite parameters and orbital elements is used to predict the orbit until the mission end date is reached. Sets of satellite parameters and orbit parameters whose dates extend beyond the end of mission are ignored.

The FLUXAVG model has two orbit routines: the first (LOP), which is used to propagate orbital elements over long periods of time, and the second (ASAP), which is used to propagate orbit elements over short periods of time.

The calculation is divided into time intervals. Each time interval begins with an epoch date and time for a set of orbital elements supplied by the user and ends with the next user-supplied set of orbital elements or with the end of the mission.

At the beginning of each time interval, LOP sets up initial conditions for operation of ASAP. Also, if the generation of additional orbital element sets is indicated by the orbit parameter file entries on record C3, then these additional elements are generated by LOP by propagating the given conditions to later times. ASAP is operated together with the kinetics routine to determine atomic oxygen flux for a period of time following the epoch time for each set of elements, whether user-supplied or calculated by LOP.

The calculation sequence may be altered by the user to handle variations in mission duration and availability of data. The possible variations are controlled by entries to records 3 and 6 of the orbit parameter file. The modes of operation are as follows:

a. ASAP can be operated until the end of the mission is reached from a single set of user-supplied orbital elements. This is accomplished by setting runtime for ASAP to exceed the end of mission time. With this mode of operation, LOP makes the initializing calculation for ASAP and is not used again.

b. ASAP can be operated for a short period of time from a user-supplied orbital element set without LOP generating additional orbital elements for subsequent times in the interval. This is accomplished by setting the parameter for additional orbital element calculations by LOP to zero and the run time for ASAP to less than the epoch time for the next user-supplied orbital element set. LOP still makes the initialization calculation for ASAP but is not active again until the epoch time for the next user-supplied orbital element set is reached which starts a new calculation interval.

c. ASAP may be operated for a short period of time at the beginning of an interval based on the user-supplied orbital element set and then again for additional orbital element sets calculated by LOP. There are two ways to control the number of additional orbital element sets calculated by LOP:

   1. The user may enter a time step for repetition of LOP orbital element calculations while setting the parameter for additional orbital element calculations to -1. With this mode of operation, the number of calculated orbital element sets is established by FLUXAVG so that the ASAP run for the last calculated orbital element set ends before the epoch time of the next user-supplied orbital element set.

   2. The user may enter both a time step for repetition of LOP orbital element calculations and the number of orbital element sets to be calculated. With this mode of operation, the user is responsible for determining that the last orbital element set calculation is completed before the interval ends.

Entry instructions for the orbit parameter file are summarized in the following listing of records that make up the file. It may be noted that all orbital element entries listed may not be known to the user. However, an entry for each element must be made. How entries for missing data are to be made is explained in the comments for records 3, 4, and 5. These directions are further summarized in Table 1 following record 5.

Figure 4 shows an example of an orbit parameter file. The records are defined as follows:

Record C1 Free format

Entry	Variable
A six-element array giving the initial epoch date and time (UTC) for this set of data as YYYY MM DD HH MM SS.SS.	ADATE

Record C2 Free format

Entry	Variable
The drag area of the satellite (km^2). If 0, set to previous value.	AREASC
The drag coefficient of the satellite. If 0, set to the previous value.	CDSCC
The satellite mass (kg). If 0, set to the previous value.	AMASSC

Record C3 Free format

Entry	Variable
Element type flag. Set 0 to indicate mean orbital elements. Set 1 to indicate osculating orbital elements.	IORBSC
Time step in days between orbital element sets calculated by LOP.	STEPDSC
This parameter controls the number of additional orbital elements sets to be propagated by LOP for this data set. If entered as -1, FLUXAVG calculates the number of additional orbital element sets to be propagated based on the above time step. If entered as 0, no additional orbital elements sets will be calculated. If a positive number is entered, then that number of orbital element sets will be calculated by LOP.	NSTDSC

Record C3 contains information on the type of orbital element data that is being entered into the program and the size and number of time steps to be made before going to the next data set.

If all six of the orbital elements are known, then set the element type flag (first entry in record C3) to indicate whether the known values are mean orbital elements or osculating orbital elements.

If the orbit is elliptical and only the semimajor axis, the eccentricity, and the inclination of orbit are known, then set the element type flag to indicate mean orbital elements.

If the orbit is circular and all six orbital elements are not known, set the element type flag to indicate mean orbital elements.

The third entry of record 3 indicates how many orbital element sets are to be propagated by LOP from this set of user-supplied orbital elements. The parameter also controls the number of runs to be made by ASAP. ASAP will run once for the initial user-supplied data and once for each additional orbital element set calculated by LOP. When calculations for the specified number of orbital element sets have been completed, a new set of user-supplied initial conditions will be read. Any or all parameters controlling the orbit can be changed at that time.

Record C4 Free format

Entry	Variable
Semimajor axis (km).	ORBSC(1)
Eccentricity.	ORBSC(2)
Inclination of orbit (degrees).	ORBSC(3)

Record C4 contains the first three of six orbital elements needed by the program for propagating orbit positions.

The requirements for orbital element data entries when not all orbital elements are known vary depending on whether the orbit is circular or elliptical. Rules for entering orbital element data have been developed to cover the range of possible conditions of program application.

If the orbit is elliptical, then enter the first three orbital elements for the ellipse into record C4.

If the orbit is stated as circular, then it is assumed that mean eccentricity is zero and that an average orbit altitude is known. A satellite cannot actually fly a circular orbit around the Earth gravity model assumed by the program, except for an orbit at the equator (zero inclination). The deviation from a constant radius orbit may be 10 to 20 km. The semimajor axis for a stated circular orbit (zero eccentricity) is determined by a trial calculation. The value of semimajor axis for the first trial calculation may be taken as the Earth's equatorial radius, 6378 km, plus the known average altitude of the satellite. The trial semimajor axis of the orbit is then increased or decreased to yield an average orbit altitude calculated by the program that equals the required known value.

For a circular orbit, enter zero eccentricity as the second entry of record C4.

Enter the known orbit inclination for the circular orbit as the third entry of record C4.

Record C5 Free format

Entry	Variable
Longitude of ascending node (0 to 360 degrees).	ORBSC(4)
Argument of perigee (0 to 360 degrees)	ORBSC(5)
Mean anomaly (0 to 360 degrees).	ORBSC(6)

Record C5 contains the last three of the six orbital elements needed by the program for propagating orbit positions. These entries may not be known by the user. However, an initial value for each of the six orbital elements is needed to satisfy requirements of the orbit routine algorithms. Hence, values must be entered. The reasoning justifying the entries to be made is as follows.

The data developed by the orbit routine are used by the kinetics routine to predict a series of atomic oxygen fluxes that define atomic oxygen exposure over a period of time. The orbit routine chosen for use with the program is general and is capable of generating a series of orbit positions that are accurate if all six orbital elements are known by the user. However, the average exposure condition sought by the user over a period of time is little affected by the initial value of three of the six orbital elements (longitude of ascending node, argument of perigee, and mean anomaly), provided the entire range of possible values of the elements is included in a long series of calculations.

The values of longitude of ascending node, argument of perigee, and mean anomaly depend on the detailed placement of the satellite in orbit and are not normally available to the user unless he has orbital element data derived from observations of a satellite already in flight. If data are available, then these data should be entered in record C5. The elements entered and the element type indicated in record C3 (IORBSC) must be in agreement, mean or osculating.

If the orbit is elliptical and longitude of ascending node, argument of perigee, and mean anomaly elements are not available, then enter randomly chosen values for each of the elements in the range form 0 to 360 degrees for each data set.

If the orbit is circular, enter a randomly chosen value for longitude of ascending node in the range form 0 to 360 degrees for each data set. Enter zero degrees for argument of perigee and mean anomaly for each data set.

Inputs to be made in records C3, C4, and C5 for the two situations for which complete orbital information is not known are summarized in Table 1.

TABLE 1. Data entries when orbital elements are not all known.

Record Number Requiring the Entry	Entry	Elliptical orbit when only 3 of the 6 elements are known.	Circular orbit where only average altitude and inclination known.
C3	Type flag	0	0
C4	Semimajor axis (km)	Known value	Enter a trial value and adjust to obtain the known average altitude
C4	Eccentricity	Known value	0
C4	Inclination of orbit	Known value	Known value
C5	Longitude of ascending node	Random number (0 to 360 degrees)	Random number (0 to 360 degrees)
C5	Argument of perigee	Random number (0 to 360 degrees)	0
C5	Mean anomaly	Random number (0 to 360 degrees)	0

Record C6 Free format

Entry	Variable
Time step (seconds) to be taken by ASAP. Enter 0, if the previous value is to be used.	STEPSSC
Number of steps. Enter 0, if the previous value is to be used.	NSTSSC

Record C6 contains parameters used by ASAP for propagating the satellite orbit to produce satellite position, atmospheric temperature, and atomic oxygen density. STEPSCC defines the time interval between calculation of these data, and NSTSCC defines the number of intervals over which the orbit is propagated.

ASAP may be used to calculate satellite position, atmospheric temperature, and atomic oxygen density continuously for an entire mission if STEPSSC times NSTSSC is greater than or equal to the mission length; that is, the difference between the mission end time and start time is specified in program control file (sec. 2.2.1) records A6 and A5, respectively.

A 360-sec time step is a typical value for a satellite in low Earth orbit. Similarly, 240 steps is a typical number of steps, which results in approximately 16, 90-minute orbits. Atomic oxygen flux is calculated by the kinetics routine for each of these times and the average flux is applied until the next orbital element recalculation is made.

Example:

Record

```
C1   1995   11   30   13   55  21.80     YY MM DD HH MM SS
C2       1.0E-06    2.00    2000.0     AREA, Cd, MASS
C3     0        7.0    0     IORB (0=MEAN), STEP (DAYS),NSTDSC
C4     6716.970   0.000     28.50     A, ECC, INCL
C5     342.2000      0.0000      0.0000     NODAL CROSS,ARG P, MA
C6      360.0  230           ASAP TIME STEP, # STEPS
C1   1995   12    1   18   52  22.50     YY MM DD HH MM SS
C2       1.0E-06    2.00    2000.0     AREA, Cd, MASS
C3     0        7.0    2     IORB (0=MEAN), STEP (DAYS),NSTDSC
C4     6730.810   0.000     28.50     A, ECC, INCL
C5     107.1000      0.0000      0.0000     NODAL CROSS,ARG P, MA
C6      360.0  230           ASAP TIME STEP, # STEPS
C1   1995   12   31   10   53  19.70     YY MM DD HH MM SS
C2       1.0E-06    2.00    2000.0     AREA, Cd, MASS
C3     0        7.0    0     IORB (0=MEAN), STEP (DAYS),NSTDSC
C4     6726.420   0.000     28.50     A, ECC, INCL
C5       2.3000      0.0000      0.0000     NODAL CROSS,ARG P, MA
C6      360.0  230           ASAP TIME STEP, # STEPS
C1   1996    1    1    6   37   3.60     YY MM DD HH MM SS
C2       1.0E-06    2.00    2000.0     AREA, Cd, MASS
C3     0        7.0    0     IORB (0=MEAN), STEP (DAYS),NSTDSC
C4     6739.030   0.000     28.50     A, ECC, INCL
C5     110.0000      0.0000      0.0000     NODAL CROSS,ARG P, MA
C6      360.0  230           ASAP TIME STEP, # STEPS
C1   1996    1   31   16   32  18.30     YY MM DD HH MM SS
C2       1.0E-06    2.00    2000.0     AREA, Cd, MASS
C3     0        7.0    0     IORB (0=MEAN), STEP (DAYS),NSTDSC
C4     6733.620   0.000     28.50     A, ECC, INCL
C5     137.8000      0.0000      0.0000     NODAL CROSS,ARG P, MA
C6      360.0  230           ASAP TIME STEP, # STEPS
```

Figure 4. Example of an Orbit Parameter File

2.3 INSTALLATION AND OPERATION OF THE DIRECT AO EXPOSURE PROGRAM

This section describes installation and operation of FLUXAVG on the CONVEX computer on which it was developed, and gives some suggestions for migrating FLUXAVG to other computers.

2.3.1 Installation on a CONVEX Computer

FLUXAVG was developed on a CONVEX C2 supercomputer running under CONVEX operating system release 9.0 and CONVEX version 4.2bsd unix. FLUXAVG is written in CONVEX FORTRAN. This section describes the installation and operation on a machine identical to that on which it was developed. It is suggested that a directory called ao_fluence and two subdirectories called asapn and fluxavg be created, and that all files be put into these directories.

All files for FLUXAVG reside on directory ao_fluence and two subdirectories, ao_fluence/fluxavg and ao_fluence/asapn. Subdirectory ao_fluence/fluxavg contains FORTRAN source code for program FLUXAVG and its subroutines listed in Table 2 as well as files for building the FLUXAVG executable. Subdirectory ao_fluence/asapn contains FORTRAN source code for all ASAP, LOP, and MSIS-86 routines listed in Table 3 and a Makefile for compiling these routines and saving them as a library. Directory ao_fluence contains the source code subdirectories, the FLUXAVG executable, and sample input and output files listed in table 4.

Follow the procedure below for loading FLUXAVG and preparing it to execute. In this procedure, **bold** text indicates commands the installer should type. Press return after each command. Remember that the unix operating system is case sensitive.

1. Create and load the directory ao_fluence and subdirectories ao_fluence/asapn and ao_fluence/fluxavg.

2. Get to subdirectory ao_fluence/asapn by typing **cd** /pathname/**ao_fluence/asapn**, where pathname is the appropriate path.

3. Type **make**. This causes the file Makefile to be run, compiling all FORTRAN routines in the subdirectory and creating library orbitlib.a.

4. Get to subdirectory ao_fluence/fluxavg by typing **cd ../fluxavg**.

5. Type **fc -o mkvers mkvers.f**. This compiles FORTRAN code mkvers.f and puts its executable on file mkvers. When executed, mkvers updates include file version.I which contains the date and time of creation of the FLUXAVG executable and its version number.

6. Edit the file Makefile so that the line that begins with ORBITLIB=... contains the correct path to orbitlib.a.

7. Type **new**. This script runs mkvers to update version .I. It then executes the make command on Makefile to compile FLUXAVG, link library ao_fluence/asapn/orbitlib.a, and build the executable file fluxavg.x. If new asks if the user wants to copy fluxavg.x to the next directory up, ao_fluence, answer y. FLUXAVG should now be installed and ready to run. If new fails, be sure it has execute permission by typing **chmod +x new** and repeat this step.

8. Get to directory ao_fluence by typing **cd ..**

9. Edit file run.fluxavg to change the line
   ```
   fluxavg.x < fluxavg.in_sample >! fluxavg.out_sample
   ```
   to
   ```
   fluxavg.x < fluxavg.in_sample >! test.out
   ```
   Also change the path in the first line to the proper path.

10. Ensure that run.fluxavg has execute permission by typing **chmod +x run.fluxavg**.

11. Run the sample test case by typing **run.fluxavg**. The sample test case takes about 6 minutes CPU time. When the run is complete, compare file fluxavg.out_sample with test.out and fluxavg.mission_sample26-Apr-93.1 with the file of the similar name but different date. These files should give the same results.

Table 2
Files in directory ao_fluence/fluxavg

cross.f	finit.f	flugen.f	flux.f
fluxavg.f	fluxgen.f	flxcal.f	getfrst.f
hz.f	les.f	Makefile	misgen.f
mkvers.f	new*	orbinp.f	orbit.f
progax.f	prthd.f	rameci.f	rdinp.f
runlop.f	satgeom.f	solgeo.f	stoeci.f
version.I	xrot.f	yrot.f	zrot.f

Table 3
Files in directory ao_fluence/asapn

angles.f	anomll.f	anomly.f	arg.f
asap.f	caljul.f	carcon.f	ccor.f
cmab.f	conang.f	concar.f	coord.f
data.f	datal.f	de.f	delm.f
delml.f	den76l.f	denss.f	der.f
derl.f	dnet.f	dot3.f	drag.f
epheml.f	eqnox.f	facnew.f	factor.f
fdf.f	gauss.f	gdg.f	gfun.f
glob5l.f	globe5.f	gts5.f	hdh.f
hfun.f	indrag.f	insrch.f	insrp.f
intrp.f	julcal.f	julial.f	julian.f
keplel.f	kepler.f	kozsak.f	kozsal.f
legend.f	lookup.f	lop.f	luso.f
luso2.f	Makefile	msis86.f	occult.f
ode.f	pltgra.f	pout.f	poutl.f
preces.f	prmsg5.f	q1evl.f	qcoff.f
rk78.f	rk78cn.f	root.f	sds.f
setsm.f	setup1.f	setup2.f	srp.f
step.f	stime.f	thdbod.f	tselec.f
userop.f	vmag.f	zero.f	

Table 4
Files in directory ao_fluence

asapn/	fluxavg/
fluxavg.in_sample	fluxavg.in_ssf
fluxavg.mission_sample26-Apr-93.1	fluxavg.mission_ssf25-Mar-93.1
fluxavg.out_sample	run.fluxavg*
fluxavg.out_ssf	fluxavg.x*
orbinp.sample	orbinp.ssf
solgeo.sample	solgeo.ssf

2.3.2 Running the Direct AO Exposure Program

Before running FLUXAVG, build its three input files describing your mission (per section 2.1.3). Edit the run.fluxavg file in the ao_fluence directory to direct your program control file to standard input and to direct standard output to your output file. FLUXAVG may be run interactively by typing **run.fluxavg** or in batch mode by typing **qsub -q v run.fluxavg** where v is the queue to which the job is to be sent. Because FLUXAVG may take significant execution time (a full Space Station Freedom calculation takes about 5 hours CPU time), running in batch mode is recommended.

As written, FLUXAVG is set to allow up to 600 output times for fluxes and fluences, 600 orbit parameters sets, 600 solar flux and geomagnetic activity sets, and 98 satellite surfaces. These dimensions are set by PARAMETER statements in the FORTRAN code. Table 5 summarizes these parameters and what they affect. Users who do not run missions which need these large dimensions may find that FLUXAVG runs more quickly if they are reduced.

Table 5
Parameters in FLUXAVG

PARAMETER	Value	Appears in COMMON Block	FORTRAN Routines Affected	PARAMETER usage
MFLU	600	/FLU/	FINIT, FLUGEN, FLUXAVG, FLUXGEN, FLXCAL, PROGAX, SATGEOM, STOECI	Maximum number of fluence output times.
MGEO	100	/FLU/	FINIT, FLUGEN, FLUXAVG, FLUXGEN, FLXCAL, PROGAX, SATGEOM, STOECI	Maximum number of satellite surfaces + 2.
MORBPP	600	/SCORB/	FLUXAVG, GETFRST, ORBINP, RUNLOP	Maximum number of orbital parameter sets.
NTSA	600	/SOLDAT/	SOLGEO, ASAP*, DER*, LOOKUP*, LOP*	Maximum number of solar and geomagnetic data sets.

Notes:

- All FORTRAN routines are in files of the same name in lower case with a .f extension.
- All files are are in directory ao_fluence/fluxavg except those marked by * which are in ao_fluence/asapn.

2.3.3 Some Information for Installation on Other Computers

This section provides information about FLUXAVG which will be useful if FLUXAVG is to be converted to run on computers other than the CONVEX described in section 2.3.1.

FLUXAVG is written in mostly ANSI standard FORTRAN and generally does not call functions specific to any particular operating system or FORTRAN compiler. However, the following exceptions are noted.

Numerous seven-character variable names are used in FLUXAVG. It is believed that they can be truncated to the ANSI standard six characters without causing duplicate variable names. However, care should be taken before doing this to ensure that there are indeed no duplicate variable names generated.

The CONVEX FORTRAN functions DATE and TIME are called. DATE returns the current date as dd-Mmm-yy where dd is the day of month, Mmm is the three character abbreviation for month, and yy is the two-digit year. Time returns time as hh:mm:ss where hh is the hour, mm is the minute, and ss is the second. DATE and TIME are used to update the file ao_fluence/fluxavg/version.I and DATE is used to build the mission file name.

The include file ao_fluence/fluxavg/version.I is included in ao_fluence/fluxavg/prthd.f to supply the date and time of program compilation and program version. If include files are not supported, prthd.f could be edited to update this information or the information could be deleted without affecting program operation.

FLUXAVG is compiled to run using CONVEX double-precision word length (8 bytes or 64 bits) for all real variables. This word length is needed to maintain numerical accuracy. All real variables in FORTRAN routines in subdirectory ao_fluence/fluxavg/asapn are declared double precision with IMPLICIT DOUBLE PRECISION (A-H,O-Z) statements. Real variables in FORTRAN routines in ao_fluence/fluxavg/fluxavg are not declared double precision explicitly, but are converted to double precision with a FORTRAN compiler option. Users converting FLUXAVG to run on other computers must exercise great care to reconcile word lengths on variables between subroutines, especially if FORTRAN compiler options are not available to perform the type conversion at compile time.

The following CONVEX FORTRAN compiler options are either recommended or mandatory when compiling FLUXAVG:

-na	Suppresses advisory diagnostic messages (recommended).
-or all	Provides full optimization report (recommended).
-O2	Optimize code with vectorization (recommended).
-pd8	All default integer, logical, real, and double precision values occupy 8 bytes of storage (mandatory).
-rl	Perform loop replication optimizations (loop unrolling, dynamic code selection) when profitable to do so (recommended).
-72	Process only the first 72 characters of each line. Lines containing tab characters will not compile properly with this option (mandatory).

2.4 APPLICATION FILE GENERATOR/PLOTTING INTERFACE

The name of the application file generator/plotting interface is FLUXPLOT. It is written in ANSI C, and code and compiled versions for Macintosh and PC computers are supplied. (The mission file will have to be transfered from the mainframe where FLUXAVG is run to the Macintosh or PC.) For the Macintosh, double click on the `FluxPlot` icon, and you will be presented with a console window for typing in your inputs. For a PC, type FLUXPLOT to the DOS prompt.

The code has also been successfully compiled and tested on Sun and SGI workstations. Use the `-lm` option to call up the math library.

At the very start of the program, you will be asked for the mission file. If the program is unable to open the file, it will print out a message and stop the program. If the mission file is large, the generation of the application files may take a few minutes.

2.4.1 Output Format Menu

The first menu allows you to choose the format for the files generated by FLUXPLOT. The menu is shown below:

```
Please choose one of the following graph formats:
    1. Spreadsheet
    2. Cricket Graph
    3. Tecplot
```

All the options generate ASCII files with tab-separated values. The spreadsheet option puts general information in the first one or two lines of the file. The Cricket Graph option puts an asterisk in the first line, and the second line contains the column headers, and is readable by the commerical plotting package Cricket Graph by Computer Associates. The Tecplot option puts a title in the first line and the column headers a the following line line, and is readable by the commerical plotting package TECPLOT by Amtec. These options only affect the files generated for plotting; none of the options affects the generation of tables.

2.4.2 Data Output Menu

The second menu allows you to choose the type of file you want. The menu is shown below:

```
Please choose one of the following outputs:
    1. Fluence versus cumulative days for a given surface or incidence
       angle.
    2. AO density, temperature, altitude or speed versus time.
    3. Angle, flux and fluence at a given time.
    4. Tables of fluence for various surfaces (angles) and dates.
    5. Exit program.
```

In the Macintosh versions, exiting the program can be accomplished by pressing ⌘Q.

2.4.3 Fluence Versus Time

First, you are prompted for an application file. If you type in an existing file name, it will be overwritten.

Next, you are shown the first 20 lines of the part of the mission file containing the data of surfaces, flux, and fluences. The index number for the surfaces is listed on the left side. Make a note of which surfaces you would like to have plots of, and then hit <Return> to see the next 20 lines. You are then prompted for which surfaces to make plots of. Separate the index numbers by spaces. If you have a range of numbers, separate them by a hyphen. For example, to plot surfaces 1, 3, 4, 5, 6, and 10, you would type:

```
1 3-6 10
```

The generated file contains a column for Time (days), and columns for each surface, where the header is the name of that surface.

2.4.4 Other Values Versus Time

First, you are prompted for an application file. If you type in an existing file name, it will be overwritten.

Next, you are presented with another menu:

```
Please choose one of the following variables:
    1. Atomic oxygen density.
    2. Temperature.
    3. Altitude.
    4. Absolute speed.
    5. Relative speed.
```

Choose which value would like plotted. The application file will have four columns: Time, and average, minimum, and maximum values.

2.4.5 Flux and Fluence at a Given Time

First, you are prompted for an application file. If you type in an existing file name, it will be overwritten. Next, you are prompted for the time in cumulative days. The program will then search in the mission file for data that is within 1 day of the time that you entered.

If you are interested in the end-of-mission data, you may need to use a text editor to look through the mission file and find out exactly how many days the mission lasted. If FLUXPLOT does not find a block of data that is within 1 day of your target date, it will give you the message `"Time not found."`

The file generated will be a table with the columns: surface name, theta, phi, average incidence angle, average flux, and total fluence. Each row corresponds to a surface, with additional rows for true ram and true 90 deg. from ram. Note that with TECPLOT files, the surface name column and the true ram and true 90 deg. rows are not included. (TECPLOT data files have a more restricted format.)

2.4.6 Tables of Fluence Versus Incidence Angle for Various Dates

First, you are prompted for an application file. If you type in an existing file name, it will be overwritten. Next, you are prompted for the minimum reboost distance in kilometers. The tables are generated so that if the satellite is reboosted, it will start that data on a new page. It assumes a reboost if the average altitude increases by a distance greater than the minimum reboost distance. If this number is chosen to be too large, it may miss the reboost; if it is chosen to be too small, it may assume a reboost when the satellite is rising in altitude due to other effects. (For Space Station Freedom, 5 km is a good value to enter.) If the satellite is not going to be reboosted, enter zero.

Next, you are shown a list of the surfaces and you are asked to choose which surfaces you want to be in the tables. Follow the directions described in section 2.4.3 (fluence versus time) to pick the surfaces.

The first two lines of the application file list the serial number and the time of file generation. Then FLUXPLOT generates a series of tables with five or fewer columns. On top of each table is a list of dates, the cumulative days for those dates, and the average altitude for those dates. The first column of each table is the average incidence angle of the surface. The remaining columns are the fluences. If there are fewer than four fluence columns, it is due to a reboost. Between each table is a formfeed character.

The tables can be imported into a word processor, but must be put into an equal-spacing font (such as Courier) so that all the columns will line up.

2.5 DIRECT ACCESS TO OUTPUT DATA

FLUXAVG generates two output files: a mission file, which contains all the data in a format that is mostly easily read by the output generator, and the standard output, which contains the data in an easier-to-read format. However, the two files contain the same information in approximately the same overall format. This section will discuss what can be found in these files.

The files begin with an identification section. This includes the names of the mission file and the input files, the software version number and information about its compilation, an exact copy of the program control file, and some commentary. The standard output file then contains a summary of information such as satellite orientation and mission start/end dates. (This information can also be found in the program control file echo section.) The next section is a copy of the solar and geomagnetic data file. This is followed by the surface normal definitions (the standard output file contains a definition of the surface normals in program coordinates) and the orbital parameters.

The last section lists the calculated flux and fluences. It is divided into blocks of time. For each block there are three parts: date information, calculated environmental values, and calculations of flux and fluence. The date information contains the fluence date, the start date and end date of the ASAP run, and the number of cumulative days from the start of the mission until the end of the date block. The next part contains atomic oxygen density, temperature, altitude, absolute satellite speed, and relative satellite speed. The average, maximum, and minimum values are calculated between the start and end dates. Lastly, the file lists the location, the average incidence angle, the average flux, and the integrated fluence for each of the satellite's surfaces. The fluence values and the cumulative days are calculated at the fluence date, and the averaged flux value is averaged over the ASAP time interval. Similarly, atomic oxygen density, temperature, altitude and speed have their average, maximum, and minimum values calculated over the ASAP time interval.

The exact format of the mission file is described in Appendix B. This will be useful in case modifications to the application file generator are made or other data-extracting software needs to be created.

3.0 TECHNICAL FEATURES OF THE COMPUTER MODEL

3.1 ALGORITHMS IN THE DIRECT AO EXPOSURE PROGRAM

3.1.1 Orbit Mechanics

FLUXAVG uses modified versions of two published orbit propagation codes: LOP (Long-term Orbit Propagator) and ASAP (Artificial Satellite Analysis Program). The unmodified versions of these codes are described in references 1 and 2 to which users should refer for descriptions of algorithms used in these codes. The first code efficiently propagates orbits over long time periods by integrating the averaged Lagrange planetary equations of motion using the ODE integration method of Shampine and Gordon. It does not, however, predict the deviation of a satellite from elliptic motion. These deviations can be as large as 10 or 20 kilometers. ASAP propagates orbits over short periods using Cowell's method in integrating the equations of motion directly. It does predict the exact position of the orbit including deviations from elliptic motion.

FLUXAVG uses LOP to propagate satellite orbits over a generally long period of time (for example, a year), starting from a single set of conventional orbital elements and outputs orbital elements at equally spaced intervals (for example, every month). The input orbital elements may be either mean or osculating. ASAP reads the output orbital elements from LOP and propagates each set of orbital elements for a short period (for example, 1 day). During this short period, ASAP outputs satellite position and velocity, atomic oxygen density, and atmospheric temperature at a number of equally spaced time intervals (every 6 minutes is typical).

As originally written, LOP and ASAP are standalone FORTRAN codes generalized to handle arbitrary planetary orbits. This generalizing means that no default values of parameters are provided and that large lists of inputs must be read in. It was desired to modify these codes to be callable as subroutines to propagate Earth orbits with a minimum number of inputs and to have them provide only the outputs needed by FLUXAVG. The code contains comments indicating which subroutines have been modified and the operation of those which have been added.

LOP and ASAP have been changed from standalone programs to FORTRAN callable subroutines. Because a number of subroutines had the same name in both codes even though they are not the same, those in LOP were modified by adding the letter L at the end of the subroutine name if the resulting name was six or fewer characters and by replacing the last letter of the subroutine with an L otherwise. Similar modifications were made to four common blocks with duplicate names. Subroutine trees for LOP and ASAP that show the calling sequence of subroutines in the two modified codes are shown in section 3.2. All code in both LOP and ASAP was converted to double precision. All input is passed to LOP and ASAP through subroutine calls, data statements, or calculations done in new subroutines added to the code.

Several new subroutines were added to LOP and ASAP. The 1976 standard atmosphere built into LOP and ASAP does not change with solar activity. It was replaced with the MSIS-86 atmospheric model discussed in the next section. A subroutine to interface to the MSIS-86 model was added. An analytic luni-solar ephemeris, based on references 5 and 9, was added. Routines were added to compute sidereal time based on reference 6, to convert to and from calendar date and Julian date based on reference 4, and to convert from conventional orbital elements to Cartesian coordinates based on reference 7.

As modified, LOP and ASAP include zonal harmonics to order 4, luni-solar gravity, and atmospheric drag. LOP does not allow the atmosphere to rotate with the Earth; ASAP does allow the atmosphere to rotate with the Earth.

3.1.2 Atmospheric Model (MSIS 86)

FLUXAVG uses the MSIS-86 atmospheric model to predict atmospheric parameters including temperature, total atmospheric density, and atomic oxygen density at each point along the orbit. The MSIS-86 model accounts for atmospheric variations due to date and time of day, satellite position (latitude, longitude, and altitude above the Earth), and solar and geomagnetic activity. Complete documentation of this model may be found in reference 3.

Atomic oxygen density in the atmosphere at orbital altitudes is strongly influenced by solar activity. The F10.7 cm solar radio flux is used as a measure of solar activity and of the associated extreme ultraviolet radiation that affects atomic oxygen generation. Atomic oxygen density variations correlate closely with solar radio noise flux (F10.7 cm flux), although the solar radio noise flux itself has little if any impact on the atmosphere.

3.1.3 Ephemeris (Lunar and Solar)

The MSIS_86 atmosphere requires the location of the Sun, and both LOP and ASAP include gravitational perturbations from the Sun and the Moon. The code described here includes a subroutine (LUSO) which computes ECI coordinates for the Sun and the Moon as a function of Julian Date. The computations used by LUSO are described in detail in reference 8. The methods are summarized here.

The equations for the solar ephemeris are taken from page 98 of the *Explanatory Supplement* (ref. 9). They consist of polynomials in time (Julian Centuries from 1900.0) for the orbital elements of the Sun.

The motion of the Moon is considerably more complicated. The equations used in LUSO are based on the Brown-Hill lunar theory as described in *Improved Lunar Ephemeris,* 1952-1959 (ref. 5). The theory described in the reference is truncated to 60 periodic terms for longitude, latitude, and parallax. The neglected terms have coefficients smaller than 20 arcseconds for longitude and latitude and 0.5 arcseconds for parallax.

3.1.4 Coordinate Systems and Coordinate System Transformation

It is convenient to use different coordinate systems for various processes in FLUXAVG. For example, satellite surface normal vector directions are most easily defined in spherical coordinates with respect to user-selected Cartesian (X,Y,Z) axes attached to the satellite, while the satellite position and velocity on orbit are defined in Earth-centered inertial (ECI) coordinates. The ECI coordinates are fixed in space while the surface normal direction coordinates move with the satellite. One coordinate system must be transformed to the other before calculations involving them both can be performed. This section describes the coordinate systems used by FLUXAVG and the transformations between them.

Earth-Centered Inertial (ECI) Coordinate System. As noted above, satellite position and velocity are calculated in ECI coordinates. The ECI coordinate system is a right-handed orthogonal Cartesian set of coordinates defined such that its center is at the center of the Earth, the X axis is in the direction of the vernal equinox at the epoch time of the orbit calculation, the Z axis is in the direction of the north pole, and the Y axis is such that (X,Y,Z) are right handed in the sense that $\mathbf{i} \times \mathbf{j} = \mathbf{k}$ where **i**, **j**, and **k** are unit vectors in the positive X, Y, and Z directions, respectively. The ECI coordinate system rotates very slowly with respect to the background of the stars (one revolution in 26,000 years). The Earth rotates in the ECI coordinate system. The ECI coordinate system is not truly inertial because its origin moves as the Earth orbits the Sun, and because of the precessional rotation. However, because all satellite motions are with respect to the Earth, we shall treat the ECI coordinate system as if it were an inertial coordinate system

User Body Axis System and FLUXAVG Internal Body Axis System. The user attaches a right-handed Cartesian body axis coordinate system to the satellite. Outward surface normal directions are measured in the body axis system using conventional spherical coordinate definitions (fig. 5). The ϕ angle is measured from the positive Z axis and the θ angle is measured from the positive X axis toward the positive Y axis. In terms of X, Y, and Z the unit surface normal direction vector is

$$X = \cos\theta \sin\phi \tag{3.1.4.1}$$

$$Y = \sin\theta \sin\phi \tag{3.1.4.2}$$

$$Z = \cos\phi \tag{3.1.4.3}$$

Internally, FLUXAVG uses a body axis system such that with respect to the satellite orientation on orbit and in the absence of roll, pitch, and yaw (discussed below), the X axis is in the zenith direction, the Z axis is in the heading direction, and the Y direction is such that (X,Y,Z) form a right handed coordinate system. The user specifies which of his body axis directions corresponds most nearly to the internal body axis system zenith (X) direction and which to the heading (Z) direction.

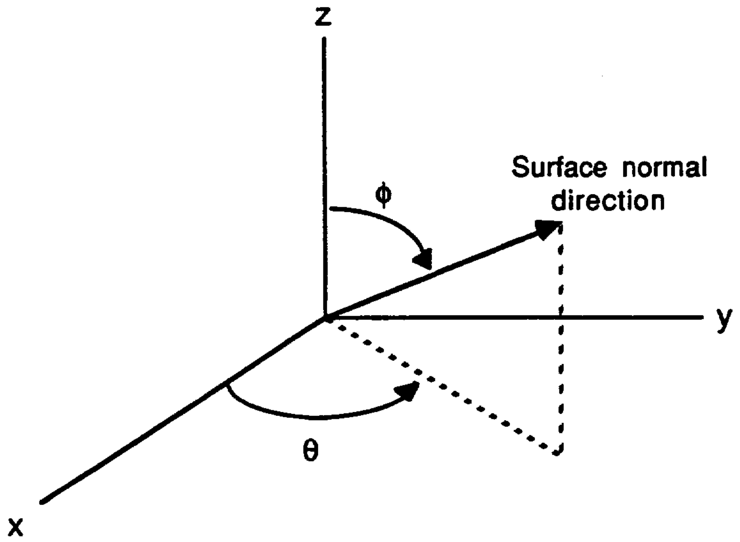


Figure 5. Surface Normal Directions Measurement in the Body Axis Coordinate System

The surface normal unit vectors must be transformed from user body axis coordinates to FLUXAVG internal body axis coordinates by appropriate rotations of coordinates about the X, Y, and Z axes. Because coordinate rotations do not commute, first a rotation about the user body Z axis is performed, followed by a rotation about the resulting Y axis, and last a rotation about the resulting X axis. Table 6 gives the rotations required to transform from user body axis system coordinates to FLUXAVG internal body axis system coordinates for each of the 24 possible correspondences between the two coordinate systems.

Table 6
Transformation From User Body Axis System to FLUXAVG Internal Body Axis System

Satellite Body Axis Nearest to the Zenith	Satellite Body Axis Nearest to the Orbital Heading					
	+x	+y	+z	-x	-y	-z
+x		z = 0° y = 0° x = 90°	z = 0° y = 0° x = 0°		z = 0° y = 0° x = 270°	z = 0° y = 0° x = 180°
+y	z = 270° y = 0° x = 270°		z = 270° y = 0° x = 0°	z = 270° y = 0° x = 90°		z = 270° y = 0° x = 180°
+z	z = 0° y = 90° x = 180°	z = 0° y = 90° x = 90°		z = 0° y = 90° x = 0°	z = 0° y = 90° x = 270°	
-x		z = 180° y = 0° x = 270°	z = 180° y = 0° x = 0°		z = 180° y = 0° x = 90°	z = 0° y =180° x = 0°
-y	z = 90° y = 0° x = 90°		z = 90° y = 0° x = 0°	z = 90° y = 0° x = 270°		z = 90° y = 0° x = 180°
-z	z = 0° y = 270° x = 0°	z = 0° y = 270° x = 90°		z = 0° y = 270° x = 180°	z = 0° y = 270° x = 270°	

Axis directions at top and left of table are user body axis system directions corresponding to heading and zenith directions, respectively. Entries in table are the rotation in degrees about the z, y, and x axes needed to transform from user body axis coordinates to FLUXAVG internal body axis coordinates.

The following rotation matrix transforms the vector (a,b,c) defined in the (X,Y,Z) coordinate system to (a',b',c') in the (X',Y',Z') coordinate system. The (X',Y',Z') coordinate system is formed by rotating the (X,Y,Z) coordinate system by an angle of γ about the Z axis (fig. 6).

$$\begin{bmatrix} a' \\ b' \\ c' \end{bmatrix} = \begin{bmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \qquad (3.1.4.4)$$

The following rotation matrix transforms the vector (a,b,c) defined in the (X,Y,Z) coordinate system to (a',b',c') in the (X',Y',Z') coordinate system. The (X',Y',Z') coordinate system is formed by rotating the (X,Y,Z) coordinate system by an angle of δ about the Y axis (fig. 7).

$$\begin{bmatrix} a' \\ b' \\ c' \end{bmatrix} = \begin{bmatrix} \cos\delta & 0 & \sin\delta \\ 0 & 1 & 0 \\ -\sin\delta & 0 & \cos\delta \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \qquad (3.1.4.5)$$

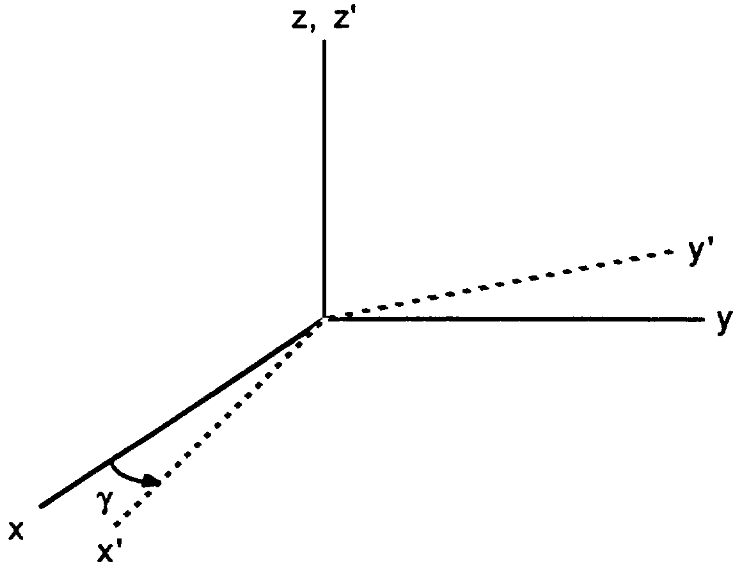


Figure 6. A Rotation by Angle γ About the z axis

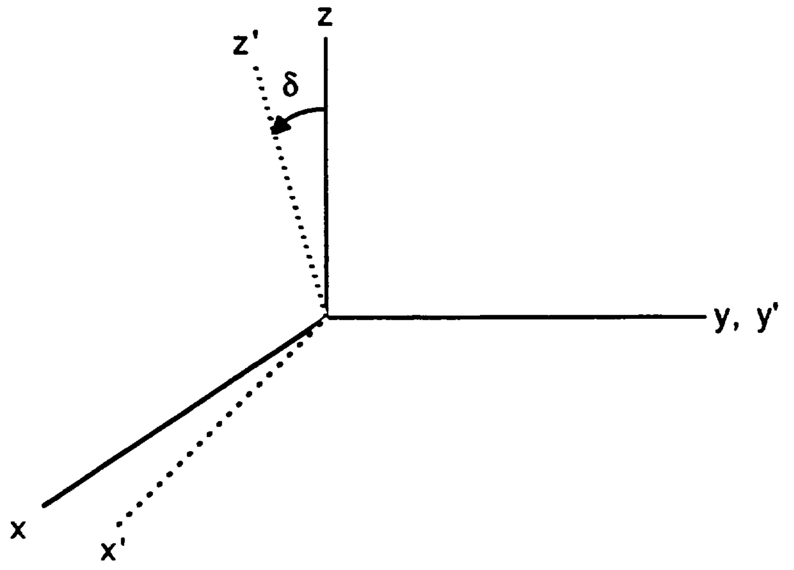


Figure 7. A Rotation by Angle δ About the y axis

The following rotation matrix transforms the vector (a,b,c) defined in the (X,Y,Z) coordinate system to (a',b',c') in the (X',Y',Z') coordinate system. The (X',Y',Z') coordinate system is formed by rotating the (X,Y,Z) coordinate system by an angle of ε about the X axis (fig. 8).

$$\begin{bmatrix} a' \\ b' \\ c' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varepsilon & -\sin\varepsilon \\ 0 & \sin\varepsilon & \cos\varepsilon \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \qquad (3.1.4.6)$$

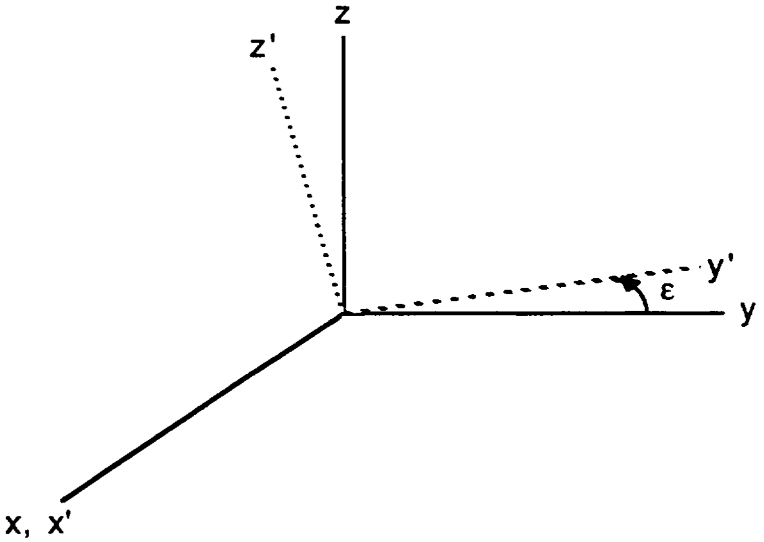


Figure 8. A Rotation by Angle ε About the x axis.

If the satellite heading and zenith directions are not aligned with the orbit heading and zenith directions, the FLUXAVG internal body axis coordinate system must be transformed so that the surface normal unit vectors are expressed in the orbit heading and zenith coordinates. This coordinate system is defined such that its X axis is aligned with zenith. Its Z axis is perpendicular to the X axis, in the plane formed by the zenith and heading direction, and approximately in the heading direction. The Y axis is such that (X,Y,Z) form an orthogonal right hand coordinate system.

Again, because rotations do not commute, a specific order must be adopted for the transformation from FLUXAVG internal body axis coordinates to zenith and heading direction coordinates; namely, first roll, followed by pitch, and last yaw. Roll is defined as a rotation about the heading direction (Z axis as given in equation 3.1.4.2.4). Pitch is a rotation about the Y axis as given in equation 3.1.4.5. Yaw is a rotation about the zenith direction (X axis as given in equation 3.1.4.6).

3.1.5 Atmospheric Co-Rotation

The atmosphere rotates with the Earth as the satellite orbits the Earth. The velocity of the satellite relative to the atmosphere equals the satellite velocity vector minus the atmospheric velocity vector. This velocity is called the relative velocity. Both the direction and magnitude of the relative velocity vector are affected by atmospheric motion. Figure 9 shows the relationship between these quantities.

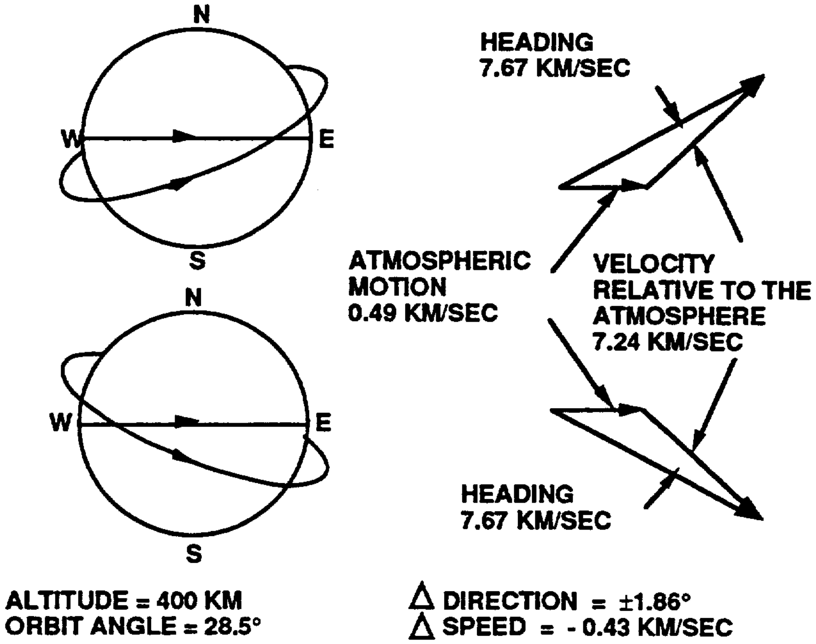


Figure 9. Co-Rotation of the Earth's Atmosphere

For small angles of inclination, the decrease in relative velocity vector magnitude due to atmospheric motion is nearly constant for all points in an orbit. For a spacecraft at an altitude of 400 km in an orbit inclined 28.5 deg to the Earth's equator, the speed is decreased 0.43 km/s. The relative velocity vector shifts 1.86 deg to right and left of the heading during each complete orbit.

Atomic oxygen fluence at zero incidence angle is decreased by approximately 5% by co-rotation of the atmosphere for a typical low-Earth-orbit satellite.

Because the atomic oxygen fluence on a surface is a function of the angle between the resultant ram vector and the surface normal vector, both vectors must be placed in the same coordinate system before this angle can be calculated. It is convenient to use the ECI coordinate system for this.

The speed of atmospheric rotation at any latitude is given by

$$v_e = r\,\Omega \cos(\text{latitude}) \tag{3.1.5.1}$$

where r is the distance from the center of the Earth to the satellite and Ω is the Earth's rotation rate. In ECI coordinates the atmospheric rotation velocity has only X and Y components, designated as v_{ex} and v_{ey}, respectively. The atmospheric rotation velocity must be expressed in terms of these components. This evaluation is straightforward; however, care must be taken to assign the proper sign to these components. Table 7 gives the values of v_{ex} and v_{ey} in terms of satellite position (X,Y,Z) in ECI coordinates.

Table 7
Atmospheric Co-Rotation Vector Components in ECI Coordinates

Case	
$x = 0$	$v_{ey} = 0$ $v_{ex} = -v_e \quad \text{if } y<0$ $\phantom{v_{ex}} = v_e \quad \text{if } y\geq 0$
$y = 0$	$v_{ex} = 0$ $v_{ey} = -v_e \quad \text{if } x>0$ $\phantom{v_{ey}} = v_e \quad \text{if } x\leq 0$
$x\neq 0,\ y\neq 0$	$\lvert v_{ex}\rvert = \dfrac{\left\lvert\frac{y}{x}\right\rvert v_e}{\sqrt{1-\left(\frac{y}{x}\right)^2}}$ $\lvert v_{ey}\rvert = \dfrac{v_e}{\sqrt{1-\left(\frac{y}{x}\right)^2}}$ $v_{ex} = -\lvert v_{ex}\rvert \quad \text{if } y>0$ $\phantom{v_{ex}} = \lvert v_{ex}\rvert \quad \text{if } y\leq 0$ $v_{ey} = -\lvert v_{ey}\rvert \quad \text{if } x<0$ $\phantom{v_{ey}} = \lvert v_{ey}\rvert \quad \text{if } x\geq 0$

3.1.6 Kinetics Routine

Molecules in a gas in thermal equilibrium have a Maxwellian speed distribution characteristic of their temperature. At 1000°K, the average molecular speed of atomic oxygen is 1.15 km/sec. The average speed of a spacecraft relative to the atmosphere at 400-km altitude in an easterly orbit is 7.24 km/sec. The importance of these variables have been analyzed and reported in reference 10. Because of thermal molecular motion, atomic oxygen flux on a surface at high incidence angles is not accurately given by the product of number density, spacecraft velocity, and projected surface area. An equation to account for the effect of thermal molecular velocity as well as vehicle velocity is derived in the following paragraphs.

Addition of Thermal Molecular and Vehicle Velocities. The velocity of a molecule with respect to the spacecraft is the vector sum of its thermal velocity and the velocity of the spacecraft reversed. This relationship is shown in figure 10.

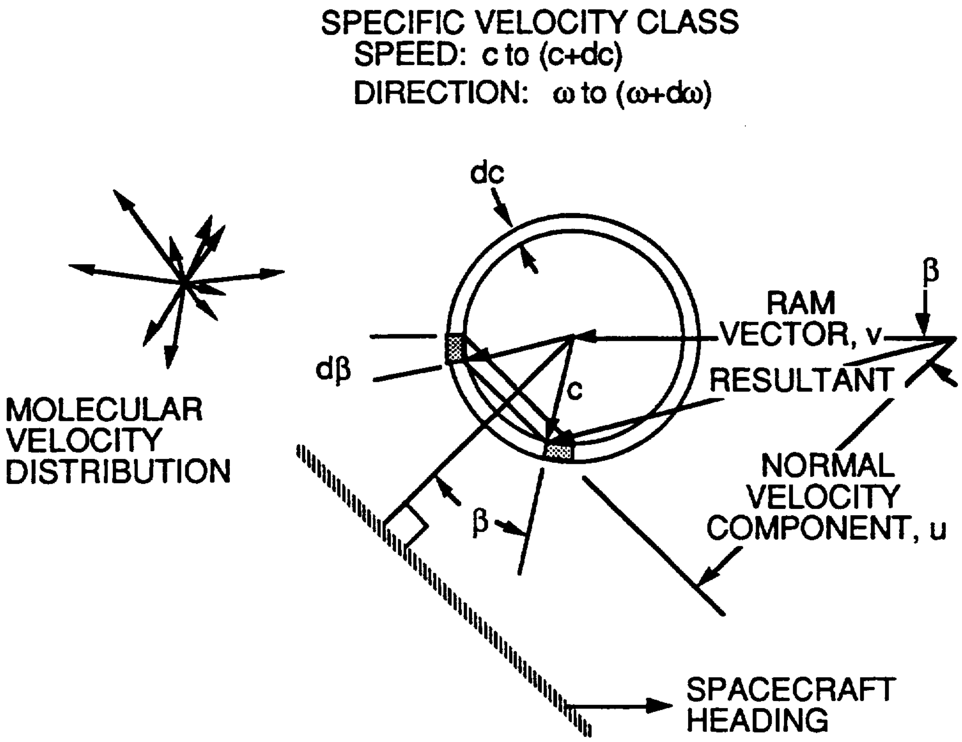


Figure 10. Addition of Vehicle and Thermal Molecular Velocity Vectors

The thermal velocity of a molecule is described by two distribution functions. G(c), the Maxwell speed distribution function represents the fraction of molecules with speed in the range c to (c+ dc). The value of the speed distribution function varies with temperature. (A symbol glossary precedes the text.)

$$G(c) = \frac{1}{N}\frac{\partial N}{\partial c} = \left(\frac{M}{2\pi RT}\right)^{\frac{3}{2}} \exp\left(-\frac{Mc^2}{2RT}\right)(4\pi c^2) \tag{3.1.6.1}$$

H, the solid angle distribution function, represents the fraction of molecules with velocity vectors directed in the range of solid angles ω to $(\omega + d\omega)$. Since all directions of the velocity vector are equally probable, the solid angle distribution function is a constant.

$$H = \frac{1}{N}\frac{\partial N}{\partial \omega} = \frac{1}{4\pi} \tag{3.1.6.2}$$

The population of atomic oxygen molecules in the vicinity of the spacecraft is considered to be divided into infinitesimal velocity classes. For a given velocity class, molecular velocity is added to the ram vector to obtain the velocity of molecules in the class relative to the spacecraft. An equation for the component of relative velocity perpendicular to the spacecraft surface is then derived for the specified molecular velocity class.

$$u = v\cos\alpha + c\cos\beta \tag{3.1.6.3}$$

Using the relative velocity equation and the two distribution functions, an equation is derived for flux at the surface caused by molecules contained in the velocity class. This equation is modified by expressing solid angle in terms of plane angle measured from the surface normal.

$$\frac{\partial^2 F}{\partial c \partial \omega} = HGNu \tag{3.1.6.4}$$

$$\frac{\partial \omega}{\partial \beta} = 2\pi\sin\beta \tag{3.1.6.5}$$

$$\frac{\partial^2 F}{\partial c \partial \beta} = \frac{1}{4\pi} GNu(2\pi\sin\beta) \tag{3.1.6.6}$$

The derivation yields a differential equation for molecular flux in terms of two independent variables and four constants. The independent variables are thermal molecular speed and the direction of the molecular velocity vector relative to the surface. The constants are temperature, number density, spacecraft velocity, and the angle the surface makes with the ram direction of the vehicle.

Limits of Integration. The differential equation for flux is integrated with respect to the independent variables, molecular speed and angle, to obtain an equation for flux in terms of temperature, number density, spacecraft velocity, and incidence angle. Values for the latter items are held constant during the integration process. To arrive at the equation for flux, limits for integration are devised for leading surfaces to include all molecules swept out by the advancing surface.

The gas molecules surrounding the spacecraft are separated into two speed populations. The first population includes those molecules that do not have sufficient velocity to "outrun" the spacecraft even if traveling directly away from the spacecraft surface. The second population includes those molecules that can "outrun" the advancing surface if traveling in a path directed at a sufficient angle away from the surface. Molecules that "outrun" the spacecraft are not included within the limits.

$$F = \int_0^{v\cos\alpha} \int_0^{\pi} \left(\frac{\partial^2 F}{\partial c \partial \beta}\right) \partial\beta \partial c + \int_{v\cos\alpha}^{\infty} \int_0^{\cos^{-1}[(-v\cos\alpha)/c]} \left(\frac{\partial^2 F}{\partial c \partial \beta}\right) \partial\beta \partial c \qquad (3.1.6.7)$$

Integration limits for trailing surfaces (surfaces on the aft side of the spacecraft) can be devised to include molecules with velocities such that they can catch the spacecraft. However, the resulting integral is identical to that derived for leading surfaces. Hence, the integral shown leads to a valid equation for flux (atoms per unit area per unit time) for both leading and trailing surfaces as follows:

$$F = \frac{1}{4} N <c> \left\{\exp\left(-U^2\right) + U\sqrt{\pi}[1 + \mathrm{erf}(U)]\right\} \qquad (3.1.6.8)$$

Where

$$<c> = \sqrt{\frac{8RT}{\pi M}}$$

and

$$U = \frac{2}{\sqrt{\pi}}\left(\frac{v}{<c>}\right)\cos\alpha;$$

To simplify the equation, terms resulting from the integration process have been gathered into two expressions. The first expression, <c>, can be recognized as the equation for average molecular speed consistent with kinetic molecular theory. The second expression, U, is a dimensionless statement for the normal component of speed for the advancing surface relative to average molecular speed multiplied by constant factors that appear in the integral.

Equation 3.1.6.8 has been derived elsewhere in connection with research on heat transfer and drag in rarefied gases (ref. 11).

Characteristics of the Closed Form Solution. To illustrate agreement with kinetic theory, two specific limiting cases are considered: (1) zero spacecraft velocity and (2) zero average molecular speed (zero temperature).

If, $v = 0$, then: $F = 1/4\ N <c>$ (3.1.6.9)

If, $<c> = 0$, then: $F = Nv \cos\alpha$ (3.1.6.10)

Otherwise: $F = 1/4\ N <c> f(U)$ (3.1.6.11)

In the case of zero spacecraft velocity, v = 0, the equation is identical to that for the collisions by perfect gas molecules with a stationary plane surface In the case of zero temperature, c = 0, the equation is identical to that for a stationary gas of known density swept out by a moving surface. In equation 3.1.6.11, the function f(U) equals the quantity shown in braces in equation 3.1.6.8.

3.1.7 Orbit Propagation, Flux Calculation, and Fluence Calculation Sequence

LOP propagates the satellite orbit over long periods and ASAP propagates the orbit in small steps used for flux calculation. The sequence of operations is most easily understood by considering a simple sample mission. Figure 11 illustrates the sequence. In the sample mission, two sets of orbital elements have been provided, one at start of mission time t_0 and one later in the mission at time t_4. For the first set of orbital elements, it is desired to calculate fluxes at mission start and at three equally spaced intervals. Note that the interval between t_3 and t_4 is not necessarily the same as the intervals between t_0, t_1, t_2 and t_3. For the second set of orbital elements the user wishes to calculate fluxes for four intervals including end of mission. In this case, FLUXAVG adjusts the LOP step size to give four equally spaced intervals between t_4 and t_8. t_8 is the time at end of mission minus the time spent running ASAP (discussed below). This ensures that the calculations end at end of mission. It should be noted that neither the time interval for flux calculations nor the number of intervals need to be the same from one set of orbital elements to the next.

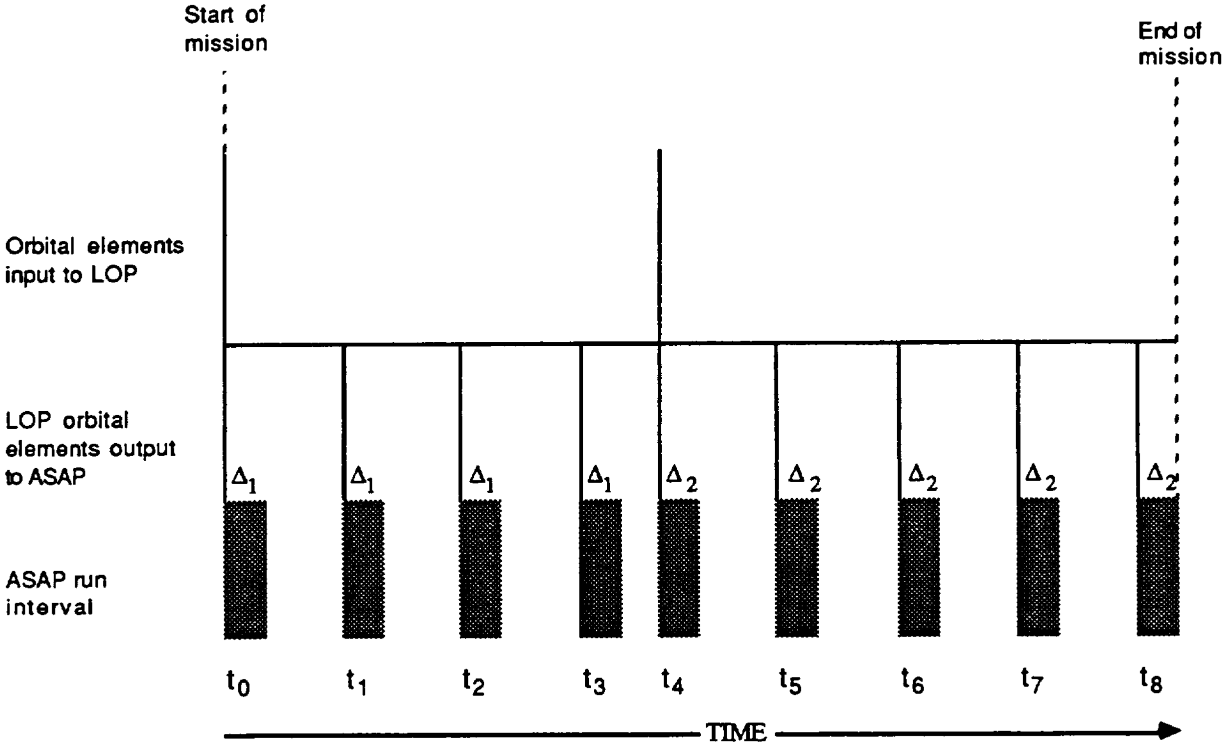


Figure 11. Orbit Position Calculation Sequence

LOP is run to propagate the orbit with the first set of orbit elements and generates and saves mean orbital elements at times t_0, t_1, t_2, and t_3 on a scratch file. ASAP is run using each set of mean orbital elements to output satellite position, velocity, atomic oxygen density, and temperature for closely spaced points on orbit over a short time interval. Typically, ASAP outputs these data about every 6 minutes for a period of about 1 day, giving a total of about 240 points. The total time interval for an ASAP run is designated Δ_1 for the first set of orbital elements and Δ_2 for the second. Δ_1 and Δ_2 need not be the same.

An instantaneous flux on each satellite surface is calculated for each point using the kinetics routine described in the preceding section. After all of the instantaneous fluxes are calculated for a single ASAP run, the instantaneous fluxes are divided by the number of points to give the average flux on each surface. In the example, the first ASAP run starts at t_0 and ends at $t_0 + \Delta_1$, so the average flux is taken over this time interval. ASAP flux calculations are next performed at t_1 and t_2. This completes the calculations involving the first set of orbital elements.

The same process is performed for the second set of orbital elements: run LOP to generate mean orbital elements at times t_4 through t_8; run ASAP to generate detailed orbit data over short time intervals Δ_2 starting at each of the times t_4 through t_8; and calculate instantaneous fluxes and average fluxes on each surface.

Fluence calculation on each surface takes place after all flux calculations are complete. By definition, there is zero fluence on any surface at mission start. At later times t_n ($n = 2, 3, \ldots, 7$ in the example) the fluence on a surface is given by

$$\Phi(t_n) = \Phi(t_{n-1}) + 1/2[F(t_{n-1}, t_{n-1} + \Delta_{n-1}) + F(t_n, t_n + \Delta_n)](t_n - t_{n-1}) \qquad (3.1.7.1)$$

where $F(t_0, t_0 + \Delta_1)$ is the average flux on the surface between times t_0 and $t_0 + \Delta_1$, and Δ_{n-1} and Δ_n may be either of Δ_1 or Δ_2 as required for the ASAP calculation intervals starting at t_{n-1} and t_n.

The last case in the mission is a special case. At the end of mission, the fluence on a surface is given by

$$\Phi(t_8 + \Delta_2) = \Phi(t_7) + 1/2[F(t_7, t_7 + \Delta_2) + F(t_8, t_8 + \Delta_2)](t_8 + \Delta_2 - t_7) \qquad (3.1.7.2)$$

In the special case where one ASAP run covers the entire mission, the fluence on a surface is given by the average flux over the mission time times the mission length in seconds.

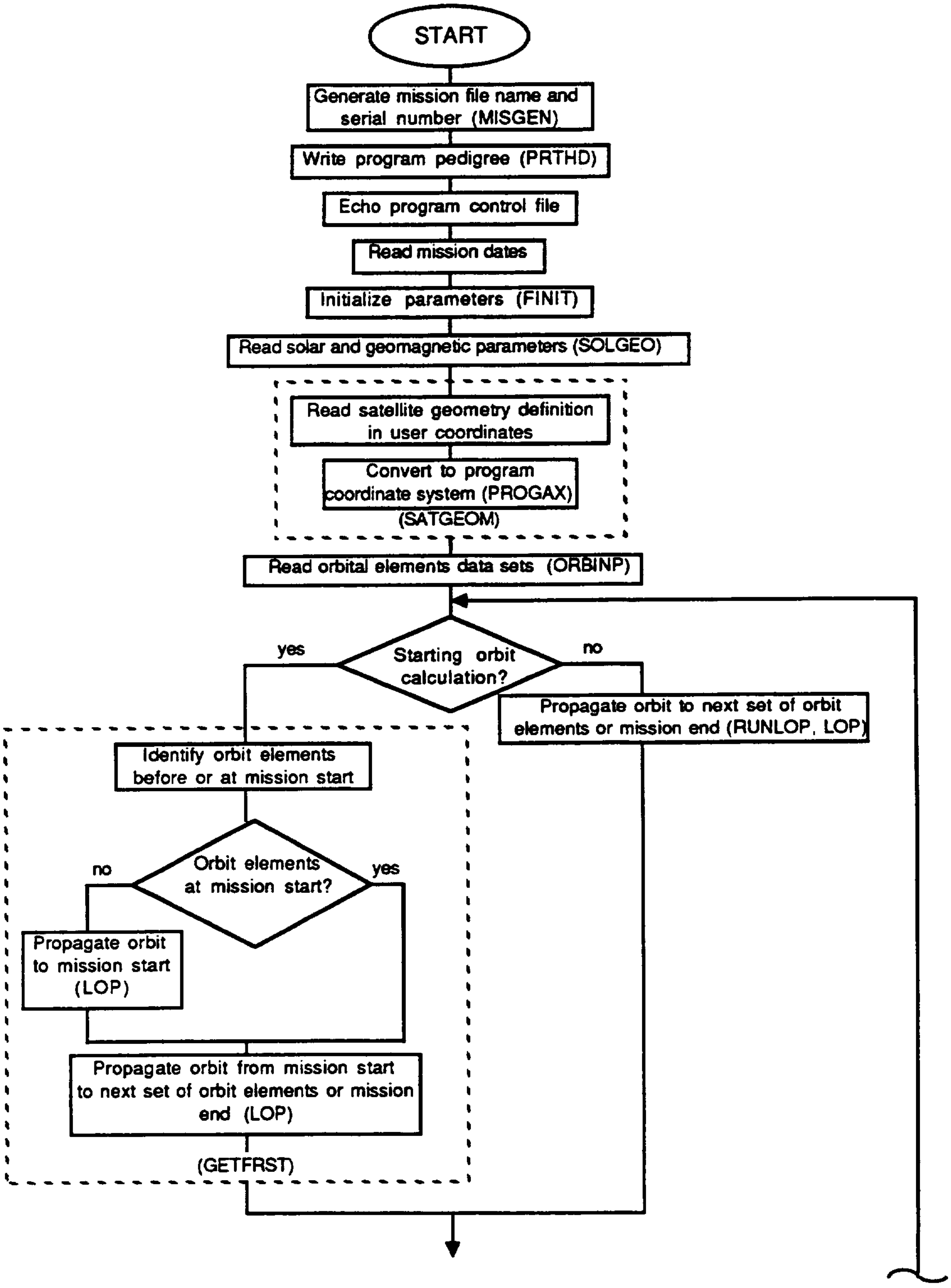
3.2 PROGRAM FLOWS

3.2.1 Program Flow for the Direct AO Exposure Model

This section describes the functional flow of FLUXAVG. The FLUXAVG block diagram (fig. 12) will be an aid to following the functional description. Figures 13 through 15 are subroutine tree diagrams for FLUXAVG, LOP, and ASAP. They indicate the order of the first call to each subroutine and function in FLUXAVG. Section 3.1 describes the algorithms used in FLUXAVG.

FLUXAVG starts by reading the mission file name root from the program control file and appending a date and serial number to it before opening the mission file. Program pedigree and the program control file are echoed to the mission file. All subsequent input and output are written to the mission file. Mission start and end dates are read from the program control file, and parameters are initialized. The file of solar flux and geomagnetic activity is read in. The satellite surface normal vectors are read in the user coordinate system and converted to the coordinate system used by FLUXAVG. The file of orbit calculation control data and orbital elements is read in.

FLUXAVG Block Diagram



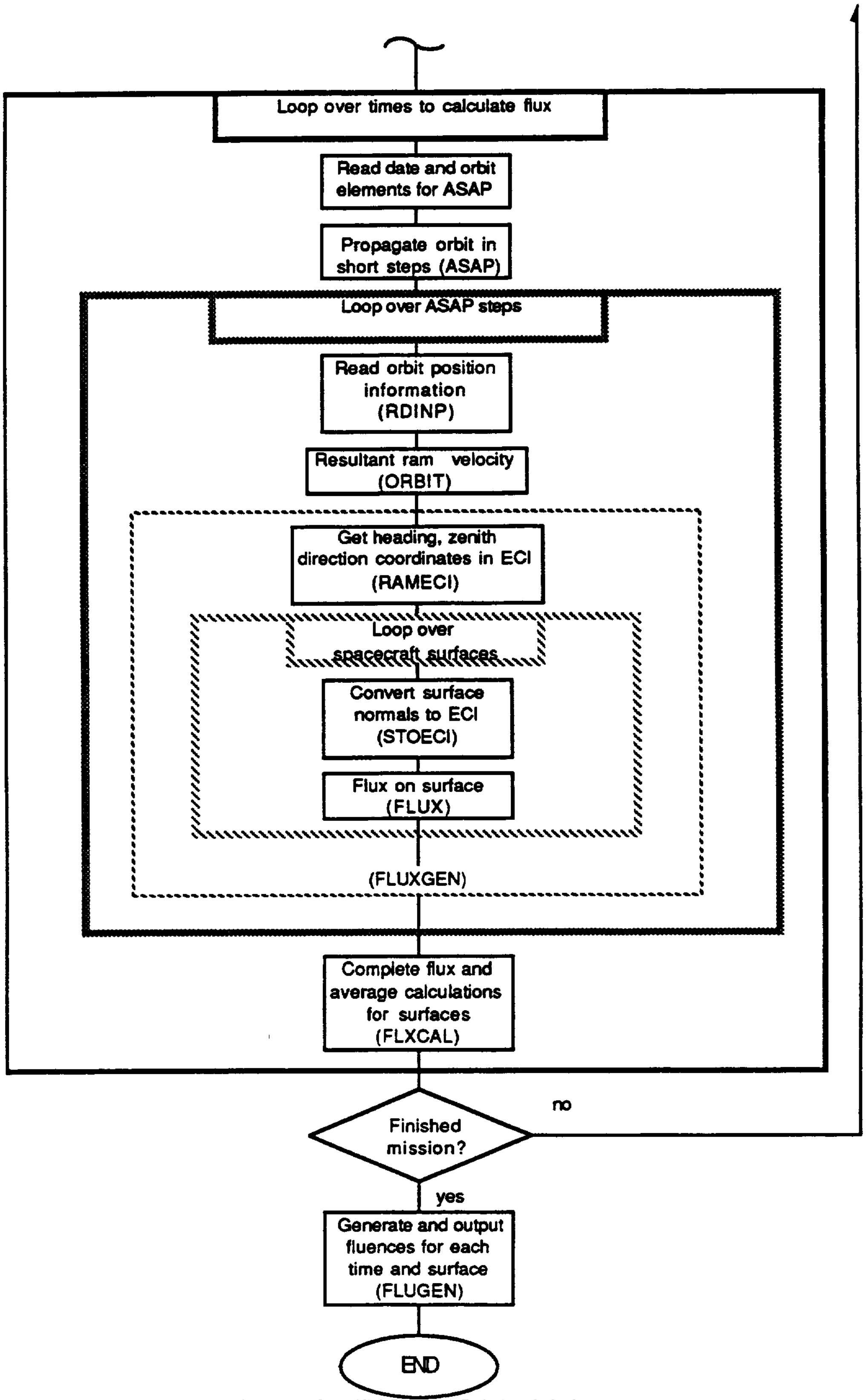


Figure 12. FLUXAVG Block Diagram

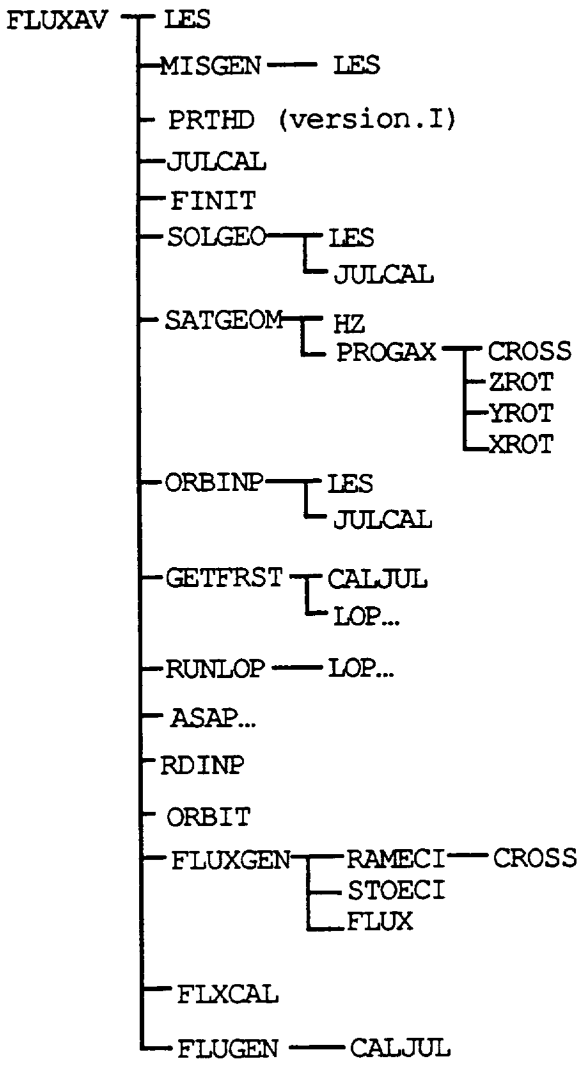


Figure 13. FLUXAVG Subroutine Tree

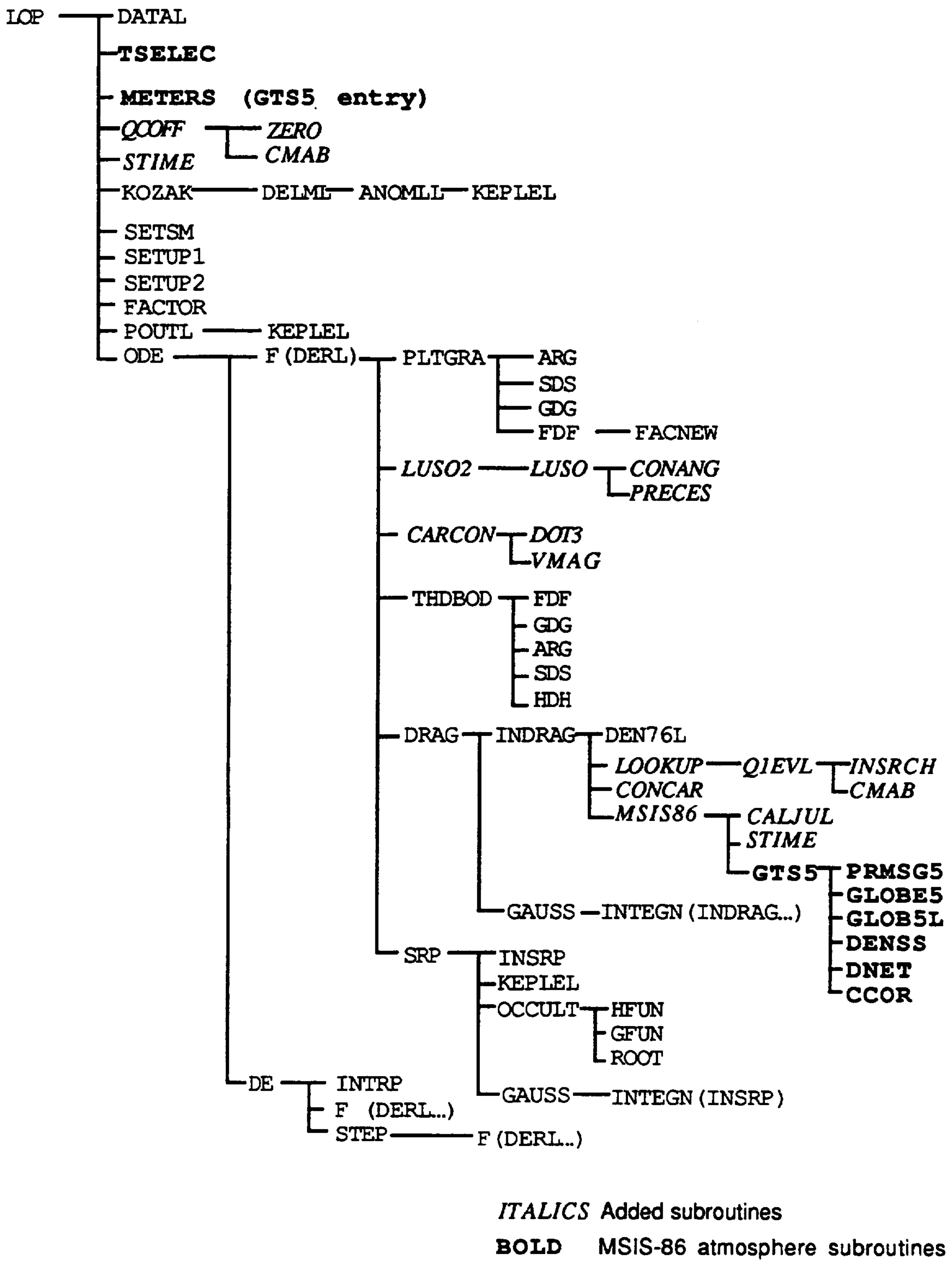
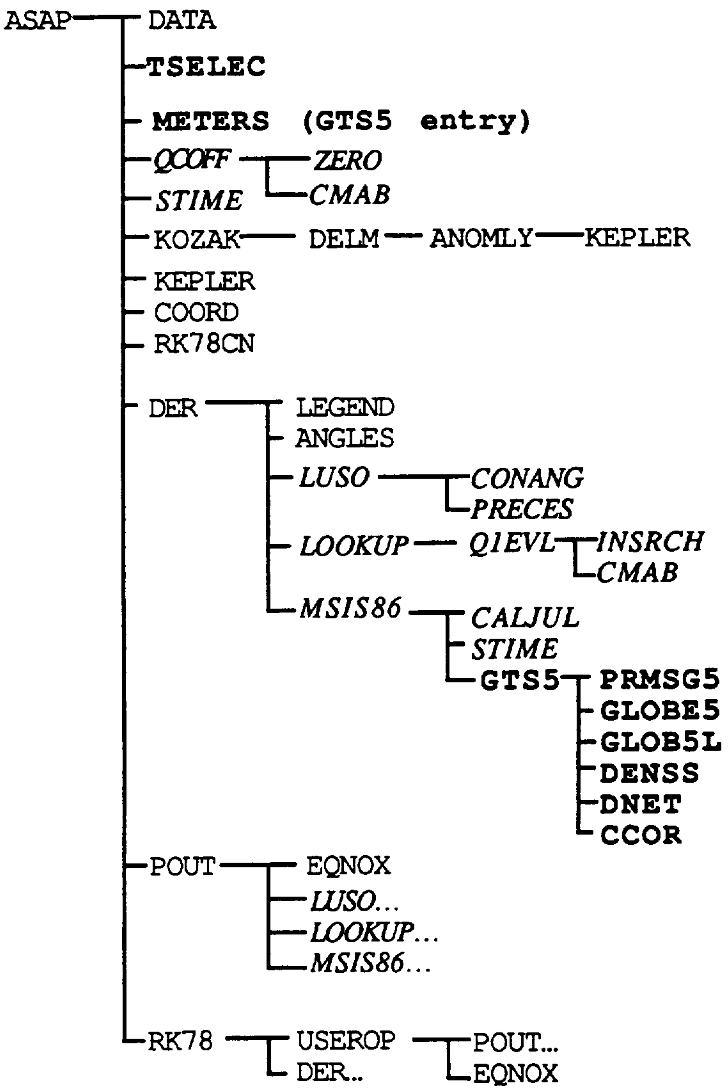


Figure 14. LOP Subroutine Tree



ITALICS Added subroutines

BOLD MSIS-86 atmosphere subroutines

Figure 15. ASAP Subroutine Tree

Calculations start by choosing the set of orbit elements at or nearest before mission start. If the orbit elements selected are before mission start, LOP is run to propagate the satellite orbit to mission start and generate a set of orbit elements at mission start. LOP is then run to propagate the orbit a selected number of steps. Typically, the user might choose the interval from one step to the next to be a week or a month. If the mission ends before the next set of orbit elements, the step size and number of steps are adjusted to end the calculations at the proper time. Orbit elements and data are saved on a file for each step. It should be noted that all dates are carried as Julian dates in FLUXAVG; they are converted to calendar dates only on output.

The first set of orbit elements is read from the file made by LOP and used as input to ASAP. ASAP propagates the orbit in a user-selected number of short time steps. Typically, the user might choose the number and duration of the steps so that 16 points per orbit are calculated for a period of 1 day. ASAP saves orbit position, velocity, time, atomic oxygen density, and temperature to a file for each point calculated. The MSIS-86 atmosphere model is called by both ASAP and LOP; all information about the atmosphere is passed to FLUXAVG through ASAP.

Flux on each satellite surface is calculated for each point on orbit in the following manner. The relative velocity is calculated as described in the preceding section. The heading and zenith coordinate system axes are transformed to ECI coordinates. The surface normal vector for each surface is transformed to ECI coordinates and the angle between the relative velocity vector and the surface normal is calculated. This information, together with atomic oxygen density and temperature data, is used to calculate the instantaneous flux on each surface. These fluxes are averaged over the number of ASAP steps, as are temperature, atomic oxygen density, altitude, and satellite speed.

At this point, FLUXAVG loops back and runs LOP on the next set of orbit elements and repeats the cycle until end of mission. FLUXAVG takes care at end of mission to cause LOP to generate the last set of orbit elements to be at end of mission minus the time ASAP will propagate the orbit. This ensures that the orbit propagation and flux calculation end exactly at end of mission.

After all atomic oxygen fluxes are calculated for the mission, fluences are calculated for each surface as described in section 3.1.7. When the fluence calculation is finished for all surfaces and all times of interest during the mission, FLUXAVG stops.

3.2.2 Program Flow for the Application File Generator

FLUXPLOT is written in C, and contains the following functions:

main	asks for mission file, calls menu functions and output functions.
GraphMenu	prints the graphics menu and asks for a choice of spreadsheet, Cricket Graph or Tecplot
getNums	gets the mission file name ID and the number of days and number of surfaces from the mission file
OutputMenu	prints the output menu and asks for a choice; opens a file for output
getchoice	gets a menu choice and checks to make sure that it is within bounds
searchf	looks through a file line by line until it finds a string at position nPlace
skipLines	reads in nLines of file *fp, and does nothing with them
pickSurfaces	gives you a choice of surfaces and asks you to pick what you want. It then generates an array of index values and returns the size of the array.
fluence_vs_t	generates a table of fluence versus cumulative days
values_vs_t	generates a table of the average, maximum, and minimum values of either atomic oxygen density, temperature, altitude, absolute speed, or relative speed, all vs time in cumulative days
value_choice	asks for a choice of atomic oxygen density, temperature, altitude, absolute speed, and relative speed, and returns the menu choice.
one_block	creates a table of angles etc., versus fluence for a given day
tables	generates a table of fluence versus cumulative days. If the altitude rises from one day to the next (i.e., reboost), then it starts on a new page

FLUXPLOT has a fairly simple structure. The main program asks for a mission file and presents an output format menu. Then it presents a data output menu and, based on the user response, it calls one of the four functions: fluence_vs_t, values_vs_t, one_block, or tables.

fluence_vs_t calls pickSurfaces so that the user can choose which surfaces will be in the graph of fluence versus time. It then loops through each date block and each surface within the date block, and checks to see if the surface is in the array. If it is, then it reads in the fluence and dumps it into the application file.

values_vs_t calls value_choice so that the user can choose from atomic oxygen density, temperature, altitude, absolute speed, or relative speed. It then loops through each time block, reads in average, maximum, and minimum values, and dumps it into the application file.

one_block asks for the target time. It then loops through each date block and reads in the time in cumulative days until the values match within 1 day. Once they match, it reads in the data lines, puts a tab marker in between all the values, and writes them into the application file.

tables calls pickSurfaces so that the user can choose which surfaces will be in the tables. It then loops through each date block and each surface within the date block, and checks to see if the surface is in the array. If it is, then it transfers the angle data to an array and the fluence data to a matrix. It checks to see if the altitude has risen more than the minimum reboost distance or if the matrix has exceeded the maximum number of columns; if it has, then it dumps all but the latest values into the application file.

A flow chart for the program is shown in figure 16.

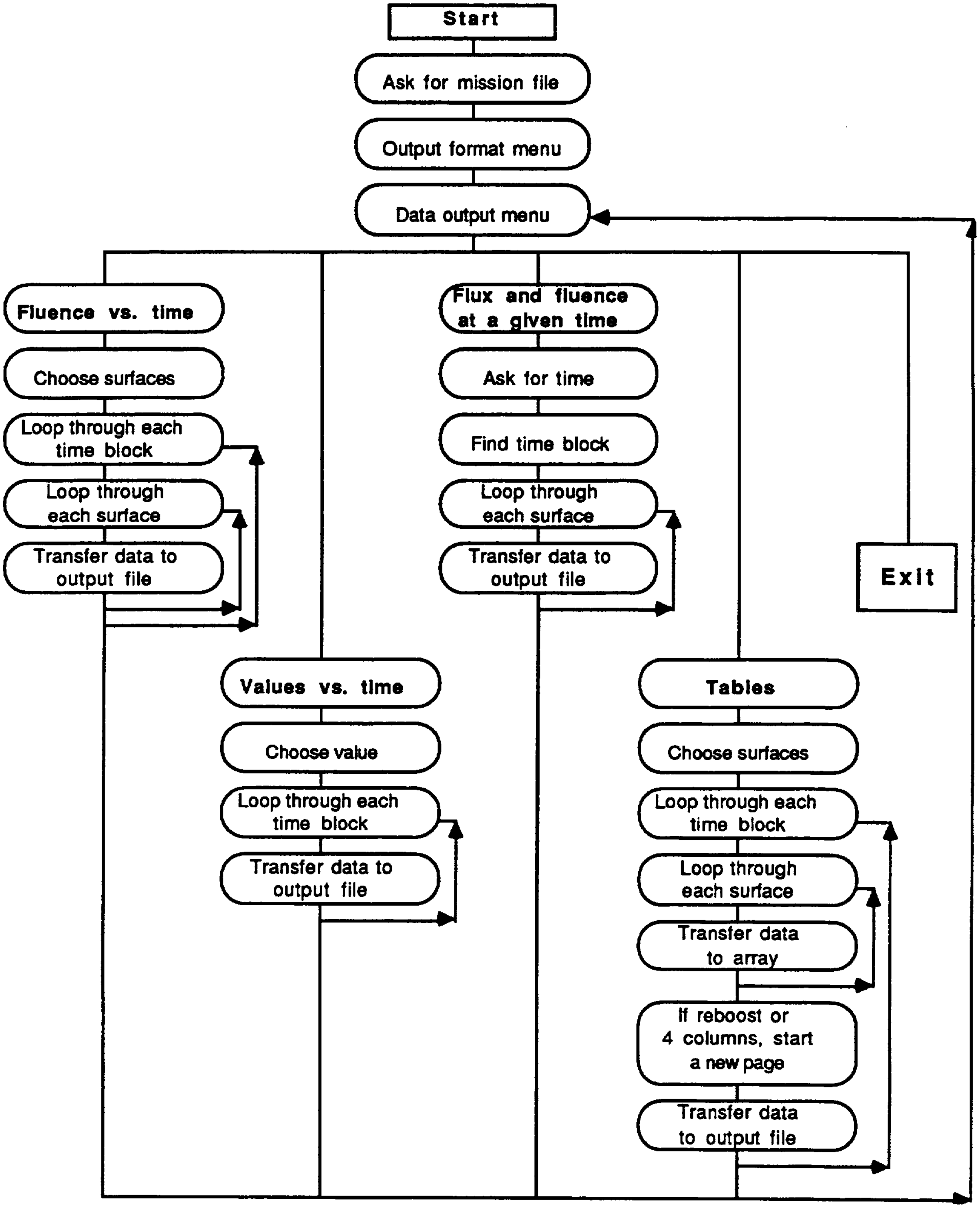


Figure 16. FLUXPLOT Flow Chart

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APPENDIX A

APPENDIX A SAMPLE PROGRAM RUN

This appendix shows the results of a sample run, starting with its input files and ending with the various application files. Picked as an example is the first three months of the Space Station Freedom mission.

A.1 Program Control File

Filename: fluxavg_in.sample

```
fluxavg.mission_sample
fluxavg.in_sample
This is a short run to test FLUXAVG.
The start of the Space Station Freedom mission is run.
                 Described in Mission Profile Grumman
                 Memo P SH-314-M092-038
                 date Sept 8, 1991
The second set of orbit elements is set to calculate fluxes and fluences
at the orbit elements epoch date and at 7 and 14 days after.  The other
sets of orbit elements calculate fluxes and fluences only on the
epoch date.
$
 0                                 IVEL FLAG FOR VELOCITY INFORMATION
1995 11 30 13 55 21.80             MISSION START DATE (yyyy mm dd hh mm ss.ss)
1996 02 03 03 51 45.3             MISSION END DATE
solgeo.sample
37                                 NAZEL NUMBER OF SURFACES
SIDE 1                    0.        90.         PHI, THETA
SIDE 2                    5.        90.
SIDE 3                    10.       90.
SIDE 4                    15.       90.
SIDE 5                    20.       90.
SIDE 6                    25.       90.
SIDE 7                    30.       90.
SIDE 8                    35.       90.
SIDE 9                    40.       90.
SIDE 10                   45.       90.
SIDE 11                   50.       90.
SIDE 12                   55.       90.
SIDE 13                   60.       90.
SIDE 14                   65.       90.
SIDE 15                   70.       90.
SIDE 16                   75.       90.
SIDE 17                   80.       90.
SIDE 18                   85.       90.
SIDE 19                   90.       90.
SIDE 20                   95.       90.
SIDE 21                   100.      90.
SIDE 22                   105.      90.
SIDE 23                   110.      90.
SIDE 24                   115.      90.
SIDE 25                   120.      90.
SIDE 26                   125.      90.
SIDE 27                   130.      90.
SIDE 28                   135.      90.
SIDE 29                   140.      90.
SIDE 30                   145.      90.
SIDE 31                   150.      90.
```

```
SIDE 32                   155.      90.
SIDE 33                   160.      90.
SIDE 34                   165.      90.
SIDE 35                   170.      90.
SIDE 36                   175.      90.
SIDE 37                   180.      90.
+Z +X
 0.0      0.0       0.0              roll,pitch,yaw
orbinp.sample
```

A.2 Solar/Geophysical Parameters

Filename: solgeo.sample

```
  YR  MO  DA  E MO AV F10.7    WK AV F10.7          WK AP
1995  11  30           92.0           92.0             17
1995  12   1           92.0           92.0             17
1995  12  31           91.8           91.8             17
1996   1   1           91.8           91.8             17
1996   1  31           91.4           91.4             17
1996   2  29           90.8           90.8             17
```

A.3 Orbit Parameters

Filename: orbit.sample

```
 1995   11   30   13   55  21.80     YY MM DD HH MM SS
     1.0E-06    2.00    2000.0     AREA, Cd, MASS
    0       7.0    0     IORB (0=MEAN), STEP (DAYS),NSTDSC
    6716.970  0.000     28.50     A, ECC, INCL
    342.2000      0.0000      0.0000     NODAL CROSS,ARG P, MA
     360.0  230          ASAP TIME STEP, # STEPS
 1995   12    1   18   52  22.50     YY MM DD HH MM SS
     1.0E-06    2.00    2000.0     AREA, Cd, MASS
    0       7.0    2     IORB (0=MEAN), STEP (DAYS),NSTDSC
    6730.810  0.000     28.50     A, ECC, INCL
    107.1000      0.0000      0.0000     NODAL CROSS,ARG P, MA
     360.0  230          ASAP TIME STEP, # STEPS
 1995   12   31   10   53  19.70     YY MM DD HH MM SS
     1.0E-06    2.00    2000.0     AREA, Cd, MASS
    0       7.0    0     IORB (0=MEAN), STEP (DAYS),NSTDSC
    6726.420  0.000     28.50     A, ECC, INCL
      2.3000      0.0000      0.0000     NODAL CROSS,ARG P, MA
     360.0  230          ASAP TIME STEP, # STEPS
 1996    1    1    6   37   3.60     YY MM DD HH MM SS
     1.0E-06    2.00    2000.0     AREA, Cd, MASS
    0       7.0    0     IORB (0=MEAN), STEP (DAYS),NSTDSC
    6739.030  0.000     28.50     A, ECC, INCL
    110.0000      0.0000      0.0000     NODAL CROSS,ARG P, MA
     360.0  230          ASAP TIME STEP, # STEPS
 1996    1   31   16   32  18.30     YY MM DD HH MM SS
     1.0E-06    2.00    2000.0     AREA, Cd, MASS
    0       7.0    0     IORB (0=MEAN), STEP (DAYS),NSTDSC
    6733.620  0.000     28.50     A, ECC, INCL
    137.8000      0.0000      0.0000     NODAL CROSS,ARG P, MA
     360.0  230          ASAP TIME STEP, # STEPS
```

A.4 Standard Output File

Filename: fluxavg_out.sample

```
1




           ******************************************************
           *  PROGRAM FLUXAVG                                   *
           *  ATOMIC OXYGEN FLUX CALCULATION                    *
           *  RELEASE VERSION 2.0                               *
           *  COMPILED 26-Apr-93   08:26:43                     *
           *                                                    *
           *  DATE OF COMPUTATION:    26-Apr-93   08:47:51      *
           ******************************************************

1THIS INPUT FILE IS
 fluxavg.in_sample
0THE MISSION FILE IS
 fluxavg.mission_sample26-Apr-93.1
0AN ECHO OF THE INPUT FILE FOLLOWS
 fluxavg.mission_sample
 fluxavg.in_sample
 This is a short run to test FLUXAVG.
 The start of the Space Station Freedom mission is run.
                  Described in Mission Profile Grumman
                  Memo P SH-314-M092-038
                  date Sept 8, 1991
 The second set of orbit elements is set to calculate fluxes and fluences
 at the orbit elements epoch date and at 7 and 14 days after.  The other
 sets of orbit elements calculate fluxes and fluences only on the
 epoch date.
 $
  0                                 IVEL FLAG FOR VELOCITY INFORMATION
 1995 11 30 13 55 21.80             MISSION START DATE (yyyy mm dd hh mm ss.ss)
 1996 02 03 03 51 45.3             MISSION END DATE
 solgeo.sample
 37                                 NAZEL NUMBER OF SURFACES
 SIDE 1                   0.        90.         PHI, THETA
 SIDE 2                   5.        90.
 SIDE 3                   10.       90.
 SIDE 4                   15.       90.
 SIDE 5                   20.       90.
 SIDE 6                   25.       90.
 SIDE 7                   30.       90.
 SIDE 8                   35.       90.
 SIDE 9                   40.       90.
 SIDE 10                  45.       90.
 SIDE 11                  50.       90.
 SIDE 12                  55.       90.
 SIDE 13                  60.       90.
 SIDE 14                  65.       90.
 SIDE 15                  70.       90.
 SIDE 16                  75.       90.
 SIDE 17                  80.       90.
 SIDE 18                  85.       90.
 SIDE 19                  90.       90.
 SIDE 20                  95.       90.
 SIDE 21                  100.      90.
 SIDE 22                  105.      90.
 SIDE 23                  110.      90.
```

```
 SIDE 24                   115.      90.
 SIDE 25                   120.      90.
 SIDE 26                   125.      90.
 SIDE 27                   130.      90.
 SIDE 28                   135.      90.
 SIDE 29                   140.      90.
 SIDE 30                   145.      90.
 SIDE 31                   150.      90.
 SIDE 32                   155.      90.
 SIDE 33                   160.      90.
 SIDE 34                   165.      90.
 SIDE 35                   170.      90.
 SIDE 36                   175.      90.
 SIDE 37                   180.      90.
 +Z +X
  0.0      0.0       0.0            roll,pitch,yaw
 orbinp.sample

 THE NAME OF THE MISSION FILE IS
 fluxavg.mission_sample26-Apr-93.1

          MISSION START AND END DATES
                YYYY   MM   DD   HH   MM  SS.SS         JULIAN DATE
          START 1995   11   30   13   55  21.80     2450052.0801134
            END 1996    2    3    3   51  45.30     2450116.6609410
          MISSION LENGTH     64.5808275 DAYS
OFILE OF SOLAR AND GEOPHYSICAL DATA IS
     solgeo.sample
         2450051.500          REFERENCE JULIAN DATE
1



          SOLAR AND GEOMAGNETIC DATA
            NO.     DATE(YMD)  3 MO AV F10.7  WK AV F10.7   WK AP   RELATIVE DAY

              1  1995  11  30           92.0         92.0      17           0.00
              2  1995  12   1           92.0         92.0      17           1.00
              3  1995  12  31           91.8         91.8      17          31.00
              4  1996   1   1           91.8         91.8      17          32.00
              5  1996   1  31           91.4         91.4      17          62.00
              6  1996   2  29           90.8         90.8      17          91.00
OREPEAT PERIOD FOR SOLAR AND GEOMAGNETIC DATA IS          91.00 DAYS
1SATELLITE SURFACE NORMAL DIRECTIONS ARE DEFINED IN SPHERICAL COORDINATES
 RELATIVE TO THE USER SELECTED AXES
 THE USER SELECTED AXES MUST FORM A RIGHT HANDED SET IN (X,Y,Z)
 THE PHI ANGLE IS MEASURED FROM THE USER Z AXIS
 THE THETA ANGLE IS MEASURED FROM THE USER X AXIS TOWARD THE Y AXIS

 THE +Z USER AXIS IS NEAREST THE SATLLITE ORBITAL HEADING
 THE +X USER AXIS IS NEAREST THE ORBIT ZENITH
     (VERTICALLY UP RELATIVE TO THE ORBIT POSITION)

 INTERNAL PROGRAM CALCULATIONS ARE DONE IN AN AXIS SET SUCH THAT
 THE Z AXIS IS APPROXIMATELY IN THE HEADING (RAM) DIRECTION
 THE X AXIS IS IN THE ZENITH DIRECTION (VERTICALLY UPWARD)
 THE Y AXIS IS SUCH THAT (X,Y,Z) FORM A RIGHT HANDED  COORDINATE SET
 ROLL, PITCH, AND YAW DEFINE THE POSITION OF THE USER SELECTED BOW AND ZENITH
 AXES RELATIVE TO THE PROGRAM AXES
      ROLL = A ROTATION ABOUT THE ORBIT (PROGRAM) HEADING (Z) AXIS
     PITCH = A ROTATION ABOUT THE ORBIT (PROGRAM) SIDE (Y) AXIS
       YAW = A ROTATION ABOUT THE ORBIT (PROGRAM) ZENITH (X) AXIS
AXIS
```

```
 THESE ROTATIONS MUST BE MEASURED IN ROLL, PITCH,  YAW ORDER
 POSITVE ROTATION ANGLES ARE MEASURED AS RIGHT HANDED ROTATIONS
     ABOUT THE POSITIVE AXIS DIRECTION
0           SATELLITE ORIENTATION IS
                YAW   =       0.00 DEGREES
                PITCH =       0.00 DEGREES
                ROLL  =       0.00 DEGREES

  NO.  SURFACE                           USER      USER      PROGRAM COORDINATES
                                          PHI      THETA   SURFACE NORMAL UNIT VECTOR
                                      (DEGREES) (DEGREES)       X          Y          Z

    1  SIDE 1                              0.00     90.00   0.00000    0.00000    1.00000
    2  SIDE 2                              5.00     90.00   0.00000    0.08716    0.99619
    3  SIDE 3                             10.00     90.00   0.00000    0.17365    0.98481
    4  SIDE 4                             15.00     90.00   0.00000    0.25882    0.96593
    5  SIDE 5                             20.00     90.00   0.00000    0.34202    0.93969
    6  SIDE 6                             25.00     90.00   0.00000    0.42262    0.90631
    7  SIDE 7                             30.00     90.00   0.00000    0.50000    0.86603
    8  SIDE 8                             35.00     90.00   0.00000    0.57358    0.81915
    9  SIDE 9                             40.00     90.00   0.00000    0.64279    0.76604
   10  SIDE 10                            45.00     90.00   0.00000    0.70711    0.70711
   11  SIDE 11                            50.00     90.00   0.00000    0.76604    0.64279
   12  SIDE 12                            55.00     90.00   0.00000    0.81915    0.57358
   13  SIDE 13                            60.00     90.00   0.00000    0.86603    0.50000
   14  SIDE 14                            65.00     90.00   0.00000    0.90631    0.42262
   15  SIDE 15                            70.00     90.00   0.00000    0.93969    0.34202
   16  SIDE 16                            75.00     90.00   0.00000    0.96593    0.25882
   17  SIDE 17                            80.00     90.00   0.00000    0.98481    0.17365
   18  SIDE 18                            85.00     90.00   0.00000    0.99619    0.08716
   19  SIDE 19                            90.00     90.00   0.00000    1.00000    0.00000
   20  SIDE 20                            95.00     90.00   0.00000    0.99619   -0.08716
   21  SIDE 21                           100.00     90.00   0.00000    0.98481   -0.17365
   22  SIDE 22                           105.00     90.00   0.00000    0.96593   -0.25882
   23  SIDE 23                           110.00     90.00   0.00000    0.93969   -0.34202
   24  SIDE 24                           115.00     90.00   0.00000    0.90631   -0.42262
   25  SIDE 25                           120.00     90.00   0.00000    0.86603   -0.50000
   26  SIDE 26                           125.00     90.00   0.00000    0.81915   -0.57358
   27  SIDE 27                           130.00     90.00   0.00000    0.76604   -0.64279
   28  SIDE 28                           135.00     90.00   0.00000    0.70711   -0.70711
   29  SIDE 29                           140.00     90.00   0.00000    0.64279   -0.76604
   30  SIDE 30                           145.00     90.00   0.00000    0.57358   -0.81915
   31  SIDE 31                           150.00     90.00   0.00000    0.50000   -0.86603
   32  SIDE 32                           155.00     90.00   0.00000    0.42262   -0.90631
   33  SIDE 33                           160.00     90.00   0.00000    0.34202   -0.93969
   34  SIDE 34                           165.00     90.00   0.00000    0.25882   -0.96593
   35  SIDE 35                           170.00     90.00   0.00000    0.17365   -0.98481
   36  SIDE 36                           175.00     90.00   0.00000    0.08716   -0.99619
   37  SIDE 37                           180.00     90.00   0.00000    0.00000   -1.00000

 THE FILE OF ORBIT DATA AND PARAMETERS IS
  orbinp.sample


 ORBITAL PARAMETERS
         5          DATA SETS NORBE ON FILE
 orbinp.sample

         Julian Date    LOP Step day   # Steps Elem Type    C drag     Area km**2
     SC Mass kg     S M Axis km     Eccent  Incl degA node deg Arg P degM Anom deg
    ASAP step s    # Steps

      2450052.080113         7.00000           0          0    2.00000     1.0000E-06
```

```
     2.0000E+03       6716.970 0.0000000    28.500   342.200      0.000      0.000
         360.00       230

      2450053.286372        7.00000         2         0   2.00000     1.0000E-06
     2.0000E+03       6730.810 0.0000000    28.500   107.100      0.000      0.000
         360.00       230

      2450082.953700        7.00000         0         0   2.00000     1.0000E-06
     2.0000E+03       6726.420 0.0000000    28.500     2.300      0.000      0.000
         360.00       230

      2450083.775736        7.00000         0         0   2.00000     1.0000E-06
     2.0000E+03       6739.030 0.0000000    28.500   110.000      0.000      0.000
         360.00       230

      2450114.189101        7.00000         0         0   2.00000     1.0000E-06
     2.0000E+03       6733.620 0.0000000    28.500   137.800      0.000      0.000
         360.00       230
1DATE AT END OF ASAP RUN (Y M D H M S)        1995  12   1  12  55  21.80
     JULIAN DATE     2450053.0384468
 DATE AT BEGINNING OF ASAP RUN                1995  11  30  13  55  21.80
     JULIAN DATE     2450052.0801134

                  AVERAGES AND RANGES ARE BASED ON  231 POINTS IN ASAP RUN
                  THE ASAP RUN COVERED    0.9583333 DAYS

           AVERAGE ATOMIC OXYGEN DENSITY     2.025E+08  ATOMS/CM**3
           MAXIMUM ATOMIC OXYGEN DENSITY     3.070E+08  ATOMS/CM**3
           MINIMUM ATOMIC OXYGEN DENSITY     1.109E+08  ATOMS/CM**3

           AVERAGE TEMPERATURE               883.05  K
           MAXIMUM TEMPERATURE              1180.02  K
           MINIMUM TEMPERATURE               738.46  K

           AVERAGE ALTITUDE                  334.75  KM
           MAXIMUM ALTITUDE                  336.86  KM
           MINIMUM ALTITUDE                  332.16  KM

           AVERAGE ABSOLUTE SATELITE SPEED    7.7109  KM/S
           MAXIMUM ABSOLUTE SATELITE SPEED    7.7124  KM/S
           MINIMUM ABSOLUTE SATELITE SPEED    7.7099  KM/S

           AVERAGE RELATIVE SATELITE SPEED    7.2839  KM/S
           MAXIMUM RELATIVE SATELITE SPEED    7.2873  KM/S
           MINIMUM RELATIVE SATELITE SPEED    7.2811  KM/S
1DATE AT END OF ASAP RUN (Y M D H M S)        1995  12   1  12  55  21.80
     JULIAN DATE     2450053.0384468
 DATE AT BEGINNING OF ASAP RUN                1995  11  30  13  55  21.80
     JULIAN DATE     2450052.0801134
 FLUENCES ARE CALCULATED THROUGH              1995  11  30  13  55  21.80
     JULIAN DATE     2450052.0801134
 CUMULATIVE DAYS EXPOSURE           0.0000000


 NO. LOCATION                       THETA     PHI   AVERAGE AVERAGE FLUX    FLUENCE
                                    (DEG)   (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                     ANGLE
                                                     (DEG)
   1 SIDE 1                         90.00    0.00       1.2     1.47E+14   0.00E+00
   2 SIDE 2                         90.00    5.00       5.0     1.47E+14   0.00E+00
   3 SIDE 3                         90.00   10.00      10.0     1.45E+14   0.00E+00
   4 SIDE 4                         90.00   15.00      15.0     1.42E+14   0.00E+00
   5 SIDE 5                         90.00   20.00      20.0     1.38E+14   0.00E+00
   6 SIDE 6                         90.00   25.00      25.0     1.33E+14   0.00E+00
```

```
   7 SIDE 7                            90.00   30.00       30.0     1.27E+14   0.00E+00
   8 SIDE 8                            90.00   35.00       35.0     1.21E+14   0.00E+00
   9 SIDE 9                            90.00   40.00       40.0     1.13E+14   0.00E+00
  10 SIDE 10                           90.00   45.00       45.0     1.04E+14   0.00E+00
  11 SIDE 11                           90.00   50.00       50.0     9.45E+13   0.00E+00
  12 SIDE 12                           90.00   55.00       55.0     8.42E+13   0.00E+00
  13 SIDE 13                           90.00   60.00       60.0     7.34E+13   0.00E+00
  14 SIDE 14                           90.00   65.00       65.0     6.19E+13   0.00E+00
  15 SIDE 15                           90.00   70.00       70.0     5.00E+13   0.00E+00
  16 SIDE 16                           90.00   75.00       75.0     3.78E+13   0.00E+00
  17 SIDE 17                           90.00   80.00       80.0     2.54E+13   0.00E+00
  18 SIDE 18                           90.00   85.00       85.0     1.40E+13   0.00E+00
  19 SIDE 19                           90.00   90.00       90.0     5.45E+12   0.00E+00
  20 SIDE 20                           90.00   95.00       95.0     1.31E+12   0.00E+00
  21 SIDE 21                           90.00  100.00      100.0     1.73E+11   0.00E+00
  22 SIDE 22                           90.00  105.00      105.0     1.22E+10   0.00E+00
  23 SIDE 23                           90.00  110.00      110.0     4.93E+08   0.00E+00
  24 SIDE 24                           90.00  115.00      115.0     1.29E+07   0.00E+00
  25 SIDE 25                           90.00  120.00      120.0     2.55E+05   0.00E+00
  26 SIDE 26                           90.00  125.00      125.0     4.29E+03   0.00E+00
  27 SIDE 27                           90.00  130.00      130.0     6.63E+01   0.00E+00
  28 SIDE 28                           90.00  135.00      135.0     1.02E+00   0.00E+00
  29 SIDE 29                           90.00  140.00      140.0     1.68E-02   0.00E+00
  30 SIDE 30                           90.00  145.00      145.0     3.28E-04   0.00E+00
  31 SIDE 31                           90.00  150.00      150.0     8.33E-06   0.00E+00
  32 SIDE 32                           90.00  155.00      155.0     3.02E-07   0.00E+00
  33 SIDE 33                           90.00  160.00      160.0     1.71E-08   0.00E+00
  34 SIDE 34                           90.00  165.00      165.0     1.64E-09   0.00E+00
  35 SIDE 35                           90.00  170.00      170.0     2.83E-10   0.00E+00
  36 SIDE 36                           90.00  175.00      175.0     9.26E-11   0.00E+00
  37 SIDE 37                           90.00  180.00      178.8     5.95E-11   0.00E+00

  38 TRUE RAM                                               0.0     1.47E+14   0.00E+00
  39 TRUE 90                                               90.0     5.48E+12   0.00E+00
1DATE AT END OF ASAP RUN (Y M D H M S)         1995   12    2   17   52   22.50
     JULIAN DATE      2450054.2447049
 DATE AT BEGINNING OF ASAP RUN                 1995   12    1   18   52   22.50
     JULIAN DATE      2450053.2863715

                  AVERAGES AND RANGES ARE BASED ON  231 POINTS IN ASAP RUN
                  THE ASAP RUN COVERED    0.9583333 DAYS

           AVERAGE ATOMIC OXYGEN DENSITY     1.542E+08  ATOMS/CM**3
           MAXIMUM ATOMIC OXYGEN DENSITY     2.225E+08  ATOMS/CM**3
           MINIMUM ATOMIC OXYGEN DENSITY     8.785E+07  ATOMS/CM**3

           AVERAGE TEMPERATURE                906.90  K
           MAXIMUM TEMPERATURE               1151.59  K
           MINIMUM TEMPERATURE                738.59  K

           AVERAGE ALTITUDE                   348.60  KM
           MAXIMUM ALTITUDE                   350.74  KM
           MINIMUM ALTITUDE                   345.94  KM

           AVERAGE ABSOLUTE SATELITE SPEED     7.7029  KM/S
           MAXIMUM ABSOLUTE SATELITE SPEED     7.7045  KM/S
           MINIMUM ABSOLUTE SATELITE SPEED     7.7019  KM/S

           AVERAGE RELATIVE SATELITE SPEED     7.2750  KM/S
           MAXIMUM RELATIVE SATELITE SPEED     7.2785  KM/S
           MINIMUM RELATIVE SATELITE SPEED     7.2722  KM/S
1DATE AT END OF ASAP RUN (Y M D H M S)         1995   12    2   17   52   22.50
     JULIAN DATE      2450054.2447049
 DATE AT BEGINNING OF ASAP RUN                 1995   12    1   18   52   22.50
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    JULIAN DATE     2450053.2863715
 FLUENCES ARE CALCULATED THROUGH              1995  12   1  18  52  22.50
    JULIAN DATE     2450053.2863715
 CUMULATIVE DAYS EXPOSURE         1.2062581

 NO. LOCATION                     THETA    PHI   AVERAGE AVERAGE FLUX   FLUENCE
                                  (DEG)   (DEG) INCIDENCE (#/CM**2/S)  (#/CM**2)
                                                  ANGLE
                                                  (DEG)
   1 SIDE 1                       90.00    0.00      1.2    1.12E+14   1.35E+19
   2 SIDE 2                       90.00    5.00      5.0    1.12E+14   1.35E+19
   3 SIDE 3                       90.00   10.00     10.0    1.10E+14   1.33E+19
   4 SIDE 4                       90.00   15.00     15.0    1.08E+14   1.31E+19
   5 SIDE 5                       90.00   20.00     20.0    1.05E+14   1.27E+19
   6 SIDE 6                       90.00   25.00     25.0    1.02E+14   1.22E+19
   7 SIDE 7                       90.00   30.00     30.0    9.70E+13   1.17E+19
   8 SIDE 8                       90.00   35.00     35.0    9.17E+13   1.11E+19
   9 SIDE 9                       90.00   40.00     40.0    8.57E+13   1.03E+19
  10 SIDE 10                      90.00   45.00     45.0    7.91E+13   9.54E+18
  11 SIDE 11                      90.00   50.00     50.0    7.19E+13   8.67E+18
  12 SIDE 12                      90.00   55.00     55.0    6.41E+13   7.73E+18
  13 SIDE 13                      90.00   60.00     60.0    5.58E+13   6.73E+18
  14 SIDE 14                      90.00   65.00     65.0    4.71E+13   5.68E+18
  15 SIDE 15                      90.00   70.00     70.0    3.81E+13   4.59E+18
  16 SIDE 16                      90.00   75.00     75.0    2.88E+13   3.47E+18
  17 SIDE 17                      90.00   80.00     80.0    1.94E+13   2.33E+18
  18 SIDE 18                      90.00   85.00     85.0    1.07E+13   1.28E+18
  19 SIDE 19                      90.00   90.00     90.0    4.22E+12   5.04E+17
  20 SIDE 20                      90.00   95.00     95.0    1.06E+12   1.23E+17
  21 SIDE 21                      90.00  100.00    100.0    1.55E+11   1.71E+16
  22 SIDE 22                      90.00  105.00    105.0    1.27E+10   1.30E+15
  23 SIDE 23                      90.00  110.00    110.0    6.03E+08   5.71E+13
  24 SIDE 24                      90.00  115.00    115.0    1.76E+07   1.59E+12
  25 SIDE 25                      90.00  120.00    120.0    3.45E+05   3.13E+10
  26 SIDE 26                      90.00  125.00    125.0    5.02E+03   4.85E+08
  27 SIDE 27                      90.00  130.00    130.0    6.03E+01   6.60E+06
  28 SIDE 28                      90.00  135.00    135.0    6.76E-01   8.82E+04
  29 SIDE 29                      90.00  140.00    140.0    8.02E-03   1.29E+03
  30 SIDE 30                      90.00  145.00    145.0    1.15E-04   2.31E+01
  31 SIDE 31                      90.00  150.00    150.0    2.27E-06   5.52E-01
  32 SIDE 32                      90.00  155.00    155.0    7.02E-08   1.94E-02
  33 SIDE 33                      90.00  160.00    160.0    3.79E-09   1.09E-03
  34 SIDE 34                      90.00  165.00    165.0    3.86E-10   1.05E-04
  35 SIDE 35                      90.00  170.00    170.0    7.82E-11   1.88E-05
  36 SIDE 36                      90.00  175.00    175.0    3.25E-11   6.52E-06
  37 SIDE 37                      90.00  180.00    178.8    2.78E-11   4.55E-06

  38 TRUE RAM                                        0.0    1.12E+14   1.35E+19
  39 TRUE 90                                        90.0    4.25E+12   5.07E+17
1DATE AT END OF ASAP RUN (Y M D H M S)        1995  12   9  17  52  22.50
    JULIAN DATE     2450061.2447049
 DATE AT BEGINNING OF ASAP RUN                1995  12   8  18  52  22.50
    JULIAN DATE     2450060.2863715

                 AVERAGES AND RANGES ARE BASED ON  231 POINTS IN ASAP RUN
                 THE ASAP RUN COVERED    0.9583333 DAYS

          AVERAGE ATOMIC OXYGEN DENSITY     1.553E+08  ATOMS/CM**3
          MAXIMUM ATOMIC OXYGEN DENSITY     2.567E+08  ATOMS/CM**3
          MINIMUM ATOMIC OXYGEN DENSITY     7.640E+07  ATOMS/CM**3

          AVERAGE TEMPERATURE                915.86  K
          MAXIMUM TEMPERATURE               1182.83  K
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          MINIMUM TEMPERATURE                744.44  K

          AVERAGE ALTITUDE                   348.39  KM
          MAXIMUM ALTITUDE                   354.52  KM
          MINIMUM ALTITUDE                   342.35  KM

          AVERAGE ABSOLUTE SATELITE SPEED     7.7030  KM/S
          MAXIMUM ABSOLUTE SATELITE SPEED     7.7089  KM/S
          MINIMUM ABSOLUTE SATELITE SPEED     7.6971  KM/S

          AVERAGE RELATIVE SATELITE SPEED     7.2752  KM/S
          MAXIMUM RELATIVE SATELITE SPEED     7.2827  KM/S
          MINIMUM RELATIVE SATELITE SPEED     7.2675  KM/S
1DATE AT END OF ASAP RUN (Y M D H M S)        1995  12   9  17  52  22.50
     JULIAN DATE     2450061.2447049
 DATE AT BEGINNING OF ASAP RUN                1995  12   8  18  52  22.50
     JULIAN DATE     2450060.2863715
 FLUENCES ARE CALCULATED THROUGH              1995  12   8  18  52  22.50
     JULIAN DATE     2450060.2863715
 CUMULATIVE DAYS EXPOSURE          8.2062581


 NO. LOCATION                        THETA     PHI   AVERAGE AVERAGE FLUX    FLUENCE
                                     (DEG)    (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                     ANGLE
                                                     (DEG)
   1 SIDE 1                          90.00     0.00      1.2     1.13E+14   8.16E+19
   2 SIDE 2                          90.00     5.00      5.0     1.13E+14   8.13E+19
   3 SIDE 3                          90.00    10.00     10.0     1.11E+14   8.03E+19
   4 SIDE 4                          90.00    15.00     15.0     1.09E+14   7.88E+19
   5 SIDE 5                          90.00    20.00     20.0     1.06E+14   7.66E+19
   6 SIDE 6                          90.00    25.00     25.0     1.02E+14   7.38E+19
   7 SIDE 7                          90.00    30.00     30.0     9.76E+13   7.05E+19
   8 SIDE 8                          90.00    35.00     35.0     9.22E+13   6.67E+19
   9 SIDE 9                          90.00    40.00     40.0     8.62E+13   6.23E+19
  10 SIDE 10                         90.00    45.00     45.0     7.95E+13   5.75E+19
  11 SIDE 11                         90.00    50.00     50.0     7.22E+13   5.22E+19
  12 SIDE 12                         90.00    55.00     55.0     6.43E+13   4.66E+19
  13 SIDE 13                         90.00    60.00     60.0     5.60E+13   4.05E+19
  14 SIDE 14                         90.00    65.00     65.0     4.72E+13   3.42E+19
  15 SIDE 15                         90.00    70.00     70.0     3.81E+13   2.76E+19
  16 SIDE 16                         90.00    75.00     75.0     2.87E+13   2.08E+19
  17 SIDE 17                         90.00    80.00     80.0     1.92E+13   1.40E+19
  18 SIDE 18                         90.00    85.00     85.0     1.05E+13   7.68E+18
  19 SIDE 19                         90.00    90.00     90.0     4.12E+12   3.03E+18
  20 SIDE 20                         90.00    95.00     95.0     1.01E+12   7.49E+17
  21 SIDE 21                         90.00   100.00    100.0     1.39E+11   1.06E+17
  22 SIDE 22                         90.00   105.00    105.0     1.05E+10   8.33E+15
  23 SIDE 23                         90.00   110.00    110.0     4.56E+08   3.78E+14
  24 SIDE 24                         90.00   115.00    115.0     1.25E+07   1.07E+13
  25 SIDE 25                         90.00   120.00    120.0     2.41E+05   2.09E+11
  26 SIDE 26                         90.00   125.00    125.0     3.68E+03   3.12E+09
  27 SIDE 27                         90.00   130.00    130.0     4.92E+01   3.97E+07
  28 SIDE 28                         90.00   135.00    135.0     6.41E-01   4.87E+05
  29 SIDE 29                         90.00   140.00    140.0     9.20E-03   6.50E+03
  30 SIDE 30                         90.00   145.00    145.0     1.63E-04   1.07E+02
  31 SIDE 31                         90.00   150.00    150.0     4.02E-06   2.45E+00
  32 SIDE 32                         90.00   155.00    155.0     1.51E-07   8.64E-02
  33 SIDE 33                         90.00   160.00    160.0     9.48E-09   5.10E-03
  34 SIDE 34                         90.00   165.00    165.0     1.06E-09   5.43E-04
  35 SIDE 35                         90.00   170.00    170.0     2.24E-10   1.10E-04
  36 SIDE 36                         90.00   175.00    175.0     9.21E-11   4.42E-05
  37 SIDE 37                         90.00   180.00    178.8     7.55E-11   3.58E-05
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  38 TRUE RAM                                            0.0      1.13E+14   8.16E+19
  39 TRUE 90                                            90.0      4.30E+12   3.09E+18
1DATE AT END OF ASAP RUN (Y M D H M S)        1995  12  16  17  52  22.50
     JULIAN DATE     2450068.2447049
 DATE AT BEGINNING OF ASAP RUN                1995  12  15  18  52  22.50
     JULIAN DATE     2450067.2863715

                 AVERAGES AND RANGES ARE BASED ON  231 POINTS IN ASAP RUN
                 THE ASAP RUN COVERED    0.9583333 DAYS

          AVERAGE ATOMIC OXYGEN DENSITY     1.455E+08  ATOMS/CM**3
          MAXIMUM ATOMIC OXYGEN DENSITY     2.393E+08  ATOMS/CM**3
          MINIMUM ATOMIC OXYGEN DENSITY     7.067E+07  ATOMS/CM**3

          AVERAGE TEMPERATURE               887.51  K
          MAXIMUM TEMPERATURE              1182.86  K
          MINIMUM TEMPERATURE               726.63  K

          AVERAGE ALTITUDE                  348.19  KM
          MAXIMUM ALTITUDE                  357.03  KM
          MINIMUM ALTITUDE                  342.76  KM

          AVERAGE ABSOLUTE SATELITE SPEED    7.7031  KM/S
          MAXIMUM ABSOLUTE SATELITE SPEED    7.7102  KM/S
          MINIMUM ABSOLUTE SATELITE SPEED    7.6945  KM/S

          AVERAGE RELATIVE SATELITE SPEED    7.2753  KM/S
          MAXIMUM RELATIVE SATELITE SPEED    7.2818  KM/S
          MINIMUM RELATIVE SATELITE SPEED    7.2643  KM/S
1DATE AT END OF ASAP RUN (Y M D H M S)        1995  12  16  17  52  22.50
     JULIAN DATE     2450068.2447049
 DATE AT BEGINNING OF ASAP RUN                1995  12  15  18  52  22.50
     JULIAN DATE     2450067.2863715
 FLUENCES ARE CALCULATED THROUGH              1995  12  15  18  52  22.50
     JULIAN DATE     2450067.2863715
 CUMULATIVE DAYS EXPOSURE          15.2062581


 NO. LOCATION                           THETA     PHI   AVERAGE AVERAGE FLUX    FLUENCE
                                        (DEG)    (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                         ANGLE
                                                         (DEG)
   1 SIDE 1                             90.00     0.00      1.2     1.06E+14   1.48E+20
   2 SIDE 2                             90.00     5.00      5.0     1.05E+14   1.47E+20
   3 SIDE 3                             90.00    10.00     10.0     1.04E+14   1.45E+20
   4 SIDE 4                             90.00    15.00     15.0     1.02E+14   1.43E+20
   5 SIDE 5                             90.00    20.00     20.0     9.94E+13   1.39E+20
   6 SIDE 6                             90.00    25.00     25.0     9.58E+13   1.34E+20
   7 SIDE 7                             90.00    30.00     30.0     9.15E+13   1.28E+20
   8 SIDE 8                             90.00    35.00     35.0     8.65E+13   1.21E+20
   9 SIDE 9                             90.00    40.00     40.0     8.09E+13   1.13E+20
  10 SIDE 10                            90.00    45.00     45.0     7.46E+13   1.04E+20
  11 SIDE 11                            90.00    50.00     50.0     6.78E+13   9.45E+19
  12 SIDE 12                            90.00    55.00     55.0     6.04E+13   8.43E+19
  13 SIDE 13                            90.00    60.00     60.0     5.26E+13   7.34E+19
  14 SIDE 14                            90.00    65.00     65.0     4.44E+13   6.19E+19
  15 SIDE 15                            90.00    70.00     70.0     3.59E+13   5.00E+19
  16 SIDE 16                            90.00    75.00     75.0     2.71E+13   3.77E+19
  17 SIDE 17                            90.00    80.00     80.0     1.82E+13   2.53E+19
  18 SIDE 18                            90.00    85.00     85.0     9.99E+12   1.39E+19
  19 SIDE 19                            90.00    90.00     90.0     3.91E+12   5.45E+18
  20 SIDE 20                            90.00    95.00     95.0     9.45E+11   1.34E+18
  21 SIDE 21                            90.00   100.00    100.0     1.27E+11   1.87E+17
  22 SIDE 22                            90.00   105.00    105.0     9.30E+09   1.43E+16
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  23 SIDE 23                      90.00  110.00     110.0     3.92E+08   6.34E+14
  24 SIDE 24                      90.00  115.00     115.0     1.08E+07   1.77E+13
  25 SIDE 25                      90.00  120.00     120.0     2.25E+05   3.49E+11
  26 SIDE 26                      90.00  125.00     125.0     3.89E+03   5.41E+09
  27 SIDE 27                      90.00  130.00     130.0     6.12E+01   7.31E+07
  28 SIDE 28                      90.00  135.00     135.0     9.49E-01   9.67E+05
  29 SIDE 29                      90.00  140.00     140.0     1.59E-02   1.41E+04
  30 SIDE 30                      90.00  145.00     145.0     3.15E-04   2.52E+02
  31 SIDE 31                      90.00  150.00     150.0     8.22E-06   6.15E+00
  32 SIDE 32                      90.00  155.00     155.0     3.09E-07   2.26E-01
  33 SIDE 33                      90.00  160.00     160.0     1.83E-08   1.35E-02
  34 SIDE 34                      90.00  165.00     165.0     1.85E-09   1.42E-03
  35 SIDE 35                      90.00  170.00     170.0     3.41E-10   2.81E-04
  36 SIDE 36                      90.00  175.00     175.0     1.19E-10   1.08E-04
  37 SIDE 37                      90.00  180.00     178.8     8.17E-11   8.33E-05

  38 TRUE RAM                                         0.0     1.06E+14   1.48E+20
  39 TRUE 90                                         90.0     3.95E+12   5.59E+18
1DATE AT END OF ASAP RUN (Y M D H M S)        1996   1   1   9  53  19.70
     JULIAN DATE     2450083.9120336
 DATE AT BEGINNING OF ASAP RUN                1995  12  31  10  53  19.70
     JULIAN DATE     2450082.9537002

                  AVERAGES AND RANGES ARE BASED ON  231 POINTS IN ASAP RUN
                  THE ASAP RUN COVERED    0.9583333 DAYS

           AVERAGE ATOMIC OXYGEN DENSITY     1.658E+08  ATOMS/CM**3
           MAXIMUM ATOMIC OXYGEN DENSITY     2.487E+08  ATOMS/CM**3
           MINIMUM ATOMIC OXYGEN DENSITY     8.914E+07  ATOMS/CM**3

           AVERAGE TEMPERATURE               864.07  K
           MAXIMUM TEMPERATURE              1173.86  K
           MINIMUM TEMPERATURE               732.69  K

           AVERAGE ALTITUDE                  344.21  KM
           MAXIMUM ALTITUDE                  346.36  KM
           MINIMUM ALTITUDE                  341.50  KM

           AVERAGE ABSOLUTE SATELITE SPEED    7.7054  KM/S
           MAXIMUM ABSOLUTE SATELITE SPEED    7.7070  KM/S
           MINIMUM ABSOLUTE SATELITE SPEED    7.7045  KM/S

           AVERAGE RELATIVE SATELITE SPEED    7.2778  KM/S
           MAXIMUM RELATIVE SATELITE SPEED    7.2814  KM/S
           MINIMUM RELATIVE SATELITE SPEED    7.2750  KM/S
1DATE AT END OF ASAP RUN (Y M D H M S)        1996   1   1   9  53  19.70
     JULIAN DATE     2450083.9120336
 DATE AT BEGINNING OF ASAP RUN                1995  12  31  10  53  19.70
     JULIAN DATE     2450082.9537002
 FLUENCES ARE CALCULATED THROUGH              1995  12  31  10  53  19.70
     JULIAN DATE     2450082.9537002
 CUMULATIVE DAYS EXPOSURE          30.8735868


 NO. LOCATION                     THETA     PHI   AVERAGE AVERAGE FLUX    FLUENCE
                                  (DEG)    (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                   ANGLE
                                                   (DEG)
   1 SIDE 1                       90.00    0.00       1.2     1.21E+14   3.01E+20
   2 SIDE 2                       90.00    5.00       5.0     1.20E+14   3.00E+20
   3 SIDE 3                       90.00   10.00      10.0     1.19E+14   2.96E+20
   4 SIDE 4                       90.00   15.00      15.0     1.16E+14   2.91E+20
   5 SIDE 5                       90.00   20.00      20.0     1.13E+14   2.83E+20
   6 SIDE 6                       90.00   25.00      25.0     1.09E+14   2.72E+20
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  7 SIDE 7                          90.00   30.00      30.0     1.04E+14   2.60E+20
  8 SIDE 8                          90.00   35.00      35.0     9.87E+13   2.46E+20
  9 SIDE 9                          90.00   40.00      40.0     9.23E+13   2.30E+20
 10 SIDE 10                         90.00   45.00      45.0     8.51E+13   2.12E+20
 11 SIDE 11                         90.00   50.00      50.0     7.74E+13   1.93E+20
 12 SIDE 12                         90.00   55.00      55.0     6.90E+13   1.72E+20
 13 SIDE 13                         90.00   60.00      60.0     6.01E+13   1.50E+20
 14 SIDE 14                         90.00   65.00      65.0     5.08E+13   1.26E+20
 15 SIDE 15                         90.00   70.00      70.0     4.10E+13   1.02E+20
 16 SIDE 16                         90.00   75.00      75.0     3.10E+13   7.70E+19
 17 SIDE 17                         90.00   80.00      80.0     2.09E+13   5.18E+19
 18 SIDE 18                         90.00   85.00      85.0     1.15E+13   2.84E+19
 19 SIDE 19                         90.00   90.00      90.0     4.46E+12   1.11E+19
 20 SIDE 20                         90.00   95.00      95.0     1.06E+12   2.70E+18
 21 SIDE 21                         90.00  100.00     100.0     1.38E+11   3.66E+17
 22 SIDE 22                         90.00  105.00     105.0     9.30E+09   2.69E+16
 23 SIDE 23                         90.00  110.00     110.0     3.41E+08   1.13E+15
 24 SIDE 24                         90.00  115.00     115.0     7.50E+06   3.01E+13
 25 SIDE 25                         90.00  120.00     120.0     1.16E+05   5.80E+11
 26 SIDE 26                         90.00  125.00     125.0     1.48E+03   9.04E+09
 27 SIDE 27                         90.00  130.00     130.0     1.81E+01   1.27E+08
 28 SIDE 28                         90.00  135.00     135.0     2.37E-01   1.77E+06
 29 SIDE 29                         90.00  140.00     140.0     3.65E-03   2.73E+04
 30 SIDE 30                         90.00  145.00     145.0     7.11E-05   5.13E+02
 31 SIDE 31                         90.00  150.00     150.0     1.88E-06   1.30E+01
 32 SIDE 32                         90.00  155.00     155.0     7.31E-08   4.84E-01
 33 SIDE 33                         90.00  160.00     160.0     4.50E-09   2.90E-02
 34 SIDE 34                         90.00  165.00     165.0     4.71E-10   3.00E-03
 35 SIDE 35                         90.00  170.00     170.0     8.92E-11   5.72E-04
 36 SIDE 36                         90.00  175.00     175.0     3.20E-11   2.10E-04
 37 SIDE 37                         90.00  180.00     178.8     2.24E-11   1.54E-04

 38 TRUE RAM                                            0.0     1.21E+14   3.01E+20
 39 TRUE 90                                            90.0     4.44E+12   1.13E+19
1DATE AT END OF ASAP RUN (Y M D H M S)        1996   1   2   5  37   3.60
     JULIAN DATE      2450084.7340694
 DATE AT BEGINNING OF ASAP RUN                1996   1   1   6  37   3.60
     JULIAN DATE      2450083.7757361

                 AVERAGES AND RANGES ARE BASED ON  231 POINTS IN ASAP RUN
                 THE ASAP RUN COVERED    0.9583333 DAYS

           AVERAGE ATOMIC OXYGEN DENSITY     1.183E+08  ATOMS/CM**3
           MAXIMUM ATOMIC OXYGEN DENSITY     1.854E+08  ATOMS/CM**3
           MINIMUM ATOMIC OXYGEN DENSITY     5.769E+07  ATOMS/CM**3

           AVERAGE TEMPERATURE               894.35  K
           MAXIMUM TEMPERATURE              1147.51  K
           MINIMUM TEMPERATURE               747.15  K

           AVERAGE ALTITUDE                  356.83  KM
           MAXIMUM ALTITUDE                  358.96  KM
           MINIMUM ALTITUDE                  354.18  KM

           AVERAGE ABSOLUTE SATELITE SPEED    7.6982  KM/S
           MAXIMUM ABSOLUTE SATELITE SPEED    7.6997  KM/S
           MINIMUM ABSOLUTE SATELITE SPEED    7.6972  KM/S

           AVERAGE RELATIVE SATELITE SPEED    7.2698  KM/S
           MAXIMUM RELATIVE SATELITE SPEED    7.2733  KM/S
           MINIMUM RELATIVE SATELITE SPEED    7.2670  KM/S
1DATE AT END OF ASAP RUN (Y M D H M S)        1996   1   2   5  37   3.60
     JULIAN DATE      2450084.7340694
 DATE AT BEGINNING OF ASAP RUN                1996   1   1   6  37   3.60
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    JULIAN DATE     2450083.7757361
FLUENCES ARE CALCULATED THROUGH            1996   1   1   6  37   3.60
    JULIAN DATE     2450083.7757361
CUMULATIVE DAYS EXPOSURE          31.6956227

NO. LOCATION                        THETA     PHI   AVERAGE AVERAGE FLUX    FLUENCE
                                    (DEG)   (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                    ANGLE
                                                    (DEG)
  1 SIDE 1                          90.00    0.00      1.2     8.60E+13   3.08E+20
  2 SIDE 2                          90.00    5.00      5.0     8.56E+13   3.07E+20
  3 SIDE 3                          90.00   10.00     10.0     8.46E+13   3.04E+20
  4 SIDE 4                          90.00   15.00     15.0     8.29E+13   2.98E+20
  5 SIDE 5                          90.00   20.00     20.0     8.06E+13   2.89E+20
  6 SIDE 6                          90.00   25.00     25.0     7.77E+13   2.79E+20
  7 SIDE 7                          90.00   30.00     30.0     7.43E+13   2.67E+20
  8 SIDE 8                          90.00   35.00     35.0     7.02E+13   2.52E+20
  9 SIDE 9                          90.00   40.00     40.0     6.56E+13   2.36E+20
 10 SIDE 10                         90.00   45.00     45.0     6.05E+13   2.17E+20
 11 SIDE 11                         90.00   50.00     50.0     5.50E+13   1.97E+20
 12 SIDE 12                         90.00   55.00     55.0     4.90E+13   1.76E+20
 13 SIDE 13                         90.00   60.00     60.0     4.26E+13   1.53E+20
 14 SIDE 14                         90.00   65.00     65.0     3.60E+13   1.29E+20
 15 SIDE 15                         90.00   70.00     70.0     2.90E+13   1.05E+20
 16 SIDE 16                         90.00   75.00     75.0     2.19E+13   7.89E+19
 17 SIDE 17                         90.00   80.00     80.0     1.47E+13   5.30E+19
 18 SIDE 18                         90.00   85.00     85.0     8.02E+12   2.91E+19
 19 SIDE 19                         90.00   90.00     90.0     3.13E+12   1.14E+19
 20 SIDE 20                         90.00   95.00     95.0     7.59E+11   2.76E+18
 21 SIDE 21                         90.00  100.00    100.0     1.04E+11   3.74E+17
 22 SIDE 22                         90.00  105.00    105.0     7.83E+09   2.75E+16
 23 SIDE 23                         90.00  110.00    110.0     3.34E+08   1.15E+15
 24 SIDE 24                         90.00  115.00    115.0     8.83E+06   3.07E+13
 25 SIDE 25                         90.00  120.00    120.0     1.62E+05   5.90E+11
 26 SIDE 26                         90.00  125.00    125.0     2.29E+03   9.18E+09
 27 SIDE 27                         90.00  130.00    130.0     2.77E+01   1.28E+08
 28 SIDE 28                         90.00  135.00    135.0     3.22E-01   1.79E+06
 29 SIDE 29                         90.00  140.00    140.0     4.01E-03   2.76E+04
 30 SIDE 30                         90.00  145.00    145.0     6.11E-05   5.18E+02
 31 SIDE 31                         90.00  150.00    150.0     1.29E-06   1.31E+01
 32 SIDE 32                         90.00  155.00    155.0     4.21E-08   4.88E-01
 33 SIDE 33                         90.00  160.00    160.0     2.37E-09   2.92E-02
 34 SIDE 34                         90.00  165.00    165.0     2.48E-10   3.02E-03
 35 SIDE 35                         90.00  170.00    170.0     5.07E-11   5.77E-04
 36 SIDE 36                         90.00  175.00    175.0     2.10E-11   2.12E-04
 37 SIDE 37                         90.00  180.00    178.8     1.79E-11   1.55E-04

 38 TRUE RAM                                           0.0     8.60E+13   3.09E+20
 39 TRUE 90                                           90.0     3.23E+12   1.15E+19
1DATE AT END OF ASAP RUN (Y M D H M S)        1996   2   1  15  32  18.30
    JULIAN DATE     2450115.1474340
 DATE AT BEGINNING OF ASAP RUN                1996   1  31  16  32  18.30
    JULIAN DATE     2450114.1891007

                 AVERAGES AND RANGES ARE BASED ON  231 POINTS IN ASAP RUN
                 THE ASAP RUN COVERED    0.9583333 DAYS

          AVERAGE ATOMIC OXYGEN DENSITY     1.209E+08  ATOMS/CM**3
          MAXIMUM ATOMIC OXYGEN DENSITY     1.926E+08  ATOMS/CM**3
          MINIMUM ATOMIC OXYGEN DENSITY     6.344E+07  ATOMS/CM**3

          AVERAGE TEMPERATURE                883.73  K
          MAXIMUM TEMPERATURE               1129.42  K
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          MINIMUM TEMPERATURE             729.33  K

          AVERAGE ALTITUDE                351.42  KM
          MAXIMUM ALTITUDE                353.55  KM
          MINIMUM ALTITUDE                348.79  KM

          AVERAGE ABSOLUTE SATELITE SPEED   7.7013  KM/S
          MAXIMUM ABSOLUTE SATELITE SPEED   7.7028  KM/S
          MINIMUM ABSOLUTE SATELITE SPEED   7.7003  KM/S

          AVERAGE RELATIVE SATELITE SPEED   7.2732  KM/S
          MAXIMUM RELATIVE SATELITE SPEED   7.2767  KM/S
          MINIMUM RELATIVE SATELITE SPEED   7.2704  KM/S
1DATE AT END OF ASAP RUN (Y M D H M S)      1996   2   1  15  32  18.30
     JULIAN DATE     2450115.1474340
 DATE AT BEGINNING OF ASAP RUN              1996   1  31  16  32  18.30
     JULIAN DATE     2450114.1891007
 FLUENCES ARE CALCULATED THROUGH            1996   1  31  16  32  18.30
     JULIAN DATE     2450114.1891007
 CUMULATIVE DAYS EXPOSURE          62.1089873


 NO. LOCATION                       THETA     PHI   AVERAGE AVERAGE FLUX   FLUENCE
                                    (DEG)    (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                     ANGLE
                                                     (DEG)
   1 SIDE 1                         90.00    0.00      1.2     8.79E+13    5.37E+20
   2 SIDE 2                         90.00    5.00      5.0     8.76E+13    5.35E+20
   3 SIDE 3                         90.00   10.00     10.0     8.65E+13    5.28E+20
   4 SIDE 4                         90.00   15.00     15.0     8.48E+13    5.18E+20
   5 SIDE 5                         90.00   20.00     20.0     8.25E+13    5.04E+20
   6 SIDE 6                         90.00   25.00     25.0     7.95E+13    4.86E+20
   7 SIDE 7                         90.00   30.00     30.0     7.59E+13    4.64E+20
   8 SIDE 8                         90.00   35.00     35.0     7.18E+13    4.39E+20
   9 SIDE 9                         90.00   40.00     40.0     6.71E+13    4.10E+20
  10 SIDE 10                        90.00   45.00     45.0     6.19E+13    3.78E+20
  11 SIDE 11                        90.00   50.00     50.0     5.62E+13    3.44E+20
  12 SIDE 12                        90.00   55.00     55.0     5.01E+13    3.06E+20
  13 SIDE 13                        90.00   60.00     60.0     4.36E+13    2.67E+20
  14 SIDE 14                        90.00   65.00     65.0     3.68E+13    2.25E+20
  15 SIDE 15                        90.00   70.00     70.0     2.97E+13    1.82E+20
  16 SIDE 16                        90.00   75.00     75.0     2.24E+13    1.37E+20
  17 SIDE 17                        90.00   80.00     80.0     1.50E+13    9.21E+19
  18 SIDE 18                        90.00   85.00     85.0     8.18E+12    5.04E+19
  19 SIDE 19                        90.00   90.00     90.0     3.17E+12    1.97E+19
  20 SIDE 20                        90.00   95.00     95.0     7.59E+11    4.76E+18
  21 SIDE 21                        90.00  100.00    100.0     1.01E+11    6.44E+17
  22 SIDE 22                        90.00  105.00    105.0     7.25E+09    4.73E+16
  23 SIDE 23                        90.00  110.00    110.0     2.90E+08    1.97E+15
  24 SIDE 24                        90.00  115.00    115.0     7.17E+06    5.17E+13
  25 SIDE 25                        90.00  120.00    120.0     1.24E+05    9.65E+11
  26 SIDE 26                        90.00  125.00    125.0     1.68E+03    1.44E+10
  27 SIDE 27                        90.00  130.00    130.0     1.99E+01    1.91E+08
  28 SIDE 28                        90.00  135.00    135.0     2.28E-01    2.51E+06
  29 SIDE 29                        90.00  140.00    140.0     2.84E-03    3.66E+04
  30 SIDE 30                        90.00  145.00    145.0     4.35E-05    6.55E+02
  31 SIDE 31                        90.00  150.00    150.0     9.15E-07    1.60E+01
  32 SIDE 32                        90.00  155.00    155.0     2.96E-08    5.83E-01
  33 SIDE 33                        90.00  160.00    160.0     1.62E-09    3.45E-02
  34 SIDE 34                        90.00  165.00    165.0     1.60E-10    3.56E-03
  35 SIDE 35                        90.00  170.00    170.0     3.08E-11    6.84E-04
  36 SIDE 36                        90.00  175.00    175.0     1.19E-11    2.55E-04
  37 SIDE 37                        90.00  180.00    178.8     9.38E-12    1.91E-04
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  38 TRUE RAM                                             0.0      8.79E+13   5.37E+20
  39 TRUE 90                                             90.0      3.27E+12   2.01E+19
1DATE AT END OF ASAP RUN (Y M D H M S)         1996   2    3    3  51  45.30
     JULIAN DATE     2450116.6609410
 DATE AT BEGINNING OF ASAP RUN                 1996   2    2    4  51  45.30
     JULIAN DATE     2450115.7026076

                  AVERAGES AND RANGES ARE BASED ON  231 POINTS IN ASAP RUN
                  THE ASAP RUN COVERED    0.9583333 DAYS

             AVERAGE ATOMIC OXYGEN DENSITY     1.237E+08  ATOMS/CM**3
             MAXIMUM ATOMIC OXYGEN DENSITY     1.992E+08  ATOMS/CM**3
             MINIMUM ATOMIC OXYGEN DENSITY     6.099E+07  ATOMS/CM**3

             AVERAGE TEMPERATURE               888.18  K
             MAXIMUM TEMPERATURE              1131.61  K
             MINIMUM TEMPERATURE               718.66  K

             AVERAGE ALTITUDE                  351.37  KM
             MAXIMUM ALTITUDE                  353.99  KM
             MINIMUM ALTITUDE                  347.77  KM

             AVERAGE ABSOLUTE SATELITE SPEED    7.7013  KM/S
             MAXIMUM ABSOLUTE SATELITE SPEED    7.7040  KM/S
             MINIMUM ABSOLUTE SATELITE SPEED    7.6995  KM/S

             AVERAGE RELATIVE SATELITE SPEED    7.2733  KM/S
             MAXIMUM RELATIVE SATELITE SPEED    7.2779  KM/S
             MINIMUM RELATIVE SATELITE SPEED    7.2699  KM/S
1DATE AT END OF ASAP RUN (Y M D H M S)         1996   2    3    3  51  45.30
     JULIAN DATE     2450116.6609410
 DATE AT BEGINNING OF ASAP RUN                 1996   2    2    4  51  45.30
     JULIAN DATE     2450115.7026076
 FLUENCES ARE CALCULATED THROUGH               1996   2    3    3  51  45.30
     JULIAN DATE     2450116.6609410
 CUMULATIVE DAYS EXPOSURE            64.5808275


 NO. LOCATION                    THETA     PHI   AVERAGE AVERAGE FLUX   FLUENCE
                                 (DEG)   (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                  ANGLE
                                                  (DEG)
   1 SIDE 1                      90.00    0.00      1.2     8.99E+13   5.56E+20
   2 SIDE 2                      90.00    5.00      5.0     8.96E+13   5.54E+20
   3 SIDE 3                      90.00   10.00     10.0     8.85E+13   5.47E+20
   4 SIDE 4                      90.00   15.00     15.0     8.68E+13   5.36E+20
   5 SIDE 5                      90.00   20.00     20.0     8.44E+13   5.22E+20
   6 SIDE 6                      90.00   25.00     25.0     8.13E+13   5.03E+20
   7 SIDE 7                      90.00   30.00     30.0     7.77E+13   4.80E+20
   8 SIDE 8                      90.00   35.00     35.0     7.34E+13   4.54E+20
   9 SIDE 9                      90.00   40.00     40.0     6.86E+13   4.24E+20
  10 SIDE 10                     90.00   45.00     45.0     6.33E+13   3.92E+20
  11 SIDE 11                     90.00   50.00     50.0     5.75E+13   3.56E+20
  12 SIDE 12                     90.00   55.00     55.0     5.12E+13   3.17E+20
  13 SIDE 13                     90.00   60.00     60.0     4.46E+13   2.76E+20
  14 SIDE 14                     90.00   65.00     65.0     3.76E+13   2.33E+20
  15 SIDE 15                     90.00   70.00     70.0     3.03E+13   1.88E+20
  16 SIDE 16                     90.00   75.00     75.0     2.28E+13   1.42E+20
  17 SIDE 17                     90.00   80.00     80.0     1.53E+13   9.53E+19
  18 SIDE 18                     90.00   85.00     85.0     8.34E+12   5.21E+19
  19 SIDE 19                     90.00   90.00     90.0     3.23E+12   2.04E+19
  20 SIDE 20                     90.00   95.00     95.0     7.72E+11   4.92E+18
  21 SIDE 21                     90.00  100.00    100.0     1.03E+11   6.66E+17
  22 SIDE 22                     90.00  105.00    105.0     7.32E+09   4.89E+16
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  23 SIDE 23                         90.00  110.00      110.0      2.92E+08    2.04E+15
  24 SIDE 24                         90.00  115.00      115.0      7.16E+06    5.33E+13
  25 SIDE 25                         90.00  120.00      120.0      1.23E+05    9.92E+11
  26 SIDE 26                         90.00  125.00      125.0      1.66E+03    1.47E+10
  27 SIDE 27                         90.00  130.00      130.0      1.94E+01    1.95E+08
  28 SIDE 28                         90.00  135.00      135.0      2.20E-01    2.56E+06
  29 SIDE 29                         90.00  140.00      140.0      2.69E-03    3.72E+04
  30 SIDE 30                         90.00  145.00      145.0      4.03E-05    6.64E+02
  31 SIDE 31                         90.00  150.00      150.0      8.33E-07    1.62E+01
  32 SIDE 32                         90.00  155.00      155.0      2.67E-08    5.89E-01
  33 SIDE 33                         90.00  160.00      160.0      1.46E-09    3.48E-02
  34 SIDE 34                         90.00  165.00      165.0      1.47E-10    3.59E-03
  35 SIDE 35                         90.00  170.00      170.0      2.89E-11    6.90E-04
  36 SIDE 36                         90.00  175.00      175.0      1.15E-11    2.58E-04
  37 SIDE 37                         90.00  180.00      178.8      9.39E-12    1.93E-04

  38 TRUE RAM                                             0.0      9.00E+13    5.56E+20
  39 TRUE 90                                             90.0      3.36E+12    2.08E+19

 --- NORMAL TERMINATION ---
```

A.5 Mission File

Filename: fluxavg.mission_sample26-Apr-93.1

```
#PROGRAM IDENTIFICATION
 MISSION FILE
 PROGRAM FLUXAVG
 ATOMIC OXYGEN EXPOSURE
 *  RELEASE VERSION 2.0                              *
 *  COMPILED 26-Apr-93   08:26:43                    *
 DATE OF COMPUTATION:    26-Apr-93   08:47:51
#END PROGRAM IDENTIFICATION
#PROGRAM CONTROL FILE ECHO
 fluxavg.mission_sample
 fluxavg.in_sample
 This is a short run to test FLUXAVG.
 The start of the Space Station Freedom mission is run.
                  Described in Mission Profile Grumman
                  Memo P SH-314-M092-038
                  date Sept 8, 1991
 The second set of orbit elements is set to calculate fluxes and fluences
 at the orbit elements epoch date and at 7 and 14 days after.  The other
 sets of orbit elements calculate fluxes and fluences only on the
 epoch date.
 $
  0                                  IVEL FLAG FOR VELOCITY INFORMATION
 1995 11 30 13 55 21.80              MISSION START DATE (yyyy mm dd hh mm ss.ss)
 1996 02 03 03 51 45.3              MISSION END DATE
 solgeo.sample
 37                                  NAZEL NUMBER OF SURFACES
 SIDE 1                    0.         90.         PHI, THETA
 SIDE 2                    5.         90.
 SIDE 3                    10.        90.
 SIDE 4                    15.        90.
 SIDE 5                    20.        90.
 SIDE 6                    25.        90.
 SIDE 7                    30.        90.
 SIDE 8                    35.        90.
 SIDE 9                    40.        90.
 SIDE 10                   45.        90.
 SIDE 11                   50.        90.
 SIDE 12                   55.        90.
 SIDE 13                   60.        90.
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 SIDE 14                      65.       90.
 SIDE 15                      70.       90.
 SIDE 16                      75.       90.
 SIDE 17                      80.       90.
 SIDE 18                      85.       90.
 SIDE 19                      90.       90.
 SIDE 20                      95.       90.
 SIDE 21                      100.      90.
 SIDE 22                      105.      90.
 SIDE 23                      110.      90.
 SIDE 24                      115.      90.
 SIDE 25                      120.      90.
 SIDE 26                      125.      90.
 SIDE 27                      130.      90.
 SIDE 28                      135.      90.
 SIDE 29                      140.      90.
 SIDE 30                      145.      90.
 SIDE 31                      150.      90.
 SIDE 32                      155.      90.
 SIDE 33                      160.      90.
 SIDE 34                      165.      90.
 SIDE 35                      170.      90.
 SIDE 36                      175.      90.
 SIDE 37                      180.      90.
 +Z +X
  0.0       0.0       0.0            roll,pitch,yaw
 orbinp.sample
#END PROGRAM CONTROL FILE ECHO
#MISSION FILE NAME
 fluxavg.mission_sample26-Apr-93.1
#END MISSION FILE NAME
#COMMENTARY
 This is a short run to test FLUXAVG.
 The start of the Space Station Freedom mission is run.
                  Described in Mission Profile Grumman
                  Memo P SH-314-M092-038
                  date Sept 8, 1991
 The second set of orbit elements is set to calculate fluxes and fluences
 at the orbit elements epoch date and at 7 and 14 days after.  The other
 sets of orbit elements calculate fluxes and fluences only on the
 epoch date.
 $
#END COMMENTARY
#SOLAR AND GEOMAGNETIC DATA ECHO
         2450051.500          REFERENCE JULIAN DATE
   YR  MO  DA  3 MO AV F10.7   WK AV F10.7          AP          RELATIVE DAY
 1995  11  30            92.           92.          17.                0.00
 1995  12   1            92.           92.          17.                1.00
 1995  12  31            92.           92.          17.               31.00
 1996   1   1            92.           92.          17.               32.00
 1996   1  31            91.           91.          17.               62.00
 1996   2  29            91.           91.          17.               91.00
#END SOLAR AND GEOMAGNETIC DATA ECHO
#SURFACE NORMAL DEFINITIONS
   37                      NAZEL
  NO.  SURFACE                        USER      USER      PROGRAM COORDINATES
                                  (DEGREES) (DEGREES)  SURFACE NORMAL UNIT VECTOR
                                                             X          Y          Z

    1  SIDE 1                          0.00     90.00   0.00000    0.00000    1.00000
    2  SIDE 2                          5.00     90.00   0.00000    0.08716    0.99619
    3  SIDE 3                         10.00     90.00   0.00000    0.17365    0.98481
    4  SIDE 4                         15.00     90.00   0.00000    0.25882    0.96593
    5  SIDE 5                         20.00     90.00   0.00000    0.34202    0.93969
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   6  SIDE 6                     25.00      90.00   0.00000   0.42262   0.90631
   7  SIDE 7                     30.00      90.00   0.00000   0.50000   0.86603
   8  SIDE 8                     35.00      90.00   0.00000   0.57358   0.81915
   9  SIDE 9                     40.00      90.00   0.00000   0.64279   0.76604
  10  SIDE 10                    45.00      90.00   0.00000   0.70711   0.70711
  11  SIDE 11                    50.00      90.00   0.00000   0.76604   0.64279
  12  SIDE 12                    55.00      90.00   0.00000   0.81915   0.57358
  13  SIDE 13                    60.00      90.00   0.00000   0.86603   0.50000
  14  SIDE 14                    65.00      90.00   0.00000   0.90631   0.42262
  15  SIDE 15                    70.00      90.00   0.00000   0.93969   0.34202
  16  SIDE 16                    75.00      90.00   0.00000   0.96593   0.25882
  17  SIDE 17                    80.00      90.00   0.00000   0.98481   0.17365
  18  SIDE 18                    85.00      90.00   0.00000   0.99619   0.08716
  19  SIDE 19                    90.00      90.00   0.00000   1.00000   0.00000
  20  SIDE 20                    95.00      90.00   0.00000   0.99619  -0.08716
  21  SIDE 21                   100.00      90.00   0.00000   0.98481  -0.17365
  22  SIDE 22                   105.00      90.00   0.00000   0.96593  -0.25882
  23  SIDE 23                   110.00      90.00   0.00000   0.93969  -0.34202
  24  SIDE 24                   115.00      90.00   0.00000   0.90631  -0.42262
  25  SIDE 25                   120.00      90.00   0.00000   0.86603  -0.50000
  26  SIDE 26                   125.00      90.00   0.00000   0.81915  -0.57358
  27  SIDE 27                   130.00      90.00   0.00000   0.76604  -0.64279
  28  SIDE 28                   135.00      90.00   0.00000   0.70711  -0.70711
  29  SIDE 29                   140.00      90.00   0.00000   0.64279  -0.76604
  30  SIDE 30                   145.00      90.00   0.00000   0.57358  -0.81915
  31  SIDE 31                   150.00      90.00   0.00000   0.50000  -0.86603
  32  SIDE 32                   155.00      90.00   0.00000   0.42262  -0.90631
  33  SIDE 33                   160.00      90.00   0.00000   0.34202  -0.93969
  34  SIDE 34                   165.00      90.00   0.00000   0.25882  -0.96593
  35  SIDE 35                   170.00      90.00   0.00000   0.17365  -0.98481
  36  SIDE 36                   175.00      90.00   0.00000   0.08716  -0.99619
  37  SIDE 37                   180.00      90.00   0.00000   0.00000  -1.00000
#END SURFACE NORMAL DEFINITIONS
#ORBITAL PARAMETERS
         5          DATA SETS NORBE ON FILE
 orbinp.sample
        Julian Date   LOP Step day   # Steps Elem Type    C drag     Area km**2
    SC Mass kg     S M Axis km     Eccent  Incl degA node deg Arg P degM Anom deg
   ASAP step s    # Steps
      2450052.080113        7.00000       0         0    2.00000     1.0000E-06
    2.0000E+03       6716.970 0.0000000    28.500   342.200     0.000      0.000
        360.00       230
      2450053.286372        7.00000       2         0    2.00000     1.0000E-06
    2.0000E+03       6730.810 0.0000000    28.500   107.100     0.000      0.000
        360.00       230
      2450082.953700        7.00000       0         0    2.00000     1.0000E-06
    2.0000E+03       6726.420 0.0000000    28.500     2.300     0.000      0.000
        360.00       230
      2450083.775736        7.00000       0         0    2.00000     1.0000E-06
    2.0000E+03       6739.030 0.0000000    28.500   110.000     0.000      0.000
        360.00       230
      2450114.189101        7.00000       0         0    2.00000     1.0000E-06
    2.0000E+03       6733.620 0.0000000    28.500   137.800     0.000      0.000
        360.00       230
#END ORBITAL PARAMETERS
#FLUX AND FLUENCE MEAN ORBITAL PARAMETERS
         8        39           # OF INPUT DATES, TOTAL # OF SURFACES
    2450052.0801134  1995  11  30  13  55  21.80     JDATE AND DATE FLUENCE
          0.0000000            CUMULATIVE DAYS EXPOSURE
    2450053.0384468  1995  12   1  12  55  21.80     JDATE AND DATE ASAP END
    2450052.0801134  1995  11  30  13  55  21.80     JDATE AND DATE ASAP START
       231                     #POINTS IN ASAP RUN
  2.025E+08    3.070E+08   1.109E+08          AVG, MAX, MIN AO DEN (#/CM**3)
      883.05      1180.02      738.46          AVG, MAX, MIN TEMPERATURE (K)
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    334.75        336.86        332.16          AVG, MAX, MIN ALTITUDE (KM)
    7.7109        7.7124        7.7099          AVG, MAX, MIN ABS SPEED (KM/S)
    7.2839        7.2873        7.2811          AVG, MAX, MIN REL SPEED (KM/S)
NO. LOCATION                       THETA     PHI    AVERAGE AVERAGE FLUX    FLUENCE
                                   (DEG)    (DEG) INCIDENCE  (#/CM**2/S)   (#/CM**2)
                                                    ANGLE
                                                    (DEG)
  1 SIDE 1                         90.00     0.00       1.2     1.47E+14    0.00E+00
  2 SIDE 2                         90.00     5.00       5.0     1.47E+14    0.00E+00
  3 SIDE 3                         90.00    10.00      10.0     1.45E+14    0.00E+00
  4 SIDE 4                         90.00    15.00      15.0     1.42E+14    0.00E+00
  5 SIDE 5                         90.00    20.00      20.0     1.38E+14    0.00E+00
  6 SIDE 6                         90.00    25.00      25.0     1.33E+14    0.00E+00
  7 SIDE 7                         90.00    30.00      30.0     1.27E+14    0.00E+00
  8 SIDE 8                         90.00    35.00      35.0     1.21E+14    0.00E+00
  9 SIDE 9                         90.00    40.00      40.0     1.13E+14    0.00E+00
 10 SIDE 10                        90.00    45.00      45.0     1.04E+14    0.00E+00
 11 SIDE 11                        90.00    50.00      50.0     9.45E+13    0.00E+00
 12 SIDE 12                        90.00    55.00      55.0     8.42E+13    0.00E+00
 13 SIDE 13                        90.00    60.00      60.0     7.34E+13    0.00E+00
 14 SIDE 14                        90.00    65.00      65.0     6.19E+13    0.00E+00
 15 SIDE 15                        90.00    70.00      70.0     5.00E+13    0.00E+00
 16 SIDE 16                        90.00    75.00      75.0     3.78E+13    0.00E+00
 17 SIDE 17                        90.00    80.00      80.0     2.54E+13    0.00E+00
 18 SIDE 18                        90.00    85.00      85.0     1.40E+13    0.00E+00
 19 SIDE 19                        90.00    90.00      90.0     5.45E+12    0.00E+00
 20 SIDE 20                        90.00    95.00      95.0     1.31E+12    0.00E+00
 21 SIDE 21                        90.00   100.00     100.0     1.73E+11    0.00E+00
 22 SIDE 22                        90.00   105.00     105.0     1.22E+10    0.00E+00
 23 SIDE 23                        90.00   110.00     110.0     4.93E+08    0.00E+00
 24 SIDE 24                        90.00   115.00     115.0     1.29E+07    0.00E+00
 25 SIDE 25                        90.00   120.00     120.0     2.55E+05    0.00E+00
 26 SIDE 26                        90.00   125.00     125.0     4.29E+03    0.00E+00
 27 SIDE 27                        90.00   130.00     130.0     6.63E+01    0.00E+00
 28 SIDE 28                        90.00   135.00     135.0     1.02E+00    0.00E+00
 29 SIDE 29                        90.00   140.00     140.0     1.68E-02    0.00E+00
 30 SIDE 30                        90.00   145.00     145.0     3.28E-04    0.00E+00
 31 SIDE 31                        90.00   150.00     150.0     8.33E-06    0.00E+00
 32 SIDE 32                        90.00   155.00     155.0     3.02E-07    0.00E+00
 33 SIDE 33                        90.00   160.00     160.0     1.71E-08    0.00E+00
 34 SIDE 34                        90.00   165.00     165.0     1.64E-09    0.00E+00
 35 SIDE 35                        90.00   170.00     170.0     2.83E-10    0.00E+00
 36 SIDE 36                        90.00   175.00     175.0     9.26E-11    0.00E+00
 37 SIDE 37                        90.00   180.00     178.8     5.95E-11    0.00E+00
 38 TRUE RAM                                            0.0     1.47E+14    0.00E+00
 39 TRUE 90                                            90.0     5.48E+12    0.00E+00


   2450053.2863715  1995  12   1  18  52  22.50     JDATE AND DATE FLUENCE
       1.2062581              CUMULATIVE DAYS EXPOSURE
   2450054.2447049  1995  12   2  17  52  22.50     JDATE AND DATE ASAP END
   2450053.2863715  1995  12   1  18  52  22.50     JDATE AND DATE ASAP START
     231                      #POINTS IN ASAP RUN
  1.542E+08    2.225E+08    8.785E+07           AVG, MAX, MIN AO DEN (#/CM**3)
     906.90      1151.59       738.59           AVG, MAX, MIN TEMPERATURE (K)
     348.60       350.74       345.94           AVG, MAX, MIN ALTITUDE (KM)
     7.7029       7.7045       7.7019           AVG, MAX, MIN ABS SPEED (KM/S)
     7.2750       7.2785       7.2722           AVG, MAX, MIN REL SPEED (KM/S)
NO. LOCATION                       THETA     PHI    AVERAGE AVERAGE FLUX    FLUENCE
                                   (DEG)    (DEG) INCIDENCE  (#/CM**2/S)   (#/CM**2)
                                                    ANGLE
                                                    (DEG)
  1 SIDE 1                         90.00     0.00       1.2     1.12E+14    1.35E+19
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  2 SIDE 2                          90.00    5.00       5.0     1.12E+14    1.35E+19
  3 SIDE 3                          90.00   10.00      10.0     1.10E+14    1.33E+19
  4 SIDE 4                          90.00   15.00      15.0     1.08E+14    1.31E+19
  5 SIDE 5                          90.00   20.00      20.0     1.05E+14    1.27E+19
  6 SIDE 6                          90.00   25.00      25.0     1.02E+14    1.22E+19
  7 SIDE 7                          90.00   30.00      30.0     9.70E+13    1.17E+19
  8 SIDE 8                          90.00   35.00      35.0     9.17E+13    1.11E+19
  9 SIDE 9                          90.00   40.00      40.0     8.57E+13    1.03E+19
 10 SIDE 10                         90.00   45.00      45.0     7.91E+13    9.54E+18
 11 SIDE 11                         90.00   50.00      50.0     7.19E+13    8.67E+18
 12 SIDE 12                         90.00   55.00      55.0     6.41E+13    7.73E+18
 13 SIDE 13                         90.00   60.00      60.0     5.58E+13    6.73E+18
 14 SIDE 14                         90.00   65.00      65.0     4.71E+13    5.68E+18
 15 SIDE 15                         90.00   70.00      70.0     3.81E+13    4.59E+18
 16 SIDE 16                         90.00   75.00      75.0     2.88E+13    3.47E+18
 17 SIDE 17                         90.00   80.00      80.0     1.94E+13    2.33E+18
 18 SIDE 18                         90.00   85.00      85.0     1.07E+13    1.28E+18
 19 SIDE 19                         90.00   90.00      90.0     4.22E+12    5.04E+17
 20 SIDE 20                         90.00   95.00      95.0     1.06E+12    1.23E+17
 21 SIDE 21                         90.00  100.00     100.0     1.55E+11    1.71E+16
 22 SIDE 22                         90.00  105.00     105.0     1.27E+10    1.30E+15
 23 SIDE 23                         90.00  110.00     110.0     6.03E+08    5.71E+13
 24 SIDE 24                         90.00  115.00     115.0     1.76E+07    1.59E+12
 25 SIDE 25                         90.00  120.00     120.0     3.45E+05    3.13E+10
 26 SIDE 26                         90.00  125.00     125.0     5.02E+03    4.85E+08
 27 SIDE 27                         90.00  130.00     130.0     6.03E+01    6.60E+06
 28 SIDE 28                         90.00  135.00     135.0     6.76E-01    8.82E+04
 29 SIDE 29                         90.00  140.00     140.0     8.02E-03    1.29E+03
 30 SIDE 30                         90.00  145.00     145.0     1.15E-04    2.31E+01
 31 SIDE 31                         90.00  150.00     150.0     2.27E-06    5.52E-01
 32 SIDE 32                         90.00  155.00     155.0     7.02E-08    1.94E-02
 33 SIDE 33                         90.00  160.00     160.0     3.79E-09    1.09E-03
 34 SIDE 34                         90.00  165.00     165.0     3.86E-10    1.05E-04
 35 SIDE 35                         90.00  170.00     170.0     7.82E-11    1.88E-05
 36 SIDE 36                         90.00  175.00     175.0     3.25E-11    6.52E-06
 37 SIDE 37                         90.00  180.00     178.8     2.78E-11    4.55E-06
 38 TRUE RAM                                            0.0     1.12E+14    1.35E+19
 39 TRUE 90                                            90.0     4.25E+12    5.07E+17


    2450060.2863715  1995  12   8  18   52   22.50     JDATE AND DATE FLUENCE
          8.2062581           CUMULATIVE DAYS EXPOSURE
    2450061.2447049  1995  12   9  17   52   22.50     JDATE AND DATE ASAP END
    2450060.2863715  1995  12   8  18   52   22.50     JDATE AND DATE ASAP START
      231                     #POINTS IN ASAP RUN
  1.553E+08    2.567E+08   7.640E+07           AVG, MAX, MIN AO DEN (#/CM**3)
     915.86      1182.83     744.44            AVG, MAX, MIN TEMPERATURE (K)
     348.39       354.52     342.35            AVG, MAX, MIN ALTITUDE (KM)
     7.7030       7.7089     7.6971            AVG, MAX, MIN ABS SPEED (KM/S)
     7.2752       7.2827     7.2675            AVG, MAX, MIN REL SPEED (KM/S)
NO. LOCATION                        THETA     PHI    AVERAGE AVERAGE FLUX     FLUENCE
                                    (DEG)    (DEG) INCIDENCE  (#/CM**2/S)   (#/CM**2)
                                                     ANGLE
                                                     (DEG)
  1 SIDE 1                          90.00    0.00       1.2     1.13E+14    8.16E+19
  2 SIDE 2                          90.00    5.00       5.0     1.13E+14    8.13E+19
  3 SIDE 3                          90.00   10.00      10.0     1.11E+14    8.03E+19
  4 SIDE 4                          90.00   15.00      15.0     1.09E+14    7.88E+19
  5 SIDE 5                          90.00   20.00      20.0     1.06E+14    7.66E+19
  6 SIDE 6                          90.00   25.00      25.0     1.02E+14    7.38E+19
  7 SIDE 7                          90.00   30.00      30.0     9.76E+13    7.05E+19
  8 SIDE 8                          90.00   35.00      35.0     9.22E+13    6.67E+19
  9 SIDE 9                          90.00   40.00      40.0     8.62E+13    6.23E+19
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10 SIDE 10                        90.00   45.00      45.0     7.95E+13   5.75E+19
11 SIDE 11                        90.00   50.00      50.0     7.22E+13   5.22E+19
12 SIDE 12                        90.00   55.00      55.0     6.43E+13   4.66E+19
13 SIDE 13                        90.00   60.00      60.0     5.60E+13   4.05E+19
14 SIDE 14                        90.00   65.00      65.0     4.72E+13   3.42E+19
15 SIDE 15                        90.00   70.00      70.0     3.81E+13   2.76E+19
16 SIDE 16                        90.00   75.00      75.0     2.87E+13   2.08E+19
17 SIDE 17                        90.00   80.00      80.0     1.92E+13   1.40E+19
18 SIDE 18                        90.00   85.00      85.0     1.05E+13   7.68E+18
19 SIDE 19                        90.00   90.00      90.0     4.12E+12   3.03E+18
20 SIDE 20                        90.00   95.00      95.0     1.01E+12   7.49E+17
21 SIDE 21                        90.00  100.00     100.0     1.39E+11   1.06E+17
22 SIDE 22                        90.00  105.00     105.0     1.05E+10   8.33E+15
23 SIDE 23                        90.00  110.00     110.0     4.56E+08   3.78E+14
24 SIDE 24                        90.00  115.00     115.0     1.25E+07   1.07E+13
25 SIDE 25                        90.00  120.00     120.0     2.41E+05   2.09E+11
26 SIDE 26                        90.00  125.00     125.0     3.68E+03   3.12E+09
27 SIDE 27                        90.00  130.00     130.0     4.92E+01   3.97E+07
28 SIDE 28                        90.00  135.00     135.0     6.41E-01   4.87E+05
29 SIDE 29                        90.00  140.00     140.0     9.20E-03   6.50E+03
30 SIDE 30                        90.00  145.00     145.0     1.63E-04   1.07E+02
31 SIDE 31                        90.00  150.00     150.0     4.02E-06   2.45E+00
32 SIDE 32                        90.00  155.00     155.0     1.51E-07   8.64E-02
33 SIDE 33                        90.00  160.00     160.0     9.48E-09   5.10E-03
34 SIDE 34                        90.00  165.00     165.0     1.06E-09   5.43E-04
35 SIDE 35                        90.00  170.00     170.0     2.24E-10   1.10E-04
36 SIDE 36                        90.00  175.00     175.0     9.21E-11   4.42E-05
37 SIDE 37                        90.00  180.00     178.8     7.55E-11   3.58E-05
38 TRUE RAM                                           0.0     1.13E+14   8.16E+19
39 TRUE 90                                           90.0     4.30E+12   3.09E+18


   2450067.2863715  1995  12  15  18  52  22.50     JDATE AND DATE FLUENCE
        15.2062581             CUMULATIVE DAYS EXPOSURE
   2450068.2447049  1995  12  16  17  52  22.50     JDATE AND DATE ASAP END
   2450067.2863715  1995  12  15  18  52  22.50     JDATE AND DATE ASAP START
     231                       #POINTS IN ASAP RUN
  1.455E+08   2.393E+08   7.067E+07          AVG, MAX, MIN AO DEN (#/CM**3)
    887.51      1182.86     726.63           AVG, MAX, MIN TEMPERATURE (K)
    348.19       357.03     342.76           AVG, MAX, MIN ALTITUDE (KM)
    7.7031       7.7102     7.6945           AVG, MAX, MIN ABS SPEED (KM/S)
    7.2753       7.2818     7.2643           AVG, MAX, MIN REL SPEED (KM/S)
NO. LOCATION                      THETA     PHI   AVERAGE  AVERAGE FLUX     FLUENCE
                                  (DEG)    (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                   ANGLE
                                                   (DEG)

 1 SIDE 1                         90.00    0.00       1.2     1.06E+14   1.48E+20
 2 SIDE 2                         90.00    5.00       5.0     1.05E+14   1.47E+20
 3 SIDE 3                         90.00   10.00      10.0     1.04E+14   1.45E+20
 4 SIDE 4                         90.00   15.00      15.0     1.02E+14   1.43E+20
 5 SIDE 5                         90.00   20.00      20.0     9.94E+13   1.39E+20
 6 SIDE 6                         90.00   25.00      25.0     9.58E+13   1.34E+20
 7 SIDE 7                         90.00   30.00      30.0     9.15E+13   1.28E+20
 8 SIDE 8                         90.00   35.00      35.0     8.65E+13   1.21E+20
 9 SIDE 9                         90.00   40.00      40.0     8.09E+13   1.13E+20
10 SIDE 10                        90.00   45.00      45.0     7.46E+13   1.04E+20
11 SIDE 11                        90.00   50.00      50.0     6.78E+13   9.45E+19
12 SIDE 12                        90.00   55.00      55.0     6.04E+13   8.43E+19
13 SIDE 13                        90.00   60.00      60.0     5.26E+13   7.34E+19
14 SIDE 14                        90.00   65.00      65.0     4.44E+13   6.19E+19
15 SIDE 15                        90.00   70.00      70.0     3.59E+13   5.00E+19
16 SIDE 16                        90.00   75.00      75.0     2.71E+13   3.77E+19
17 SIDE 17                        90.00   80.00      80.0     1.82E+13   2.53E+19
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 18 SIDE 18                     90.00    85.00      85.0      9.99E+12    1.39E+19
 19 SIDE 19                     90.00    90.00      90.0      3.91E+12    5.45E+18
 20 SIDE 20                     90.00    95.00      95.0      9.45E+11    1.34E+18
 21 SIDE 21                     90.00   100.00     100.0      1.27E+11    1.87E+17
 22 SIDE 22                     90.00   105.00     105.0      9.30E+09    1.43E+16
 23 SIDE 23                     90.00   110.00     110.0      3.92E+08    6.34E+14
 24 SIDE 24                     90.00   115.00     115.0      1.08E+07    1.77E+13
 25 SIDE 25                     90.00   120.00     120.0      2.25E+05    3.49E+11
 26 SIDE 26                     90.00   125.00     125.0      3.89E+03    5.41E+09
 27 SIDE 27                     90.00   130.00     130.0      6.12E+01    7.31E+07
 28 SIDE 28                     90.00   135.00     135.0      9.49E-01    9.67E+05
 29 SIDE 29                     90.00   140.00     140.0      1.59E-02    1.41E+04
 30 SIDE 30                     90.00   145.00     145.0      3.15E-04    2.52E+02
 31 SIDE 31                     90.00   150.00     150.0      8.22E-06    6.15E+00
 32 SIDE 32                     90.00   155.00     155.0      3.09E-07    2.26E-01
 33 SIDE 33                     90.00   160.00     160.0      1.83E-08    1.35E-02
 34 SIDE 34                     90.00   165.00     165.0      1.85E-09    1.42E-03
 35 SIDE 35                     90.00   170.00     170.0      3.41E-10    2.81E-04
 36 SIDE 36                     90.00   175.00     175.0      1.19E-10    1.08E-04
 37 SIDE 37                     90.00   180.00     178.8      8.17E-11    8.33E-05
 38 TRUE RAM                                         0.0      1.06E+14    1.48E+20
 39 TRUE 90                                         90.0      3.95E+12    5.59E+18


   2450082.9537002  1995  12  31  10  53  19.70     JDATE AND DATE FLUENCE
        30.8735868         CUMULATIVE DAYS EXPOSURE
   2450083.9120336  1996   1   1   9  53  19.70     JDATE AND DATE ASAP END
   2450082.9537002  1995  12  31  10  53  19.70     JDATE AND DATE ASAP START
     231                   #POINTS IN ASAP RUN
  1.658E+08    2.487E+08   8.914E+07         AVG, MAX, MIN AO DEN (#/CM**3)
     864.07      1173.86      732.69         AVG, MAX, MIN TEMPERATURE (K)
     344.21       346.36      341.50         AVG, MAX, MIN ALTITUDE (KM)
     7.7054       7.7070      7.7045         AVG, MAX, MIN ABS SPEED (KM/S)
     7.2778       7.2814      7.2750         AVG, MAX, MIN REL SPEED (KM/S)
NO. LOCATION                    THETA     PHI    AVERAGE  AVERAGE FLUX    FLUENCE
                                (DEG)    (DEG)  INCIDENCE  (#/CM**2/S)   (#/CM**2)
                                                  ANGLE
                                                  (DEG)
  1 SIDE 1                      90.00     0.00       1.2      1.21E+14    3.01E+20
  2 SIDE 2                      90.00     5.00       5.0      1.20E+14    3.00E+20
  3 SIDE 3                      90.00    10.00      10.0      1.19E+14    2.96E+20
  4 SIDE 4                      90.00    15.00      15.0      1.16E+14    2.91E+20
  5 SIDE 5                      90.00    20.00      20.0      1.13E+14    2.83E+20
  6 SIDE 6                      90.00    25.00      25.0      1.09E+14    2.72E+20
  7 SIDE 7                      90.00    30.00      30.0      1.04E+14    2.60E+20
  8 SIDE 8                      90.00    35.00      35.0      9.87E+13    2.46E+20
  9 SIDE 9                      90.00    40.00      40.0      9.23E+13    2.30E+20
 10 SIDE 10                     90.00    45.00      45.0      8.51E+13    2.12E+20
 11 SIDE 11                     90.00    50.00      50.0      7.74E+13    1.93E+20
 12 SIDE 12                     90.00    55.00      55.0      6.90E+13    1.72E+20
 13 SIDE 13                     90.00    60.00      60.0      6.01E+13    1.50E+20
 14 SIDE 14                     90.00    65.00      65.0      5.08E+13    1.26E+20
 15 SIDE 15                     90.00    70.00      70.0      4.10E+13    1.02E+20
 16 SIDE 16                     90.00    75.00      75.0      3.10E+13    7.70E+19
 17 SIDE 17                     90.00    80.00      80.0      2.09E+13    5.18E+19
 18 SIDE 18                     90.00    85.00      85.0      1.15E+13    2.84E+19
 19 SIDE 19                     90.00    90.00      90.0      4.46E+12    1.11E+19
 20 SIDE 20                     90.00    95.00      95.0      1.06E+12    2.70E+18
 21 SIDE 21                     90.00   100.00     100.0      1.38E+11    3.66E+17
 22 SIDE 22                     90.00   105.00     105.0      9.30E+09    2.69E+16
 23 SIDE 23                     90.00   110.00     110.0      3.41E+08    1.13E+15
 24 SIDE 24                     90.00   115.00     115.0      7.50E+06    3.01E+13
 25 SIDE 25                     90.00   120.00     120.0      1.16E+05    5.80E+11
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26 SIDE 26                            90.00  125.00     125.0     1.48E+03   9.04E+09
27 SIDE 27                            90.00  130.00     130.0     1.81E+01   1.27E+08
28 SIDE 28                            90.00  135.00     135.0     2.37E-01   1.77E+06
29 SIDE 29                            90.00  140.00     140.0     3.65E-03   2.73E+04
30 SIDE 30                            90.00  145.00     145.0     7.11E-05   5.13E+02
31 SIDE 31                            90.00  150.00     150.0     1.88E-06   1.30E+01
32 SIDE 32                            90.00  155.00     155.0     7.31E-08   4.84E-01
33 SIDE 33                            90.00  160.00     160.0     4.50E-09   2.90E-02
34 SIDE 34                            90.00  165.00     165.0     4.71E-10   3.00E-03
35 SIDE 35                            90.00  170.00     170.0     8.92E-11   5.72E-04
36 SIDE 36                            90.00  175.00     175.0     3.20E-11   2.10E-04
37 SIDE 37                            90.00  180.00     178.8     2.24E-11   1.54E-04
38 TRUE RAM                                               0.0     1.21E+14   3.01E+20
39 TRUE 90                                               90.0     4.44E+12   1.13E+19


   2450083.7757361  1996   1   1   6  37   3.60     JDATE AND DATE FLUENCE
        31.6956227            CUMULATIVE DAYS EXPOSURE
   2450084.7340694  1996   1   2   5  37   3.60     JDATE AND DATE ASAP END
   2450083.7757361  1996   1   1   6  37   3.60     JDATE AND DATE ASAP START
     231                      #POINTS IN ASAP RUN
  1.183E+08   1.854E+08   5.769E+07          AVG, MAX, MIN AO DEN (#/CM**3)
     894.35     1147.51      747.15          AVG, MAX, MIN TEMPERATURE (K)
     356.83      358.96      354.18          AVG, MAX, MIN ALTITUDE (KM)
     7.6982      7.6997      7.6972          AVG, MAX, MIN ABS SPEED (KM/S)
     7.2698      7.2733      7.2670          AVG, MAX, MIN REL SPEED (KM/S)
NO. LOCATION                          THETA     PHI   AVERAGE AVERAGE FLUX    FLUENCE
                                      (DEG)    (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                       ANGLE
                                                       (DEG)
  1 SIDE 1                            90.00    0.00       1.2     8.60E+13   3.08E+20
  2 SIDE 2                            90.00    5.00       5.0     8.56E+13   3.07E+20
  3 SIDE 3                            90.00   10.00      10.0     8.46E+13   3.04E+20
  4 SIDE 4                            90.00   15.00      15.0     8.29E+13   2.98E+20
  5 SIDE 5                            90.00   20.00      20.0     8.06E+13   2.89E+20
  6 SIDE 6                            90.00   25.00      25.0     7.77E+13   2.79E+20
  7 SIDE 7                            90.00   30.00      30.0     7.43E+13   2.67E+20
  8 SIDE 8                            90.00   35.00      35.0     7.02E+13   2.52E+20
  9 SIDE 9                            90.00   40.00      40.0     6.56E+13   2.36E+20
 10 SIDE 10                           90.00   45.00      45.0     6.05E+13   2.17E+20
 11 SIDE 11                           90.00   50.00      50.0     5.50E+13   1.97E+20
 12 SIDE 12                           90.00   55.00      55.0     4.90E+13   1.76E+20
 13 SIDE 13                           90.00   60.00      60.0     4.26E+13   1.53E+20
 14 SIDE 14                           90.00   65.00      65.0     3.60E+13   1.29E+20
 15 SIDE 15                           90.00   70.00      70.0     2.90E+13   1.05E+20
 16 SIDE 16                           90.00   75.00      75.0     2.19E+13   7.89E+19
 17 SIDE 17                           90.00   80.00      80.0     1.47E+13   5.30E+19
 18 SIDE 18                           90.00   85.00      85.0     8.02E+12   2.91E+19
 19 SIDE 19                           90.00   90.00      90.0     3.13E+12   1.14E+19
 20 SIDE 20                           90.00   95.00      95.0     7.59E+11   2.76E+18
 21 SIDE 21                           90.00  100.00     100.0     1.04E+11   3.74E+17
 22 SIDE 22                           90.00  105.00     105.0     7.83E+09   2.75E+16
 23 SIDE 23                           90.00  110.00     110.0     3.34E+08   1.15E+15
 24 SIDE 24                           90.00  115.00     115.0     8.83E+06   3.07E+13
 25 SIDE 25                           90.00  120.00     120.0     1.62E+05   5.90E+11
 26 SIDE 26                           90.00  125.00     125.0     2.29E+03   9.18E+09
 27 SIDE 27                           90.00  130.00     130.0     2.77E+01   1.28E+08
 28 SIDE 28                           90.00  135.00     135.0     3.22E-01   1.79E+06
 29 SIDE 29                           90.00  140.00     140.0     4.01E-03   2.76E+04
 30 SIDE 30                           90.00  145.00     145.0     6.11E-05   5.18E+02
 31 SIDE 31                           90.00  150.00     150.0     1.29E-06   1.31E+01
 32 SIDE 32                           90.00  155.00     155.0     4.21E-08   4.88E-01
 33 SIDE 33                           90.00  160.00     160.0     2.37E-09   2.92E-02
```

```
 34 SIDE 34                         90.00  165.00      165.0      2.48E-10   3.02E-03
 35 SIDE 35                         90.00  170.00      170.0      5.07E-11   5.77E-04
 36 SIDE 36                         90.00  175.00      175.0      2.10E-11   2.12E-04
 37 SIDE 37                         90.00  180.00      178.8      1.79E-11   1.55E-04
 38 TRUE RAM                                             0.0      8.60E+13   3.09E+20
 39 TRUE 90                                             90.0      3.23E+12   1.15E+19


   2450114.1891007  1996   1  31  16  32  18.30     JDATE AND DATE FLUENCE
        62.1089873            CUMULATIVE DAYS EXPOSURE
   2450115.1474340  1996   2   1  15  32  18.30     JDATE AND DATE ASAP END
   2450114.1891007  1996   1  31  16  32  18.30     JDATE AND DATE ASAP START
     231                      #POINTS IN ASAP RUN
  1.209E+08   1.926E+08   6.344E+07          AVG, MAX, MIN AO DEN (#/CM**3)
     883.73      1129.42     729.33          AVG, MAX, MIN TEMPERATURE (K)
     351.42       353.55     348.79          AVG, MAX, MIN ALTITUDE (KM)
     7.7013       7.7028     7.7003          AVG, MAX, MIN ABS SPEED (KM/S)
     7.2732       7.2767     7.2704          AVG, MAX, MIN REL SPEED (KM/S)
NO. LOCATION                        THETA     PHI   AVERAGE AVERAGE FLUX    FLUENCE
                                    (DEG)    (DEG) INCIDENCE  (#/CM**2/S)  (#/CM**2)
                                                     ANGLE
                                                     (DEG)
  1 SIDE 1                          90.00    0.00        1.2      8.79E+13   5.37E+20
  2 SIDE 2                          90.00    5.00        5.0      8.76E+13   5.35E+20
  3 SIDE 3                          90.00   10.00       10.0      8.65E+13   5.28E+20
  4 SIDE 4                          90.00   15.00       15.0      8.48E+13   5.18E+20
  5 SIDE 5                          90.00   20.00       20.0      8.25E+13   5.04E+20
  6 SIDE 6                          90.00   25.00       25.0      7.95E+13   4.86E+20
  7 SIDE 7                          90.00   30.00       30.0      7.59E+13   4.64E+20
  8 SIDE 8                          90.00   35.00       35.0      7.18E+13   4.39E+20
  9 SIDE 9                          90.00   40.00       40.0      6.71E+13   4.10E+20
 10 SIDE 10                         90.00   45.00       45.0      6.19E+13   3.78E+20
 11 SIDE 11                         90.00   50.00       50.0      5.62E+13   3.44E+20
 12 SIDE 12                         90.00   55.00       55.0      5.01E+13   3.06E+20
 13 SIDE 13                         90.00   60.00       60.0      4.36E+13   2.67E+20
 14 SIDE 14                         90.00   65.00       65.0      3.68E+13   2.25E+20
 15 SIDE 15                         90.00   70.00       70.0      2.97E+13   1.82E+20
 16 SIDE 16                         90.00   75.00       75.0      2.24E+13   1.37E+20
 17 SIDE 17                         90.00   80.00       80.0      1.50E+13   9.21E+19
 18 SIDE 18                         90.00   85.00       85.0      8.18E+12   5.04E+19
 19 SIDE 19                         90.00   90.00       90.0      3.17E+12   1.97E+19
 20 SIDE 20                         90.00   95.00       95.0      7.59E+11   4.76E+18
 21 SIDE 21                         90.00  100.00      100.0      1.01E+11   6.44E+17
 22 SIDE 22                         90.00  105.00      105.0      7.25E+09   4.73E+16
 23 SIDE 23                         90.00  110.00      110.0      2.90E+08   1.97E+15
 24 SIDE 24                         90.00  115.00      115.0      7.17E+06   5.17E+13
 25 SIDE 25                         90.00  120.00      120.0      1.24E+05   9.65E+11
 26 SIDE 26                         90.00  125.00      125.0      1.68E+03   1.44E+10
 27 SIDE 27                         90.00  130.00      130.0      1.99E+01   1.91E+08
 28 SIDE 28                         90.00  135.00      135.0      2.28E-01   2.51E+06
 29 SIDE 29                         90.00  140.00      140.0      2.84E-03   3.66E+04
 30 SIDE 30                         90.00  145.00      145.0      4.35E-05   6.55E+02
 31 SIDE 31                         90.00  150.00      150.0      9.15E-07   1.60E+01
 32 SIDE 32                         90.00  155.00      155.0      2.96E-08   5.83E-01
 33 SIDE 33                         90.00  160.00      160.0      1.62E-09   3.45E-02
 34 SIDE 34                         90.00  165.00      165.0      1.60E-10   3.56E-03
 35 SIDE 35                         90.00  170.00      170.0      3.08E-11   6.84E-04
 36 SIDE 36                         90.00  175.00      175.0      1.19E-11   2.55E-04
 37 SIDE 37                         90.00  180.00      178.8      9.38E-12   1.91E-04
 38 TRUE RAM                                             0.0      8.79E+13   5.37E+20
 39 TRUE 90                                             90.0      3.27E+12   2.01E+19
```

```
    2450116.6609410  1996   2   3   3  51  45.30     JDATE AND DATE FLUENCE
         64.5808275          CUMULATIVE DAYS EXPOSURE
    2450116.6609410  1996   2   3   3  51  45.30     JDATE AND DATE ASAP END
    2450115.7026076  1996   2   2   4  51  45.30     JDATE AND DATE ASAP START
      231                    #POINTS IN ASAP RUN
  1.237E+08   1.992E+08   6.099E+07          AVG, MAX, MIN AO DEN (#/CM**3)
     888.18     1131.61      718.66          AVG, MAX, MIN TEMPERATURE (K)
     351.37      353.99      347.77          AVG, MAX, MIN ALTITUDE (KM)
     7.7013      7.7040      7.6995          AVG, MAX, MIN ABS SPEED (KM/S)
     7.2733      7.2779      7.2699          AVG, MAX, MIN REL SPEED (KM/S)
NO. LOCATION                    THETA     PHI   AVERAGE AVERAGE FLUX    FLUENCE
                                (DEG)   (DEG) INCIDENCE  (#/CM**2/S)   (#/CM**2)
                                                  ANGLE
                                                  (DEG)
  1 SIDE 1                      90.00     0.00       1.2     8.99E+13   5.56E+20
  2 SIDE 2                      90.00     5.00       5.0     8.96E+13   5.54E+20
  3 SIDE 3                      90.00    10.00      10.0     8.85E+13   5.47E+20
  4 SIDE 4                      90.00    15.00      15.0     8.68E+13   5.36E+20
  5 SIDE 5                      90.00    20.00      20.0     8.44E+13   5.22E+20
  6 SIDE 6                      90.00    25.00      25.0     8.13E+13   5.03E+20
  7 SIDE 7                      90.00    30.00      30.0     7.77E+13   4.80E+20
  8 SIDE 8                      90.00    35.00      35.0     7.34E+13   4.54E+20
  9 SIDE 9                      90.00    40.00      40.0     6.86E+13   4.24E+20
 10 SIDE 10                     90.00    45.00      45.0     6.33E+13   3.92E+20
 11 SIDE 11                     90.00    50.00      50.0     5.75E+13   3.56E+20
 12 SIDE 12                     90.00    55.00      55.0     5.12E+13   3.17E+20
 13 SIDE 13                     90.00    60.00      60.0     4.46E+13   2.76E+20
 14 SIDE 14                     90.00    65.00      65.0     3.76E+13   2.33E+20
 15 SIDE 15                     90.00    70.00      70.0     3.03E+13   1.88E+20
 16 SIDE 16                     90.00    75.00      75.0     2.28E+13   1.42E+20
 17 SIDE 17                     90.00    80.00      80.0     1.53E+13   9.53E+19
 18 SIDE 18                     90.00    85.00      85.0     8.34E+12   5.21E+19
 19 SIDE 19                     90.00    90.00      90.0     3.23E+12   2.04E+19
 20 SIDE 20                     90.00    95.00      95.0     7.72E+11   4.92E+18
 21 SIDE 21                     90.00   100.00     100.0     1.03E+11   6.66E+17
 22 SIDE 22                     90.00   105.00     105.0     7.32E+09   4.89E+16
 23 SIDE 23                     90.00   110.00     110.0     2.92E+08   2.04E+15
 24 SIDE 24                     90.00   115.00     115.0     7.16E+06   5.33E+13
 25 SIDE 25                     90.00   120.00     120.0     1.23E+05   9.92E+11
 26 SIDE 26                     90.00   125.00     125.0     1.66E+03   1.47E+10
 27 SIDE 27                     90.00   130.00     130.0     1.94E+01   1.95E+08
 28 SIDE 28                     90.00   135.00     135.0     2.20E-01   2.56E+06
 29 SIDE 29                     90.00   140.00     140.0     2.69E-03   3.72E+04
 30 SIDE 30                     90.00   145.00     145.0     4.03E-05   6.64E+02
 31 SIDE 31                     90.00   150.00     150.0     8.33E-07   1.62E+01
 32 SIDE 32                     90.00   155.00     155.0     2.67E-08   5.89E-01
 33 SIDE 33                     90.00   160.00     160.0     1.46E-09   3.48E-02
 34 SIDE 34                     90.00   165.00     165.0     1.47E-10   3.59E-03
 35 SIDE 35                     90.00   170.00     170.0     2.89E-11   6.90E-04
 36 SIDE 36                     90.00   175.00     175.0     1.15E-11   2.58E-04
 37 SIDE 37                     90.00   180.00     178.8     9.39E-12   1.93E-04
 38 TRUE RAM                                         0.0     9.00E+13   5.56E+20
 39 TRUE 90                                         90.0     3.36E+12   2.08E+19


#END FLUX AND FLUENCE MEAN ORBITAL PARAMETERS
```

A.6 Fluence Versus Time

Filename: sample1.xls
Spreadsheet format, output option 1 (fluence versus time), for surfaces 1-5.

```
Time vs. fluence for various average incidence angles.
 Filename: fluxavg.mission_sample26-Apr-93.1
 Time (days)      SIDE 1      SIDE 2      SIDE 3      SIDE 4      SIDE 5
           0    0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00
           1    1.350e+19   1.350e+19   1.330e+19   1.310e+19   1.270e+19
           8    8.160e+19   8.130e+19   8.030e+19   7.880e+19   7.660e+19
          15    1.480e+20   1.470e+20   1.450e+20   1.430e+20   1.390e+20
          31    3.010e+20   3.000e+20   2.960e+20   2.910e+20   2.830e+20
          32    3.080e+20   3.070e+20   3.040e+20   2.980e+20   2.890e+20
          62    5.370e+20   5.350e+20   5.280e+20   5.180e+20   5.040e+20
          65    5.560e+20   5.540e+20   5.470e+20   5.360e+20   5.220e+20
```

A.7 Altitude Versus Time

Filename: sample2.xls
Spreadsheet format, output option 2 (values versus time), for altitude.

```
Altitude (km) vs. Time (Days).  Filename: fluxavg.mission_sample26-Apr-93.1
 Time (days)        Average     Maximum     Minimum
           0         334.75      336.86      332.16
           1         348.60      350.74      345.94
           8         348.39      354.52      342.35
          15         348.19      357.03      342.76
          31         344.21      346.36      341.50
          32         356.83      358.96      354.18
          62         351.42      353.55      348.79
          65         351.37      353.99      347.77
```

A.8 Fluence Versus Angle at a Given Time

Filename: sample3.xls
Spreadsheet format, output option 3 (fluence versus angle), for time = 65 days.

```
Data calculated for Time =     64.6 days.  Filename: fluxavg.mission_sample26-Apr-93.1
Angles in degrees, flux in atoms/cm^2/s, fluence in atoms/cm^2.
Location            Theta       Phi        Ave Inc Ang      Ave Flux       Fluence
SIDE 1              90.00        0.00          1.2         8.99E+13       5.56E+20
SIDE 2              90.00        5.00          5.0         8.96E+13       5.54E+20
SIDE 3              90.00       10.00         10.0         8.85E+13       5.47E+20
SIDE 4              90.00       15.00         15.0         8.68E+13       5.36E+20
SIDE 5              90.00       20.00         20.0         8.44E+13       5.22E+20
SIDE 6              90.00       25.00         25.0         8.13E+13       5.03E+20
SIDE 7              90.00       30.00         30.0         7.77E+13       4.80E+20
SIDE 8              90.00       35.00         35.0         7.34E+13       4.54E+20
SIDE 9              90.00       40.00         40.0         6.86E+13       4.24E+20
SIDE 10             90.00       45.00         45.0         6.33E+13       3.92E+20
SIDE 11             90.00       50.00         50.0         5.75E+13       3.56E+20
SIDE 12             90.00       55.00         55.0         5.12E+13       3.17E+20
SIDE 13             90.00       60.00         60.0         4.46E+13       2.76E+20
SIDE 14             90.00       65.00         65.0         3.76E+13       2.33E+20
SIDE 15             90.00       70.00         70.0         3.03E+13       1.88E+20
SIDE 16             90.00       75.00         75.0         2.28E+13       1.42E+20
SIDE 17             90.00       80.00         80.0         1.53E+13       9.53E+19
SIDE 18             90.00       85.00         85.0         8.34E+12       5.21E+19
SIDE 19             90.00       90.00         90.0         3.23E+12       2.04E+19
SIDE 20             90.00       95.00         95.0         7.72E+11       4.92E+18
SIDE 21             90.00      100.00        100.0         1.03E+11       6.66E+17
SIDE 22             90.00      105.00        105.0         7.32E+09       4.89E+16
SIDE 23             90.00      110.00        110.0         2.92E+08       2.04E+15
SIDE 24             90.00      115.00        115.0         7.16E+06       5.33E+13
SIDE 25             90.00      120.00        120.0         1.23E+05       9.92E+11
SIDE 26             90.00      125.00        125.0         1.66E+03       1.47E+10
SIDE 27             90.00      130.00        130.0         1.94E+01       1.95E+08
SIDE 28             90.00      135.00        135.0         2.20E-01       2.56E+06
SIDE 29             90.00      140.00        140.0         2.69E-03       3.72E+04
SIDE 30             90.00      145.00        145.0         4.03E-05       6.64E+02
SIDE 31             90.00      150.00        150.0         8.33E-07       1.62E+01
SIDE 32             90.00      155.00        155.0         2.67E-08       5.89E-01
SIDE 33             90.00      160.00        160.0         1.46E-09       3.48E-02
SIDE 34             90.00      165.00        165.0         1.47E-10       3.59E-03
SIDE 35             90.00      170.00        170.0         2.89E-11       6.90E-04
SIDE 36             90.00      175.00        175.0         1.15E-11       2.58E-04
SIDE 37             90.00      180.00        178.8         9.39E-12       1.93E-04
TRUE RAM                                       0.0         9.00E+13       5.56E+20
TRUE 90                                       90.0         3.36E+12       2.08E+19
```

A.9 Tables of Fluence

Filename: sample4.txt
Output option 4 (tables), min. reboost = 5 km, surfaces 1-5.

```
Filename: fluxavg.mission_sample26-Apr-93.1
Date generated: Mon Apr 26 14:55:06 1993

                   ATOMIC OXYGEN MISSION TOTAL FLUENCE
                               Atoms/cm^2

                                  Date
                  12/01/95
                            Cumulative days
        Average         0
      Incidence              Altitude (km)
          Angle       335

              1   0.00e+00
              5   0.00e+00
             10   0.00e+00
             15   0.00e+00
             20   0.00e+00

                   ATOMIC OXYGEN MISSION TOTAL FLUENCE
                               Atoms/cm^2

                                  Date
                  12/02/95   12/09/95   12/16/95    1/01/96
                            Cumulative days
        Average         1          8         15         31
      Incidence              Altitude (km)
          Angle       349        348        348        344

              1   1.35e+19   8.16e+19   1.48e+20   3.01e+20
              5   1.35e+19   8.13e+19   1.47e+20   3.00e+20
             10   1.33e+19   8.03e+19   1.45e+20   2.96e+20
             15   1.31e+19   7.88e+19   1.43e+20   2.91e+20
             20   1.27e+19   7.66e+19   1.39e+20   2.83e+20


                   ATOMIC OXYGEN MISSION TOTAL FLUENCE
                               Atoms/cm^2

                                  Date
                   1/02/96    2/01/96    2/03/96
                            Cumulative days
        Average        32          62        65
      Incidence              Altitude (km)
          Angle       357        351        351

              1   3.08e+20   5.37e+20   1.48e+20
              5   3.07e+20   5.35e+20   1.47e+20
             10   3.04e+20   5.28e+20   1.45e+20
             15   2.98e+20   5.18e+20   1.43e+20
             20   2.89e+20   5.04e+20   1.39e+20
```

APPENDIX B

APPENDIX B MISSION FILE FORMAT

The format of the mission file is described in this section so that programs can be generated or modified to select specific parts of the file. The file is divided into several sections. Each section is delimited by a # in the first column of the line starting the section and the line ending the section. Line numbers in the tables below start with the first line following the section identifier. All lines except section and end identifiers are blank in column 1. Many lines in the data file have comments entered to the right of the data field. These comments are not used by the application file generator, but are provided solely for the convenience of those who look at the mission file.

For an example of a mission file, see Appendix A5.

Section 1. PROGRAM IDENTIFICATION

Section Identifier: `#PROGRAM IDENTIFICATION`

Value	Line	Column	Format	Variable
3 lines of program and mission file text	1-3	2-79	A	
Version	4	2-79	A	VERS
Text ("COMPILED")	5	2-12	A	
FLUXAVG compilation date	5	13-22	A	
FLUXAVG compilation time	5	26-33	A	
Text ("DATE OF COMPUTATION")	6	2-24	A	
Run date	6	25-34	A10	RDATE
Run time	6	38-45	A8	RTIME

End Identifier: `#END PROGRAM IDENTIFICATION`

Section 2. PROGRAM CONTROL FILE ECHO

Section Identifier: `#PROGRAM CONTROL FILE ECHO`

This section contains an exact copy of the program control file, except that all characters are shifted right one character. Refer to section 2.2.1 for a description of the program control file.

End Identifier: `#END PROGRAM CONTROL FILE ECHO`

Section 3. MISSION FILE NAME

Section Identifier: `#MISSION FILE NAME`

Value	Column	Format	Variable
Name of this mission file	2-79	A	MISFLO

End Identifier: `#END MISSION FILE NAME`

Section 4. COMMENTARY

Section Identifier: `#COMMENTARY`

This section contains comments. The number of lines is unspecified, but the comments end with a line that consists of a $ in the second column.

Value	Line	Column	Format	Variable
Comments	open	2-78	A	LINE
$	last	2	A	

End Identifier: `#END COMMENTARY`

Section 5. SOLAR AND GEOMAGNETIC DATA ECHO

Section Identifier: `#SOLAR AND GEOMAGNETIC DATA ECHO`

Record D1

FORTRAN format (F20.3,10X,'REFERENCE JULIAN DATE')

Value	Line	Column	Format	Variable
Julian date of first record of solar and geomagnetic parameters	1	1-20	F20.3	AJDREF

Record D2

Value	Line	Column	Format	Variable
Header line	2	2-80	A	

Record D3

FORTRAN format (1X,3I4,3F15.0,F20.2)

Value	Line	Column	Format	Variable
Four digit year.	3-end	2-5	I4	IY
Two digit month.	3-end	6-9	I4	IM
Day of the month	3-end	10-13	I4	ID
90 day average F10.7 cm solar flux (10^4 Jansky)	3-end	14-28	F15.0	FA3
Daily average F10.7 cm solar flux (10^4 Jansky)	3-end	29-43	F15.0	FA
Geomagnetic index A_p	3-end	44-58	F15.0	AP
Number of days since the date of the first set of solar and geomagnetic parameters.	3-end	59-78	F20.2	TSOLT(NTSOLT)

Record D3 is repeated once for each set of solar and geomagnetic data contained in the solar and geomagnetic data file.

End Identifier: `#END SOLAR AND GEOMAGNETIC DATA ECHO`

Section 6. SURFACE NORMAL DEFINITIONS

Section Identifier: `#SURFACE NORMAL DEFINITIONS`

Record E1

FORTRAN format (I5,20X,'NAZEL')

Value	Line	Column	Format	Variable
The number of satellite surface normals to be read in.	1	1-5	I5	NAZEL

Record E2

Value	Line	Column	Format	Variable
Header lines	2-5	2-80	A	

Record E3

FORTRAN format (I5,2X,A,F8.2,F10.2,3F10.5)

Value	Line	Column	Format	Variable
Surface index	6-end	1-5	I5	N
Name of the surface.	6-end	8-32	A25	ROWLAB
Surface normal direction angle phi (degrees) measured from the user defined Z-coordinate.	6-end	33-40	F8.2	SATEL
Surface normal direction angle theta (degrees) measured from the user defined X-coordinate toward the user defined Y-coordinate.	6-end	41-50	F10.2	SATAZ
Cartesian X component of surface normal unit vector in the zenith and heading axis set.	6-end	51-60	F10.5	SATX
Cartesian Y component of surface normal unit vector in the zenith and heading axis set.	6-end	61-70	F10.5	SATY
Cartesian Z component of surface normal unit vector in the zenith and heading axis set.	6-end	71-80	F10.5	SATZ

Record E3 is repeated once for each of the surfaces specified in record E1.

End Identifier: `#END SURFACE NORMAL DEFINITIONS`

Section 7. ORBITAL PARAMETERS

Section Identifier: `#ORBITAL PARAMETERS`

Record F1

FORTRAN format (I10,10X,'DATA SETS NORBE ON FILE'/1X,A)

Value	Line	Column	Format	Variable
Number of data sets in orbit parameter file	1	1-10	I10	NORBE
Name of orbit parameter file	2	2-79	A	ONAME

Record F2

Value	Line	Column	Format	Variable
Header lines	3-5	2-80	A	

Record F3

FORTRAN format (F20.6,F15.5,2I10,F10.5,E15.4/E15.4,F15.3,F10.7,A4,F10.3/F15.2,I10)

Value	Line*	Column	Format	Variable
Julian epoch date of orbital elements	6+3n	1-20	F20.6	AJDZSC
Time step size in days for LOP.	6+3n	21-35	F15.5	STEPDSC
Number of time steps for LOP.	6+3n	36-45	I10	NSTDSC
Element type flag. 0 to indicates mean orbital elements. 1 to indicates osculating orbital elements.	6+3n	46-55	I10	IORBSC
The drag coefficient of the satellite.	6+3n	56-65	F10.5	CDSCC
The drag area of the satellite (km^2).	6+3n	66-80	1PE15.4	AREASC
The satellite mass (kg).	7+3n	1-15	1PE15.4	AMASSC
Semimajor axis (km).	7+3n	16-30	0PF15.3	ORBSC(1,N)
Eccentricity.	7+3n	31-40	F10.7	ORBSC(2,N)
Inclination of orbit (degrees).	7+3n	41-50	F10.3	ORBSC(3,N)
Longitude of ascending node (degrees).	7+3n	51-60	F10.3	ORBSC(4,N)
Argument of perigee (degrees).	7+3n	61-70	F10.3	ORBSC(5,N)
Mean anomaly (degrees).	7+3n	71-80	F10.3	ORBSC(6,N)
Time step (seconds) for ASAP.	8+3n	1-15	F15.2	STEPSSC
Number of steps for ASAP.	8+3n	16-25	I10	NSTSSC

*Line numbers are calculated with n=1 to NORBE.

Record F3 is repeated once for each of the surfaces specified in record F1.

End Identifier: `#END ORBITAL PARAMETERS`

Section 8. FLUX AND FLUENCE

Section Identifier: `#FLUX AND FLUENCE MEAN ORBITAL PARAMETERS`

Record G1

FORTRAN format (I10,I10,10X,'# OF INPUT DATES, TOTAL # OF SURFACES')

Value	Line	Column	Format	Variable
Number of input dates. The output sequence beginning with record G2 is repeated for each input date.	1	1-10	I10	NDAY
Number of surface normals + 2 (constant ram facing direction and constant 90 deg, to ram facing direction)	1	11-20	I10	NAZEL+2

Note: Unlike the other records, record G1 is only repeated once.

Record G2

FORTRAN format (F20.7,2X,5I4,F7.2,5X,'JDATE AND DATE ASAP END')

Value	Line	Column	Format	Variable
End date (Julian) of fluence calculation	2	1-20	F20.7	FLXDAY(1,N)
End year	2	23-26	I4	BDATE(1)
End month	2	27-30	I4	BDATE(2)
End day	2	31-34	I4	BDATE(3)
End hour	2	35-38	I4	BDATE(4)
End minute	2	39-42	I4	BDATE(5)
End second	2	43-49	F7.2	BDATE(6)

Notes: (1) In special cases, the variable is EDATE instead of BDATE;
(2) Calendar date and times are UTC.

Record G3

FORTRAN format (F20.7,10X,'CUMULATIVE DAYS EXPOSURE')

Value	Line	Column	Format	Variable
Time in cumulative days	3	1-20	F20.7	CUMDA

Note: Calendar date and times are UTC.

Record G4

FORTRAN format (F20.7,2X,5I4,F7.2,5X,'JDATE AND DATE ASAP END')

Value	Line	Column	Format	Variable
End date (Julian) of ASAP run	4	1-20	F20.7	FLXDAY(2,N)
End year	4	23-26	I4	EDATE(1)
End month	4	27-30	I4	EDATE(2)
End day	4	31-34	I4	EDATE(3)
End hour	4	35-38	I4	EDATE(4)
End minute	4	39-42	I4	EDATE(5)
End second	4	43-49	F7.2	EDATE(6)

Note: Calendar date and times are UTC.

Record G5

FORTRAN format (F20.7,2X,5I4,F7.2,5X,'JDATE AND DATE ASAP START')

Value	Line	Column	Format	Variable
Start date (Julian) of ASAP run	5	1-20	F20.7	FLXDAY(1,N)
Start year	5	23-26	I4	BDATE(1)
Start month	5	27-30	I4	BDATE(2)
Start day	5	31-34	I4	BDATE(3)
Start hour	5	35-38	I4	BDATE(4)
Start minute	5	39-42	I4	BDATE(5)
Start second	5	43-49	F7.2	BDATE(6)

Record G6

FORTRAN format (I10,20X,'#POINTS IN ASAP RUN')

Value	Line	Column	Format	Variable
Number of points in ASAP routine	6	1-10	I10	NPOINT

Record G7

FORTRAN format (E12.3,2E12.3,10X,'AVG, MAX, MIN AO DEN (#/CM**3)')

Value	Line	Column	Format	Variable
Average atomic oxygen density (#/cm^3)	7	1-12	E12.3	ODENS
Maximum atomic oxygen density (#/cm^3)	7	13-24	E12.3	ODMAX
Minimum atomic oxygen density (#/cm^3)	7	25-36	E12.3	ODMIN

Record G8

FORTRAN format (3F12.2,10X,'AVG, MAX, MIN TEMPERATURE (K)')

Value	Line	Column	Format	Variable
Average temperature (°K)	8	1-12	F12.2	TEMPAV
Maximum temperature (°K)	8	13-24	F12.2	TEMPMAX
Minimum temperature (°K)	8	25-36	F12.2	TEMPMIN

Record G9

FORTRAN format (3F12.2,10X,'AVG, MAX, MIN ALTITUDE (KM)')

Value	Line	Column	Format	Variable
Average altitude (km)	9	1-12	F12.2	AVALT
Maximum altitude (km)	9	13-24	F12.2	AVAMAX
Minimum altitude (km)	9	25-36	F12.2	AVAMIN

Record G10

FORTRAN format (3F12.4,10X,'AVG, MAX, MIN ABS SPEED (KM/S)')

Value	Line	Column	Format	Variable
Average absolute satellite speed (km/s)	10	1-12	F12.4	VSAV
Maximum absolute satellite speed (km/s)	10	13-24	F12.4	VSMAX
Minimum absolute satellite speed (km/s)	10	25-36	F12.4	VSMIN

Record G11

FORTRAN format (3F12.4,10X,'AVG, MAX, MIN REL SPEED (KM/S)')

Value	Line	Column	Format	Variable
Average satellite speed, relative to the atomosphere (km/s)	11	1-12	F12.4	VFAV
Maximum satellite speed, relative to the atomosphere (km/s)	11	13-24	F12.4	VFMAX
Minimum satellite speed, relative to the atomosphere (km/s)	11	25-36	F12.4	VFMIN

Relative velocity is the vehicle velocity minus the velocity of the atmosphere. Vehicle and atmospheric velocity vectors must both be defined in the same coordinate system for the determination of relative velocity. This is described in detail in section 3.1.5.

Record G12

Value	Line	Column	Format	Variable
Header lines	12-15	2-80	A	

Record G13

FORTRAN format (I4,1X,A,2F8.2,F10.1,1PE13.2,E11.2)

Value	Line*	Column	Format	Variable
Surface index	16+n	1-4	I4	I
Name of the surface. The last two surfaces face constant ram direction and 90° to constant ram direction.	16+n	6-30	A25	ROWLAB
Surface normal direction angle theta (degrees) measured from the user defined X-axis. Column is blank for last 2 entries.	16+n	31-38	F8.2	SATAZ
Surface normal direction angle phi (degrees) measured from the user defined Z-axis. Column is blank for last 2 entries.	16+n	39-46	F8.2	SATEL
Average incidence angle (degrees)	16+n	47-56	F10.1	ANGINC
Average flux (#/cm^2/s)	16+n	57-69	E13.2	FLUNCE(I,N,1)
Fluence at date of fluence calculation (record G2) (#/cm^2)	16+n	70-80	E11.2	FLUNCE(I,N,2)

*Line numbers are calculated with n=1 to NAZEL+2.

Record 13 is repeated for each surface specified in record G1.

Record G14

Value	Line
Three blank lines	17+n to 19+n

End Identifier: `#END FLUX AND FLUENCE MEAN ORBITAL PARAMETERS`

APPENDIX C

APPENDIX C SOLAR AND GEOMAGNETIC DATA

The solar and geomagnetic data used by the MSIS-86 atmospheric model called by the orbit routine is contained in the solar and geomagnetic data file. For this file, it is necessary to know the 10.7 cm radio flux (90 day average and daily average) and the geomagnetic index A_p for dates during the mission. Past measurements of these values have been made by the National Geophysical Data Center, and models to predict future values are available from NASA Goddard and NASA Marshall. One can obtain this data using anonymous File Transfer Protocol (FTP) over Internet. Historical data from Goddard is recommended because it contains an 81-day mean that can be used as the 90-day mean data in the solar and geomagnetic data file. However, the Goddard model does not predict the geomagnetic index A_p. (**Important:** the indices A_p and a_p are not the same! A_p is the arithmetic mean of the day's eight a_p values.) For A_p predictions, use the data provided by NASA Marshall.

C.1 NASA GODDARD DATA

NASA Goddard provides a service called EnviroNET. You can access this over the Internet by telnet to envnet.gsfc.nasa.gov (IP #128.183.104.16). EnviroNET is a fairly user-friendly program that will guide you through its options with a set of menus. First, log in using the account name **envnet** and password **henniker**. Enter user information. From the appropriate menu, choose **I** for Interactive models. Then choose the F10.7 Datafile Output Available model. Use **R** to run the model, and input parameters as described in the sections C.1.1 and C.1.2.

C.1.1 Observed (Historical) Solar-Geophysical Parameters

Observed/Historical solar-geophysical parameters are also available from the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) for use as input to various analysis models. They include: daily observations of the 10.7 cm solar flux (F10.7), geomagnetic index (A_p) and sunspot number RZ; 3-hourly geomagnetic indices (K_p and a_p); and, 81-day mean of the 10.7 cm solar flux. A sample copy of a file generated from the model is attached at the end of this section.

NASA GSFC provides the following description of their monthly product:

```
The National Geophysical Data Center provides the observations here with no
restrictions on their use.  Please contact us at the address below with your
comments and questions about the form and the content of this information
product or about the measurements themselves.

NATIONAL GEOPHYSICAL DATA CENTER
Solar-Terrestrial Physics Division (E/GC2)
325 Broadway
Boulder, Colorado 80303 USA
Telephone: (303) 497-6346   Telex: 592811 NOAA MASC BDR

                              OTTAWA 2800 MHz SOLAR FLUX
The sun emits radio energy with a slowly varying intensity.  This radio flux,
which originates from atmospheric layers high in the sun's chromosphere and
low in its corona, changes gradually from day-to-day, in response to the
number of spot groups on the disk.  Radio intensity levels consist of
emission from three sources:  from the undisturbed solar surface, from
developing active regions, and from short-lived enhancements above the daily
level.  Solar flux density at 2800 megaHertz has been recorded routinely by
radio telescope near Ottawa since February 14, 1947.  Each day, levels are
determined at local noon (1700 GMT) and then corrected to within a few
```

percent for factors such as antenna gain, atmospheric absorption, bursts in progress, and background sky temperature. The fluxes from the entire solar disk are at a frequency of 2800 megaHertz (10.7 cm wavelength) in units of 10 to the -22 Joules/second/square meter/Hertz.

Besides being useful to spacecraft and payload designers in predicting electromagnetic interference, this information is also used as inputs for other EnviroNET models.

INPUTS
------

1) STARTING YEAR: must be a valid integer in the Historical data range.

2) STARTING DAY: must be an integer between 1 and 365.
(366 for Leap years).

3) ENDING YEAR: must be a valid integer in the Historical data range.

4) ENDING DAY: must be an integer between 1 and 365.
(366 for Leap years).

OUTPUTS
----

1) F107C: is the current solar radio flux for the input day, adjusted to 1 AU. Measurements are taken at 1700 UT daily, at the 10.7 cm wavelength, and expressed in units of 10E-22 Watts/meter sq/Hertz (which are also expresed as 10E4 Janskys (Jy)). Observations began on February 14, 1947. From that date through December 31, 1973, the fluxes given here don't reflect the revisions Ottawa made in 1966. This model's F107C output can be used as an input to the MSIS-86 model, where it is called "current flux." It can also be used as an input to the Marshall Engineering Thermosphere (MET) model.

2) F107M: is the mean value of the solar flux for the input day, taken over an 81-day (three solar rotation period) period. It is also used as an input to the MSIS-86 model, where it is called "average flux". The data is given in units of 10E-22 Watts/meter sq/hertz.

3) RZ: is the current sunspot number. Records contain the Zurich number through December 31, 1980, and the International Brussels number thereafter. This output may be used as an input to the IRI model.

4) Kp: is a three-hour planetary average index of geomagnetic activity. The subscript "p" means planetary and designates a global magnetic activity index. The following 13 observatories, which lie between 46 and 63 degrees north and south geomagnetic latitude, now contribute to the planetary indices: Lerwick (UK), Eskdalemuir (UK), Hartland (UK), Ottawa (Canada), Fredericksburg (USA), Meannook (Canada), Sitka (USA), Eyrewell (New Zealand), Canberra (Australia), Lovo (Sweden), Rude Skov (Denmark), Wingst (Germany), and Witteveen (The Netherlands).

Kp is in 28 steps from 0 (quiet) to 9 (greatly disturbed) with fractional parts expressed in thirds of a unit. A K-value equal to 2.7, for example, means 2 and 2/3 or 3-; a K-value equal to 3.0 means 3 and 0/3 or 3 exactly; and a K-value equal to 3.3 means 3 and 1/3 or 3+. Values increment in the following format -- 0, 0+, 1-, 1, 1+, 2-, 2, 2+, up to 9. The arithmetic mean of the K values scaled at the 13 observatories listed above gives Kp. K indices isolate solar particle effects on the earth's magnetic field; over a 3-hour period, they classify into disturbance levels the range of variation of the more unsettled horizontal field component. Each activity level relates almost logarithmically to its corresponding disturbance amplitude. Three-hour indices discriminate conservatively between true magnetic field perturbations and the quiet-day variations produced by ionospheric currents.

5) ap: The a-index ranges from 0 to 400 and represents a K-value converted to a linear scale in gammas (nanoTeslas)--a scale that measures equivalent disturbance amplitude of a station at which K=9 has a lower limit of 500 gammas. In geomagnetic indices, "a" refers to amplitudes measured over a 3-hour period.

6) Ap: Planetary equivalent daily amplitude--the arithmetic mean of the day's eight ap values. This index of geomagnetic activity isused as an input to the MSIS-86 model, where it is called "magnetic index Ap."

Sample file

```
                                    Historical Output
  Year    Day    Hour    F107C    F107M        RZ         Kp        ap        AP
==========================================================================================
  1993     1      0      118.3    132.9        46         2.0        7.0      10.0
  1993     1      3      118.3    132.9        46         3.3       18.0      10.0
  1993     1      6      118.3    132.9        46         3.0       15.0      10.0
  1993     1      9      118.3    132.9        46         2.0        7.0      10.0
  1993     1     12      118.3    132.9        46         2.0        7.0      10.0
  1993     1     15      118.3    132.9        46         2.0        7.0      10.0
  1993     1     18      118.3    132.9        46         2.0        7.0      10.0
  1993     1     21      118.3    132.9        46         3.0       15.0      10.0
  1993     2      0      117.4    133.0        37         3.3       18.0      24.0
  1993     2      3      117.4    133.0        37         3.3       18.0      24.0
  1993     2      6      117.4    133.0        37         3.3       18.0      24.0
  1993     2      9      117.4    133.0        37         4.7       39.0      24.0
  1993     2     12      117.4    133.0        37         4.0       27.0      24.0
  1993     2     15      117.4    133.0        37         4.0       27.0      24.0
  1993     2     18      117.4    133.0        37         4.0       27.0      24.0
  1993     2     21      117.4    133.0        37         3.7       22.0      24.0
  1993     3      0      120.6    132.6        36         5.3       56.0      33.0
  1993     3      3      120.6    132.6        36         5.0       48.0      33.0
  1993     3      6      120.6    132.6        36         4.0       27.0      33.0
  1993     3      9      120.6    132.6        36         4.3       32.0      33.0
  1993     3     12      120.6    132.6        36         3.3       18.0      33.0
  1993     3     15      120.6    132.6        36         4.3       32.0      33.0
  1993     3     18      120.6    132.6        36         4.0       27.0      33.0
  1993     3     21      120.6    132.6        36         3.7       22.0      33.0
  1993     4      0      117.1    132.2        52         5.3       56.0      31.0
  1993     4      3      117.1    132.2        52         3.3       18.0      31.0
  1993     4      6      117.1    132.2        52         3.7       22.0      31.0
  1993     4      9      117.1    132.2        52         4.3       32.0      31.0
  1993     4     12      117.1    132.2        52         4.7       39.0      31.0
  1993     4     15      117.1    132.2        52         3.7       22.0      31.0
  1993     4     18      117.1    132.2        52         4.0       27.0      31.0
  1993     4     21      117.1    132.2        52         4.3       32.0      31.0
  1993     5      0      120.8    131.9        66         3.3       18.0      17.0
  1993     5      3      120.8    131.9        66         3.7       22.0      17.0
  1993     5      6      120.8    131.9        66         3.0       15.0      17.0
```

1993	5	9	120.8	131.9	66	3.7	22.0	17.0
1993	5	12	120.8	131.9	66	3.3	18.0	17.0
1993	5	15	120.8	131.9	66	2.3	9.0	17.0
1993	5	18	120.8	131.9	66	3.0	15.0	17.0
1993	5	21	120.8	131.9	66	3.0	15.0	17.0
1993	6	0	125.8	131.5	84	3.3	18.0	16.0
1993	6	3	125.8	131.5	84	3.7	22.0	16.0
1993	6	6	125.8	131.5	84	3.0	15.0	16.0
1993	6	9	125.8	131.5	84	2.7	12.0	16.0
1993	6	12	125.8	131.5	84	3.0	15.0	16.0
1993	6	15	125.8	131.5	84	3.0	15.0	16.0
1993	6	18	125.8	131.5	84	3.3	18.0	16.0
1993	6	21	125.8	131.5	84	3.0	15.0	16.0
1993	7	0	126.3	131.3	81	2.7	12.0	23.0
1993	7	3	126.3	131.3	81	3.7	22.0	23.0
1993	7	6	126.3	131.3	81	2.3	9.0	23.0
1993	7	9	126.3	131.3	81	4.0	27.0	23.0
1993	7	12	126.3	131.3	81	2.7	12.0	23.0
1993	7	15	126.3	131.3	81	4.0	27.0	23.0
1993	7	18	126.3	131.3	81	4.7	39.0	23.0
1993	7	21	126.3	131.3	81	4.7	39.0	23.0

C.1.1 Forecast (Predicted) Solar-Geophysical Parameters, Solar Cycle

Solar-cycle forecasts of solar-geophysical parameters are also available from the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) for use as input to predictions models of orbital lifetime, etc. They include mean monthly predictions of the 10.7 cm solar flux ($F_{10.7}$) and the geomagnetic indices (K_p and a_p). This entire product is revised or updated monthly. A sample copy of a file generated from the model is attached at the end of this section.

NASA GSFC provides the following description with their product:

```
The authors bear no responsibility for the resultant use or misuse of the
predicted solar data. For questions or comments about the predicted data,
contact the author below:

Kenneth H. Schatten
Code 910.1 NASA.GSFC
Greenbelt, MD 20771
Telephone: (301) 286-3831


FOR REFERENCES TO THE PREDICTION TECHNIQUE, SEE:

                Schatten and Sofia, Geophys. Res. Lett., 14, 632, 1987, or
                Schatten et al., Geophys. Res. Lett., 5, 411, 1978.

INPUTS
------

1) STARTING YEAR: must be a valid integer in the predicted data range.

2) STARTING MONTH: must be an integer between 1 and 12.

3) ENDING YEAR: must be a valid integer in the predicted data range.
```

4) ENDING MONTH: must be an integer between 1 and 12.

OUTPUTS

1) F107: provides the predicted monthly mean smoothed estimate of future solar radio flux. This attempts an extension into the future of the PENTICTON 10.7 CM FLUX solar radio telescope data tuned to 10.7 cm wavelength (published by NOAA in their solar-geophysical data bulletins).

2) Kp: measure of the monthly mean estimated planetary index of geomagnetic activity.

3) ap: measure of the weighted planetary geomagnetic index. This index shows a large natural variability associated with geomagnetic storm which the user should be aware of.

```
                                Predicted Output
   Year     Month    F107 (monthly mean) Kp (monthly mean)  ap (monthly mean)
==============================================================================
   1994       1           115.0              6.0              78.0
   1994       2           111.0              6.0              77.0
   1994       3           110.0              5.7              74.0
   1994       4           108.0              5.7              73.0
   1994       5           106.0              5.7              72.0
   1994       6           102.0              5.7              70.0
   1994       7           101.0              5.7              68.0
   1994       8            98.0              5.7              68.0
   1994       9            96.0              5.7              67.0
   1994      10            95.0              5.7              66.0
   1994      11            94.0              5.7              66.0
   1994      12            92.0              5.7              65.0
   1995       1            91.0              5.7              64.0
   1995       2            90.0              5.7              64.0
   1995       3            89.0              5.7              63.0
   1995       4            88.0              5.7              62.0
   1995       5            87.0              5.7              63.0
   1995       6            87.0              5.7              62.0
   1995       7            85.0              5.7              62.0
   1995       8            86.0              5.3              61.0
   1995       9            84.0              5.7              62.0
   1995      10            84.0              5.3              61.0
   1995      11            85.0              5.3              61.0
   1995      12            83.0              5.3              61.0
   1996       1            83.0              5.3              61.0
   1996       2            83.0              5.3              61.0
   1996       3            83.0              5.3              61.0
   1996       4            83.0              5.3              61.0
   1996       5            83.0              5.3              61.0
   1996       6            83.0              5.3              61.0
   1996       7            83.0              5.3              61.0
   1996       8            83.0              5.3              61.0
   1996       9            83.0              5.3              61.0
   1996      10            83.0              5.3              61.0
   1996      11            83.0              5.3              61.0
   1996      12            83.0              5.3              61.0
```

C.2 NASA MARSHALL DATA

Solar-cycle forecasts of solar-geophysical parameters are available from the National Aeronautics and Space Administration (NASA) George C. Marshall Space Flight Center (MSFC) for use as input to predictions models of orbital lifetime, etc. They include 13-month smoothed predictions of the 10.7 cm solar flux ($F_{10.7}$) and the geomagnetic index (A_p). The most recent forecast product can be obtained via Internet by anonymous FTP to SAIL1.MSFC.NASA.GOV (IP #128.158.1.100); use anonymous for name and real identification for password. Only one file is available: transfer it to your account. The entire forecast product is revised or updated monthly. A sample copy of a file is attached at the end of this section.

NASA MSFC provides the following description with their monthly forecast product:

> Our best estimate for cycle 22 smooth 10.7 cm solar flux is computed using a linear regression method over solar cycles 9 - 21 and is considered the most likely estimate we would expect in the future based on the most recent observed data. The 97.7 and 2.3 percentiles for the current solar cycle 22 are based on deviation distributions of observed and predicted cycles 9 - 21. Both the estimates and the inputs from the data base to the linear regression method represent smoothed values over a 13-month period. We also show data for a mean cycle which is the statistical mean of the previous cycles 9 - 21 and only included to compare observed values with mean values.
>
> For the purpose of establishing an updated statistical estimate of future solar activity, September 1986 is used for the 10.7 cm solar flux minimum of cycle 22 and December 1986 the A_p initialization epoch. The best estimate for the duration of cycle 22 is 11 years, based on the mean of the periods for cycles 1 - 21. The +2 sigma values of the duration of a cycle over the data base ranges from approximately 9 - 13 years so that the forthcoming actual date of minimum and maximum may vary from the estimated values. It should be recognized that there is a possibility that the actual solar activity can exceed the envelopes presented here. The changes of orbital density due to variations in the daily $F_{10.7}$ and the 3-hourly A_p inputs required for the atmospheric model are not represented by the smoothed statistical estimates given in these tables. This dynamic component of the total density level cannot be projected into the future with any acceptable degree of statistical confidence using the existing techniques.
>
> The cycle 23 long-range estimate is based on the observed solar cycle 1 - 21 data base. The 50 percentile is the mean of cycles 1 -21. The upper and lower bounds are from the distribution of the standard

error deviations of the mean linear regression estimates of cycles 1 - 21. The epoch date for the start of cycle 23 is assumed to be 11 years after the start of cycle 22.

Sample file

```
FORECAST SOLAR-GEOPHYSICAL PARAMETERS -- SOLAR CYCLE 22

1      TIME             10.7 CM SOLAR FLUX   F10.7       GEOMAGNETIC INDEX   AP
0                    BEST           PERCENTILE                   PERCENTILE
                   ESTIMATE  97.7%    MEAN     2.3%    97.7%      50%      2.3%
                                      CYCLE

    1993.4170   JUN   113.4     115.4     108.9     111.9      15.4      14.9      14.5
    1993.5004   JUL   112.0     116.1     107.4     108.3      15.6      14.9      14.3
    1993.5836   AUG   110.0     116.4     105.8     104.2      16.0      14.8      13.9
    1993.6670   SEP   107.5     115.3     104.0      99.7      16.6      14.8      13.3
    1993.7504   OCT   105.5     115.6     102.6      96.4      17.4      14.6      12.2
    1993.8336   NOV   104.3     116.6     101.5      93.8      17.9      14.5      11.3
    1993.9170   DEC   103.5     117.0     100.7      90.1      18.7      14.6      11.1
    1994.0004   JAN   103.1     117.2     100.3      89.1      19.5      14.8      10.8
    1994.0836   FEB   102.5     117.9      99.7      87.9      19.5      14.8      10.5
    1994.1670   MAR   101.8     119.0      99.0      87.3      19.6      14.7      10.3
    1994.2504   APR   101.1     119.2      98.1      87.6      19.8      14.5      10.3
    1994.3336   MAY    99.7     118.0      97.0      88.0      20.2      14.4      10.1
    1994.4170   JUN    97.7     116.6      95.5      86.6      20.7      14.3       9.5
    1994.5004   JUL    95.7     114.5      94.1      84.6      21.5      14.3       8.9
    1994.5836   AUG    94.2     111.8      92.9      82.8      22.2      14.3       8.8
    1994.6670   SEP    93.3     110.4      91.9      81.5      22.6      14.4       9.1
    1994.7504   OCT    92.4     108.9      90.9      81.0      22.9      14.4       9.0
    1994.8336   NOV    91.2     106.4      89.6      79.9      22.8      14.4       9.0
    1994.9170   DEC    89.9     107.1      88.3      77.9      22.4      14.4       9.2
    1995.0004   JAN    88.2     107.6      87.0      75.8      21.4      14.3       9.3
    1995.0836   FEB    86.7     107.0      85.8      72.6      20.6      14.2       9.4
    1995.1670   MAR    85.4     106.8      84.8      70.5      19.9      14.2       9.4
    1995.2504   APR    84.2     106.4      83.9      70.0      19.7      14.3       9.2
    1995.3336   MAY    83.4     104.8      83.2      69.6      19.4      14.3       9.3
    1995.4170   JUN    82.7     103.9      82.6      69.1      19.9      14.3       9.7
    1995.5004   JUL    82.2     104.2      82.1      68.1      20.3      14.3       9.8
    1995.5836   AUG    81.6     103.4      81.4      68.7      20.4      14.1      10.0
    1995.6670   SEP    80.8     101.5      80.7      68.5      20.5      14.0      10.5
    1995.7504   OCT    80.0      99.7      79.9      68.3      20.5      13.9      10.0
    1995.8336   NOV    79.2      97.9      79.2      68.2      20.1      13.7       9.9
    1995.9170   DEC    78.7      96.3      78.7      68.4      19.8      13.6       9.6
    1996.0004   JAN    78.3      95.0      78.2      68.5      19.3      13.5       9.5
    1996.0836   FEB    77.7      93.4      77.5      68.4      18.6      13.5       9.7
    1996.1670   MAR    77.0      91.7      76.9      68.3      17.7      13.4       9.5
    1996.2504   APR    76.4      90.1      76.3      68.1      16.8      13.3       9.8
    1996.3336   MAY    75.7      88.5      75.6      68.0      16.2      13.2      10.1
    1996.4170   JUN    75.1      87.0      75.0      67.9      16.4      13.1       9.9
    1996.5004   JUL    74.5      85.5      74.4      67.8      16.6      13.0      10.0
    1996.5836   AUG    73.9      84.0      73.9      67.7      16.8      12.9      10.0
    1996.6670   SEP    73.4      82.6      73.3      67.6      17.1      12.8      10.1
    1996.7504   OCT    72.8      81.3      72.8      67.5      17.1      12.7      10.1
    1996.8336   NOV    72.3      80.0      72.3      67.4      16.4      12.3       9.8
    1996.9170   DEC    71.9      78.8      71.8      67.3      15.7      11.9       9.5
    1997.0004   JAN    71.4      77.7      71.4      67.2      15.0      11.5       9.2
    1997.0836   FEB    71.0      76.7      71.0      67.2      14.3      11.2       8.9
    1997.1670   MAR    70.7      75.8      70.6      67.1      13.7      10.8       8.6
    1997.2504   APR    70.3      75.1      70.3      67.0      13.1      10.5       8.4
    1997.3336   MAY    70.1      74.4      70.1      67.0      12.5      10.2       8.2
    1997.4170   JUN    69.9      73.9      69.9      67.0      12.1       9.9       7.9
```

1997.5004	JUL	69.7	73.5	69.7	66.9	11.7	9.7	7.8
1997.5836	AUG	69.6	73.3	69.6	66.9	11.3	9.5	7.6

FORECAST SOLAR-GEOPHYSICAL PARAMETERS -- SOLAR CYCLE 23

1 TIME		10.7 CM SOLAR FLUX F10.7			GEOMAGNETIC INDEX AP		
0		PERCENTILE			PERCENTILE		
		97.7%	50%	2.3%	97.7%	50%	2.3%
1997.6670	SEP	73.2	69.6	66.9	11.1	9.4	7.5
1997.7504	OCT	73.4	69.7	66.9	10.9	9.3	7.5
1997.8336	NOV	74.0	70.0	67.0	10.9	9.3	7.4
1997.9170	DEC	74.5	70.3	67.1	11.1	9.3	7.4
1998.0004	JAN	74.8	70.7	67.0	11.4	9.4	7.6
1998.0836	FEB	75.6	71.1	67.0	11.5	9.4	7.6
1998.1670	MAR	76.5	71.5	67.1	11.6	9.6	7.7
1998.2504	APR	77.8	72.2	67.2	11.7	9.8	7.7
1998.3336	MAY	79.3	72.8	67.3	11.8	9.9	7.6
1998.4170	JUN	81.5	73.6	67.3	11.8	10.0	7.6
1998.5004	JUL	83.9	74.5	67.6	12.1	10.2	7.6
1998.5836	AUG	86.6	75.6	67.4	12.4	10.2	7.7
1998.6670	SEP	89.3	76.9	67.8	12.8	10.3	7.9
1998.7504	OCT	91.4	78.4	68.0	13.2	10.5	8.0
1998.8336	NOV	93.8	80.0	67.7	14.0	10.5	8.0
1998.9170	DEC	97.4	82.0	68.1	15.0	10.7	8.1
1999.0004	JAN	102.8	84.0	68.1	15.6	11.0	8.3
1999.0836	FEB	109.8	86.5	67.9	15.8	10.9	8.4
1999.1670	MAR	116.9	89.1	68.4	16.3	11.2	8.3
1999.2504	APR	123.9	91.6	67.6	17.3	11.5	8.4
1999.3336	MAY	129.9	94.3	67.8	18.3	12.0	8.3
1999.4170	JUN	135.6	97.4	69.0	18.6	12.2	8.4
1999.5004	JUL	143.0	100.7	69.2	18.7	12.1	8.7
1999.5836	AUG	151.6	103.9	68.5	18.5	11.8	9.1
1999.6670	SEP	159.6	107.2	68.3	18.2	11.8	9.3
1999.7504	OCT	168.2	110.6	67.7	18.0	11.9	9.7
1999.8336	NOV	178.0	113.5	68.8	18.3	12.3	9.5
1999.9170	DEC	186.6	116.1	70.8	18.3	12.2	9.3
2000.0004	JAN	191.0	118.4	68.1	17.5	12.6	9.5
2000.0836	FEB	193.4	120.7	70.4	17.0	12.8	10.1
2000.1670	MAR	196.4	123.1	72.4	17.3	12.7	9.8
2000.2504	APR	199.7	125.9	71.0	17.3	12.7	9.8
2000.3336	MAY	205.5	129.2	72.5	18.4	12.8	9.7
2000.4170	JUN	211.9	132.4	73.3	19.8	13.0	10.1
2000.5004	JUL	214.6	135.2	72.0	19.8	13.1	9.9
2000.5836	AUG	217.6	137.5	73.8	19.8	13.1	10.1
2000.6670	SEP	223.6	139.3	72.3	20.0	13.4	10.4
2000.7504	OCT	227.4	140.8	71.9	20.2	13.7	10.3
2000.8336	NOV	229.1	142.5	73.6	20.6	13.4	10.4
2000.9170	DEC	231.4	144.1	74.8	20.7	12.9	10.6
2001.0004	JAN	233.2	145.3	75.4	20.8	12.7	10.6
2001.0836	FEB	236.5	146.4	74.8	21.0	13.5	10.6
2001.1670	MAR	240.5	146.9	72.6	21.4	13.5	10.5
2001.2504	APR	242.7	147.0	75.9	21.9	13.5	10.7
2001.3336	MAY	242.0	146.8	76.0	22.0	13.0	10.9
2001.4170	JUN	240.9	145.9	75.4	20.8	12.8	10.6
2001.5004	JUL	242.5	145.3	73.1	19.9	12.6	10.3
2001.5836	AUG	243.0	145.2	72.5	19.6	12.2	10.5
2001.6670	SEP	239.8	145.3	75.0	19.1	11.9	10.7
2001.7504	OCT	235.5	144.9	72.9	19.1	12.0	10.8
2001.8336	NOV	231.5	143.9	74.3	18.9	12.1	11.0
2001.9170	DEC	230.4	143.0	78.0	18.7	12.3	10.7
2002.0004	JAN	231.1	142.4	76.4	18.5	12.5	10.9
2002.0836	FEB	230.0	142.1	76.8	18.5	12.5	10.7
2002.1670	MAR	227.7	142.3	78.8	18.2	13.5	10.3

2002.2504	APR	226.1	142.4	80.2	18.1	13.4	10.6
2002.3336	MAY	225.7	142.2	84.4	18.6	13.9	11.3
2002.4170	JUN	224.7	142.0	84.8	19.1	14.2	11.4
2002.5004	JUL	223.7	141.6	84.8	19.5	14.3	11.3
2002.5836	AUG	221.6	140.6	88.6	20.2	14.2	11.2
2002.6670	SEP	217.0	139.2	89.3	20.8	14.1	11.5
2002.7504	OCT	213.4	138.6	90.7	21.2	14.3	11.7
2002.8336	NOV	210.2	138.6	92.7	21.0	14.1	11.5
2002.9170	DEC	205.0	138.2	95.5	20.3	14.3	11.7
2003.0004	JAN	200.5	137.7	94.2	20.6	14.1	12.0
2003.0836	FEB	195.7	136.4	95.3	21.7	14.3	12.2
2003.1670	MAR	194.1	134.9	97.0	22.5	14.3	12.0
2003.2504	APR	193.4	133.4	98.1	22.5	14.6	11.5
2003.3336	MAY	189.9	131.5	97.1	22.1	14.2	11.3
2003.4170	JUN	185.5	129.6	96.7	21.5	14.0	11.3
2003.5004	JUL	180.6	127.8	96.7	21.3	13.9	11.3
2003.5836	AUG	176.4	126.5	97.0	21.9	14.0	11.2
2003.6670	SEP	174.4	125.3	96.4	22.9	13.8	11.1
2003.7504	OCT	172.6	124.0	97.8	23.3	13.9	11.1
2003.8336	NOV	167.2	122.1	97.9	23.2	13.9	11.2
2003.9170	DEC	159.8	120.0	96.6	23.1	13.9	11.3
2004.0004	JAN	154.3	117.8	94.4	22.9	14.2	10.8
2004.0836	FEB	152.2	115.9	94.5	22.0	14.2	10.9
2004.1670	MAR	150.5	114.0	94.3	21.9	14.1	11.2
2004.2504	APR	147.6	111.9	92.7	22.0	14.2	11.5
2004.3336	MAY	144.4	110.3	90.1	22.3	14.7	11.7
2004.4170	JUN	140.3	108.8	90.3	22.4	15.0	11.3
2004.5004	JUL	136.0	107.4	89.0	22.3	15.3	11.3
2004.5836	AUG	130.9	105.7	87.0	21.5	15.5	11.3
2004.6670	SEP	123.5	104.0	86.5	20.9	15.5	11.3
2004.7504	OCT	118.1	102.5	86.9	21.0	15.0	11.2
2004.8336	NOV	118.5	101.4	84.4	21.4	14.7	11.2
2004.9170	DEC	120.0	100.7	83.3	22.0	14.9	11.4
2005.0004	JAN	120.7	100.2	81.8	21.8	14.5	11.4
2005.0836	FEB	121.5	99.7	81.2	21.8	13.7	11.3
2005.1670	MAR	122.5	98.9	81.4	22.0	13.1	11.3
2005.2504	APR	122.6	98.1	81.1	22.3	12.4	11.2
2005.3336	MAY	121.2	96.9	80.2	22.6	12.1	11.3
2005.4170	JUN	119.7	95.5	77.5	23.3	12.7	10.9
2005.5004	JUL	117.4	94.0	75.4	24.0	13.0	11.1
2005.5836	AUG	114.5	92.8	74.4	24.5	13.6	11.1
2005.6670	SEP	113.1	91.9	74.0	24.7	13.6	11.5
2005.7504	OCT	111.4	90.8	73.4	24.6	13.6	11.1
2005.8336	NOV	109.7	89.6	73.6	24.3	13.6	11.6
2005.9170	DEC	109.8	88.3	73.4	23.4	13.6	11.4
2006.0004	JAN	109.9	87.0	72.3	22.6	13.2	11.2
2006.0836	FEB	109.0	85.8	73.3	21.9	13.4	11.1
2006.1670	MAR	108.6	84.8	72.0	21.6	13.9	11.1
2006.2504	APR	108.1	83.9	70.9	21.2	13.9	11.3
2006.3336	MAY	106.4	83.2	70.7	20.9	14.0	11.1
2006.4170	JUN	105.4	82.6	70.3	20.4	13.9	10.4
2006.5004	JUL	105.7	82.0	70.5	19.6	13.2	9.8
2006.5836	AUG	104.9	81.4	70.0	19.6	12.8	9.5
2006.6670	SEP	102.9	80.7	69.8	19.7	13.2	9.2
2006.7504	OCT	101.2	79.9	70.6	19.4	13.0	8.9
2006.8336	NOV	99.5	79.2	70.4	19.0	12.9	9.0
2006.9170	DEC	98.0	78.7	70.2	18.5	12.7	9.1
2007.0004	JAN	96.7	78.1	69.1	17.8	12.7	9.8
2007.0836	FEB	95.7	77.6	69.6	16.9	13.0	10.5
2007.1670	MAR	95.6	77.0	68.9	16.4	13.3	10.7
2007.2504	APR	96.2	76.7	69.2	16.6	13.5	10.3
2007.3336	MAY	96.4	76.5	68.8	16.8	13.4	9.9
2007.4170	JUN	95.4	76.3	68.9	17.0	13.4	9.6
2007.5004	JUL	93.6	76.1	68.4	17.3	13.2	9.2

2007.5836	AUG	92.1	75.8	67.8	17.6	12.6	8.9
2007.6670	SEP	90.5	75.5	68.2	17.5	11.9	9.1
2007.7504	OCT	89.0	75.2	68.4	17.3	11.9	9.3
2007.8336	NOV	88.0	74.9	67.9	16.8	11.8	9.1
2007.9170	DEC	86.4	74.8	68.0	16.0	11.5	9.2
2008.0004	JAN	89.0	75.0	68.1	14.6	11.5	9.1
2008.0836	FEB	93.7	75.3	68.2	13.5	11.5	9.5
2008.1670	MAR	97.2	75.5	68.3	13.6	11.3	8.9
2008.2504	APR	100.0	75.8	69.0	13.3	11.0	8.5
2008.3336	MAY	104.7	76.2	68.1	12.9	10.8	8.4
2008.4170	JUN	111.5	76.7	68.7	12.6	10.7	8.4
2008.5004	JUL	118.1	77.4	68.0	12.3	10.6	8.3
2008.5836	AUG	125.1	78.2	67.4	11.7	10.4	8.6

C.2 NOAA NGDC DATA

Observed solar-geophysical parameters are available from the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC) for use as input to various analysis models. They include daily observations of the 10.7 cm solar flux ($F_{10.7}$) and geomagnetic index (A_p). The data will be available in the near future via Internet by anonymous FTP to MERIDIAN.NGDC.NOAA.GOV (IP #192.149.148); use anonymous for name and real identification for password. Meanwhile, the data is accessible via TELNET to MERIDIAN.NGDC.NOAA.GOV (IP #192.149.148.109) and can be either extracted or printed. Use the directions provided in the NEWUSER.DOC file to select and transfer the required data file, and obtain the data format in the LENHART.DOC file. A sample copy of a file is shown below.

Sample file

```
OBSERVED SOLAR-GEOPHYSICAL PARAMETERS -- 1993

 93 1 121771620333020202020030193  7 18 15  7  7  7  7 15 100.63 46118.30
 93 1 221771733333347404040037303 18 18 18 39 27 27 27 22 241.26 41117.40
 93 1 321771853504043334340037340 56 48 27 32 18 32 27 22 331.36 38120.60
 93 1 421771953333743473740043333 56 18 22 32 39 22 27 32 311.36 52117.10
 93 1 521772033373037332330030253 18 22 15 22 18  9 15 15 170.94 71120.80
 93 1 621772133373027303033330250 18 22 15 12 15 15 18 15 160.94 84125.80
 93 1 721772227372340274047472870 12 22  9 27 12 27 39 39 231.15 81126.30
 93 1 821772333272020233737737233 18 12  7  7  9 22 22 22 150.84 89128.60
 93 1 921772440273323333332727243 27 12 18  9 18 18 12 12 160.94 94124.50
 93 110217725334060404030101026 3 18 27 80 27 27 15  4  4 251.26100127.70
 93 111217726202313335340374026 0  7  9  5 18 56 27 22 27 211.15 91127.40
 93 112217727403327202030231320 7 27 18 12  7  7 15  9  5 120.73 94135.60
 93 1132178 1201313202733204719 3  7  5  5  7 12 18  7 39 120.73 96136.60
 93 1142178 2374727333733334028 7 22 39 12 18 22 18 18 27 221.15 69128.80
 93 1152178 3333020272330273722 7 18 15  7 12  9 15 12 22 140.84 58121.90
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 93 9 62186213027232727173027207 15 12  9 12 12  6 15 12 120.73 14 80.20
 93 9 72186221330231020171027150  5 15  9  4  7  6  4 12  80.42 12 79.60
 93 9 82186233723131710101323147 22  9  5  6  4  4  5  9  80.42 12 80.20
 93 9 921862413 3101313131713 97  5  2  4  5  5  5  6  5  50.21 16 80.10
 93 910218625 71713101317 310 90  3  6  5  4  5  6  2  4  40.21  9 80.10
 93 9112186262310 71717131723127  9  4  3  6  6  5  6  9  60.31 12 79.80
 93 91221862713 3201323333357197  5  2  7  5  9 18 18 67 160.94  9 79.50
 93 9132187 15777736357605343483 67179154 94 67 80 56 32 911.87 10 81.10
 93 9142187 25030504037433333317 48 15 48 27 22 32 18 18 281.26 10 82.60
 93 9152187 34037372730202723240 27 22 22 12 15  7 12  9 160.94  9 85.60
 93 9162187 417131013202023 7123  6  5  4  5  7  7  9  3  60.31 23 89.00
 93 9172187 5 71720101010 713 93  3  6  7  4  4  4  3  5  40.21 19 85.90
93 9182187 6 7171317 7 7 7 7 80  3  6  5  6  3  3  3  3  40.10 19 86.00
 93 9192187 72013101713 7 0 7 87  7  5  4  6  5  3  0  3  40.10 14 85.00
 93 9202187 8 713173737434050243  3  5  6 22 22 32 27 48 211.15 13 80.30
 93 9212187 9532310 717272720183 56  9  4  3  6 12 12  7 140.84 14 80.60
 93 922218710172720171010 717123  6 12  7  6  4  4  3  6  60.31 14 79.80
 93 923218711 3 0 31030203050147  2  0  2  4 15  7 15 48 120.73 16 82.00
 93 9242187124017272730334040253 27  6 12 12 15 18 27 27 181.05 23 90.00
 93 9252187132020173030272727197  7  7  6 15 15 12 12 12 110.63 43 96.50
 93 9262187142333233020131323180  9 18  9 15  7  5  5  9 100.52 43106.80
 93 9272187153327201717202717177 18 12  7  6  6  7 12  6  90.52 43104.90
 93 928218716 310 71720303027143  2  4  3  6  7 15 15 12  80.42 52111.70
 93 9292187172013274040505037277  7  5 12 27 27 48 48 22 241.26 48116.80
 93 9302187184043272013132050227 27 32 12  7  5  5  7 48 181.05 40120.90
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 9310 3218721 0 310 710172720 93  0  2  4  3  4  6 12  7  50.21 87124.80
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 9310112188 24033334343533037313 27 18 18 32 32 56 15 22 281.26 65102.30
 9310122188 34037332740332027257 27 22 18 12 27 18  7 12 181.05 56 97.30
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9310152188 613 71013 7 7 3 3 63  5  3  4  5  3  3  2  2  30.10 52 93.50
9310162188 71313131010171320110  5  5  5  4  4  6  5  7  50.21 56 90.30
9310172188 8333010 710172023150 18 15  4  3  4  6  7  9  80.42 38 89.40
9310182188 92033131017171010130  7 18  5  4  6  6  4  4  70.31 37 86.70
9310192188102730172010102327163 12 15  6  7  4  4  9 12  90.52 44 88.10
9310202188111 7 710 3 7132013 90  6  3  4  2  3  5  7  5  40.21 63 93.50
93102121881217232020177 3 7113  6  9  7  7  6  3  2  3  50.21 66 94.20
9310222188134040272020273033237 27 27 12  7  7 12 15 18 160.94 61 91.30
9310232188142033401723203023207  7 18 27  6  9  7 15  9 120.73 61 91.40
9310242188154323171710272317177 32  9  6  6  4 12  9  6 100.63 52 90.60
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9310292188204023171327271330190 27  9  6  5 12 12  5 15 110.73 21 90.50
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93103121882210 3201717302323143  4  2  7  6  6 15  9  9  70.42 25 90.10
9311 1218823302317233030302020315  9  6  9 15 15 15  7 110.73 10 90.00
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9311 3218825 3 0 7 713233360147  2  0  3  3  5  9 18 80 150.84 18 92.40
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9311 5218827403353474343434334727 18 56 39 32 32 32 32 341.36 30 94.80
9311 62189 1372743434037404331022 12 32 32 27 22 27 32 261.26 33 94.90
9311 72189 2372733373743374329322 12 18 22 22 32 22 32 231.15 31 93.50
9311 82189 3372723302733433325322 12  9 15 12 18 32 18 170.94 33 90.20
9311 92189 4303323272017233020315 18  9 12  7  6  9 15 110.73 23 88.70
9311102189 53030302027272710200 15 15 15  7 12 12 12  4 120.73 25 88.20
9311112189 6133317171710 7 7120  5 18  6  6  6  4  3  3  60.31 14 87.00
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9311132189 8 717201327272317150  3  6  7  5 12 12  9  6  80.42 21 92.20
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APPENDIX D

APPENDIX D ORBIT LIBRARY

This appendix describes four missions which have been modeled using FLUXAVG version 2.0 and their input and output files, which are included on the tape of software associated with this manual. Two of the missions are historical, LDEF and EOIM3; and two are predictive, ACESS and SSF. Each mission is briefly described below.

Table D1 lists the files for the four missions. The files for each mission are in separate subdirectories of directory `orblib`. The following conventions have been used to name the files. The files beginning with `run.fluxavg.` are scripts to run FLUXAVG using the input files for the mission. All program control files contain the sequence `.in` in their names. All orbit files contain the sequence `orbinp` in their names. All solar/geomagnetic files contain the sequence `solgeo.` in their names. All mission files contain the sequence `.mission` in their names. All standard output files contain the sequence `.out` in their names.

D.1 ALL COMPOSITES EXPERIMENTAL SPACECRAFT STRUCTURE (ACESS)

FLUXAVG was used to predict atomic oxygen exposure on unshielded surfaces for one year to the ACESS satellite. This satellite will fly in a Sun-synchronous orbit. In the example given, the orbit plane was assumed to be parallel to a vector from the center of the Earth to the Sun. Mean solar and geomagnetic activity was assumed with daily and 90-day average F10.7 values set equal. The mission was chosen to run from July 1, 1995, to July 16, 1996. The ACESS satellite was modeled as an octagonal cylinder with its axis oriented radially outward from the center of the earth. Because the sides of ACESS are symmetric in this model, only half of them were modeled. A single set of mean conventional orbit elements was used for orbit propagation throughout the mission. These orbit elements model an elliptical orbit with 461 km perigee and 1800 km apogee. One-day average fluxes and fluences were calculated every 15 days. All files for ACESS are in subdirectory `acess`.

D.2 ENERGETIC OXYGEN INTERACTION WITH MATERIALS 3 (EOIM3)

FLUXAVG was used to calculate the true ram and side atomic oxygen fluences for the EOIM3 experiment which flew on the STS-46 mission. EOIM3 was exposed to atomic oxygen for 42 hours starting at 10:30 GMT August 6, 1992. Actual F10.7 and a_p values at mission time were used. Because observed orbital elements for the Space Shuttle were unavailable, the orbit was modeled as circular with approximately 225 km average altitude. FLUXAVG was run to call ASAP to calculate fluxes approximately 16 times per orbit throughout the mission. All files for EOIM3 are on subdirectory `eoim3`.

D.3 LONG DURATION EXPOSURE EXPERIMENT (LDEF)

Atomic oxygen fluxes and fluences for LDEF were previously calculated (refs. D1 and D2) using a computer code called FLUXAVO, which was specifically designed to make this calculation. This program determined fluxes and accumulated fluences using a point-by-point calculation at 5.57 minute intervals for the entire 2106 day mission. Orbit positions were derived from NORAD observations of LDEF.

We have recalculated the LDEF fluxes using the revised model FLUXAVG version 2.0, which is designed to allow a more flexible input of orbital and environmental data. This model uses osculating orbit elements derived from the NORAD orbit positions and velocities. FLUXAVG calculates fluences for intervals of time starting with each NORAD observation. The calculation is based on a periodically determined mean orbit flux. We have recalculated the mean orbit flux at 7-day intervals between each NORAD observation.

The results of these two calculations are in satisfactory agreement as shown in table D2. All files for the FLUXAVG version 2.0 LDEF mission calculation are on subdirectory `ldef`.

D.4 SPACE STATION FREEDOM (SSF)

FLUXAVG was used to model atomic oxygen exposure for a Space Station Freedom mission from planned assembly start November 30, 1995, to October 18, 2029. Details of this calculation are given in reference D3. All files for this mission used for input to FLUXAVG and resulting output files are in subdirectory `ssf`.

Table D1
Files in the Orbit Library

These files are in directory ao_fluence/orblib

Subdirectory	File Name	Length (blocks)
acess		
	fluxavg.in_nrl	900
	fluxavg.mission_nrl16-Jul-93.4	48888
	fluxavg.out_par.mean	73156
	orbinp.nrl_par	325
	run.fluxavg.acess*	113
	solgeo.nrl_mean	928
eoim3		
	eoim3_sts46_jpl.mission15-Jul-93.1	5953
	eoim3_sts46jpl.in	824
	fluxavg.out_eoim3	8118
	orbinp.eoim3	325
	run.fluxavg.eoim3*	113
	solgeo.eoim3	406
ldef		
	fluxavg.in_ldef	1604
	fluxavg.mission_ldef12-Jan-94.3	390040
	fluxavg.out_ldef	487859
	ldef_orbinp	35226
	run.fluxavg.ldef*	109
	solgeo.dat	17632
ssf		
	fluxavg.in7	2129
	fluxavg.mission_ssf26-Apr-93.1	2452748
	fluxavg.out_ssf	2959337
	orbinp.ssf	178848
	run.fluxavg.ssf*	103
	solgeo.ssf	32074

TABLE D2
Comparison of FLUXAVG Version 2.0 LDEF Calculations with FLUAV0 (Ref. D1 & D2) Calculations Excluding Unplanned Exposure at Recovery

	Altitude range (km)		**AO Fluence (#/cm^2)**		**AO Density (#/cm^3)**
	Minimum	**Maximum**	**Ram**	**Side**	
Date and time: 4/14/84 17:27 GMT					
FLUXAVG version 2.0	470.27	482.45	1.37E19	5.54E17	2.921E7
FLUXAVO (refs. D1 and D2)	472.7	481.9	1.43E19	5.70E17	3.22E7
(FLUXAVO-FLUXAVG)/FLUXAVG			+4.4%	+2.9%	+10.2%
Date and time: 1/6/85 12:13 GMT					
FLUXAVG version 2.0	469.11	477.59	2.34E20	9.08E18	5.597E6
FLUXAVO (refs. D1 and D2)	470.5	481.7	2.42E20	9.32E18	6.16E6
(FLUXAVO-FLUXAVG)/FLUXAVG			+3.4%	+2.6%	+10.1%
Date and time: 1/16/86 06:10 GMT					
FLUXAVG version 2.0	466.66	474.94	4.06E20	1.53E19	6.828E6
FLUXAVO (refs. D1 and D2)	468.8	477.4	4.17E20	1.56E19	6.36E6
(FLUXAVO-FLUXAVG)/FLUXAVG			+2.7%	+2.0%	-6.8%
Date and time: 1/28/87 21:24 GMT					
FLUXAVG version 2.0	463.31	475.02	5.82E20	2.17E19	5.672E6
FLUXAVO (refs. D1 and D2)	465.3	475.0	5.94E20	2.19E19	5.74E6
(FLUXAVO-FLUXAVG)/FLUXAVG			+2.1%	+0.9%	+1.2%
Date and time: 1/29/88 20:52 GMT					
FLUXAVG version 2.0	459.56	470.52	8.69E20	3.24E19	1.658E7
FLUXAVO (refs. D1 and D2)	460.6	469.6	8.90E20	3.29E19	1.64E7
(FLUXAVO-FLUXAVG)/FLUXAVG			+2.4%	+1.54%	-1.1%
Date and time: 1/8/89 04:47 GMT					
FLUXAVG version 2.0	442.10	447.04	2.06E21	8.26E19	1.425E8
FLUXAVO (refs. D1 and D2)	441.7	452.3	2.17E21	8.65E19	1.39E8
(FLUXAVO-FLUXAVG)/FLUXAVG			+5.3%	+4.1%	-2.5%
Date and time: 7/24/89 03:59 GMT					
FLUXAVG version 2.0	403.77	409.80	4.28E21	1.82E20	1.761E8
FLUXAVO (refs. D1 and D2)	404.6	414.5	4.55E21	1.93E20	1.75E8
(FLUXAVO-FLUXAVG)/FLUXAVG			+6.3%	+6.04%	-0.6%
Date and time: 1/12/90 15:16 GMT					
FLUXAVG version 2.0	331.46	340.12	8.41E21	3.65E20	4.677E8
FLUXAVO (refs. D1 and D2)	329.6	345.3	9.09E21	3.93E20	5.40E8
(FLUXAVO-FLUXAVG)/FLUXAVG			+8.1%	+7.7%	+15.5%

REFERENCES

D1. R. J. Bourassa and J. R. Gillis, Atomic Oxygen Exposure of LDEF Experiment Trays, NASA Contractor Report 189627 (May 1992) and revised calculations September 1992.

D2. Errata: LDEF AO Fluence, LDEF Spaceflight Environmental Effects Newsletter, **III**, 3-4 (November 15, 1992).

D3. R. J. Bourassa and P. E. Gruenbaum, Atomic Oxygen Exposure Predictions for Space Station Freedom, Boeing Memorandum 9-5571-SGH-93-0017 (May 1993).

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One of the primary causes of material degradation in low Earth orbit (LEO) is exposure to atomic oxygen. When atomic oxygen molecules collide with an orbiting spacecraft, the relative velocity is 7 to 8 km/sec and the collision energy is 4 to 5 eV per atom. Under these conditions, atomic oxygen may initiate a number of chemical and physical reactions with exposed materials. These reactions contribute to material degradation, surface erosion, and contamination. Interpretation of these effects on materials and the design of space hardware to withstand on-orbit conditions requires quantitative knowledge of the atomic oxygen exposure environment.

Atomic oxygen flux is a function of orbit altitude, the orientation of the orbit plan to the Sun, solar and geomagnetic activity, and the angle between exposed surfaces and the spacecraft heading. We have developed a computer model to predict the atomic oxygen exposure of spacecraft in low Earth orbit. The application of this computer model is discussed in this document.

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