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A Program to Compute the Aerodynamic Solar Radiation Forces and Torques on Satellites

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Prepared by: V. Carrara

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Approved by:

J. Soul - Program Manager

B. Berridge - Director Programs

Spar Aerospace Limited

Satellite and Aerospace Systems Division

21025 Trans-Canada Highway
Ste-Anne-de-Bellevue, Quebec
Canada H9X 3R2
Telephone (514) 457-2150
Telex 05-822792

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Spar Aerospace Limited
Ste-Anne-de-Bellevue, Quebec

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Report Approval Request

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Author(s): Valdemir Carrara

Section: SASD, Systems Engineering

Approval: D. Jung (Supervisor's Signature)

Approval: J.R.G. Cox (Manager's Signature)

INGÉNIEUR · ENGINEER J.R.G. COX 4509 QUÉBEC

Approved by: Director, Product Marketing and Engineering

F. Passier

A003

Spar Aerospace Limited
Satellite and Aerospace Systems Division

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Technical Report Abstract

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Abstract – Briefly summarize objectives, methods, results, & applications. Type single spaced.

Programs to evaluate forces and torques acting on low Earth orbit satellites have been developed by SPAR since 1981 [1], [2], [3] and [4]. As these perturbations are strongly dependent on the spacecraft's geometry, a computer program that utilizes a standard method to describe the satellite shape becomes important. This work presents the ARFTS (Aerodynamic and solar Radiation Forces and Torques on Satellites) program, which uses a NASTRAN file (and hence the CAD facilities) to inform the program of the position and orientation of each surface of the spacecraft. The program supports spacecraft of varying configurations or with articulated appendages (like rotating solar arrays or dual-spin spacecraft), allowing misalignment studies (for orbit and attitude control system design) and torque-reduction analyses.

Keywords – State identifying terms to a maximum of five.

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1.0 INTRODUCTION

The main subject of this work was to develop a computer program that calculates the drag coefficient for a satellite of general shape, as well as the aerodynamic and solar radiation forces and torques. The constraints imposed on the program were the fast running, user's easy interaction and relatively large precision.

The developed program automatically propagates the orbit and calculates the forces and torques for each point. The outputs are the aerodynamic forces and torques as functions of time (the user can choose the reference system in which he wishes the forces and torques to be presented), as well as the linear and angular impulses utilized for orbit and attitude control specifications, respectively. Others applications can include the spacecraft geometry analysis, torque reduction studies, drag and solar pressure coefficient determinations, and numeric orbit and attitude propagations.

The results are presented in several files, including the atmospheric local density and temperature (dynamic model), geocentric coordinates of the spacecraft (latitude, longitude and altitude), direction of incidence of the atmospheric molecules, sun-aspect angles and an orbit resume of the variation in the linear and angular momenta of the satellite.

The spacecraft geometry must be provided by the user, through a data file, assuring independence of the program with the satellite shape and increasing its applicability. The format of the spacecraft geometry data file is compatible with the NASTRAN (NASA STRuctured ANalysis), largely utilized in finite elements calculations, for satellite thermal control analysis and structure design. It makes it easy for the user to change the geometry (and check it) using the CAD facilities [5].

To avoid loss of generality, the program was constructed in a way to support non-rigid satellites, such as dual-spin spacecraft or sun-oriented solar arrays. The geometry of the appendages is also given in the geometry data file, but the position, orientation and angular-ratio of each appendage can be changed without changing the spacecraft configuration. It is particularly useful in misalignment and torque reduction studies as well as the analysis of forces and torques in satellites with variable geometry.

As the forces and torques acting on satellites can be difficult or easy to check depending on the coordinate system where they are plotted, Section 2 defines all the systems utilized by the program. Section 3 describes the program structure without the employed theory, which is readily available in the literature ([4], [6] and [7], for example). Section 4 includes an extensive description of the input elements to the program and the output files. The conclusions of the work are presented in Section 5. Finally, the program is applied to the RADARSAT satellite as an example, shown in Appendix A. Appendix B presents the main program and subroutines listing.

2.0 SYSTEM OF COORDINATES

Due to the large number of coordinate systems used by the program, a brief description of each frame is presented here :

1- Inertial system. This system has the X axis pointing to the vernal equinox and the Z axis passing through the Earth's North Pole. Its center coincides with the Earth center.

2- Ascending node system. By definition, this system is geocentric and inertial too, but it has its X axis passing through the orbit ascending node and the Z axis through the north pole. The name comes from the angle between its X axis and the inertial system X axis, as shown in Figure 2.1.

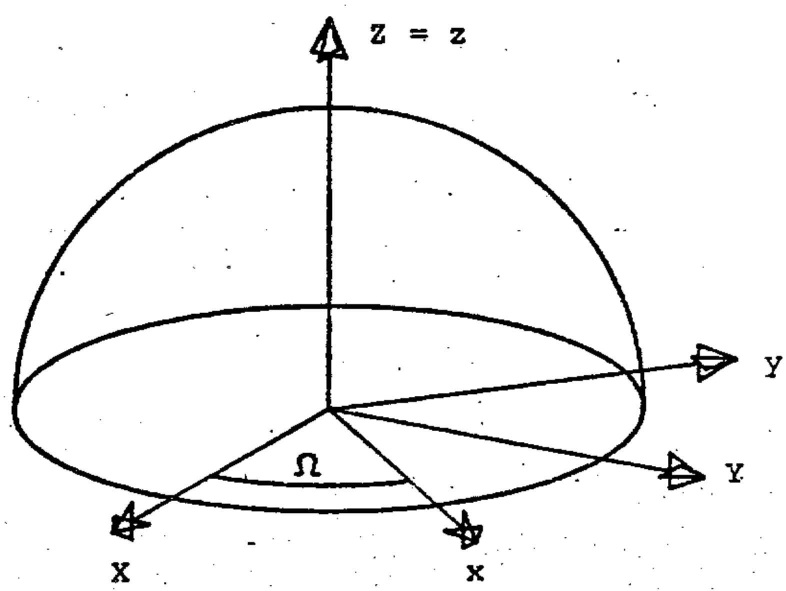

Fig 2.1. Ascending node system (xyz) and inertial system (XYZ). Ω is the orbit right ascension of the ascending node.

3- Orbit plane system. Like the last system, this system has its X axis coincident with the orbit ascending node but its Z axis normal to the orbit plane. Its center coincides with the Earth center. The orbit plane system is related to the ascending node system by a rotation about its X axis by an angle equal to the orbit inclination, as can be seen in Figure 2.2.

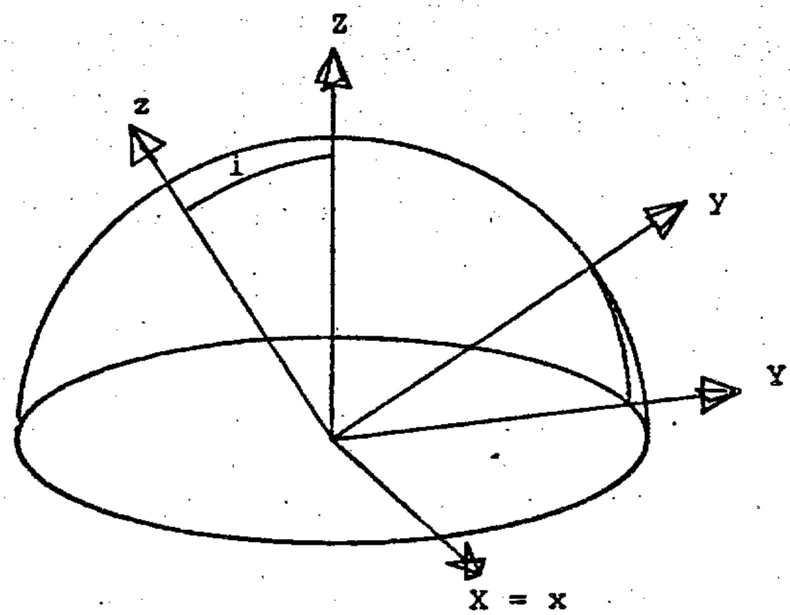

Fig. 2.2. Orbit plane system (xyz) and ascending node system (XYZ). i is the orbit inclination.

4- Orbital system. This is a non-inertial system, centered at the Earth center and with its X axis passing through the instantaneous position of the spacecraft. Its Z axis is normal to the orbit plane, as shown in Figure 2.3. The satellite velocity points towards the positive Y direction. The time-dependent true anomaly, f, relates the orbital system to the orbit plane system.

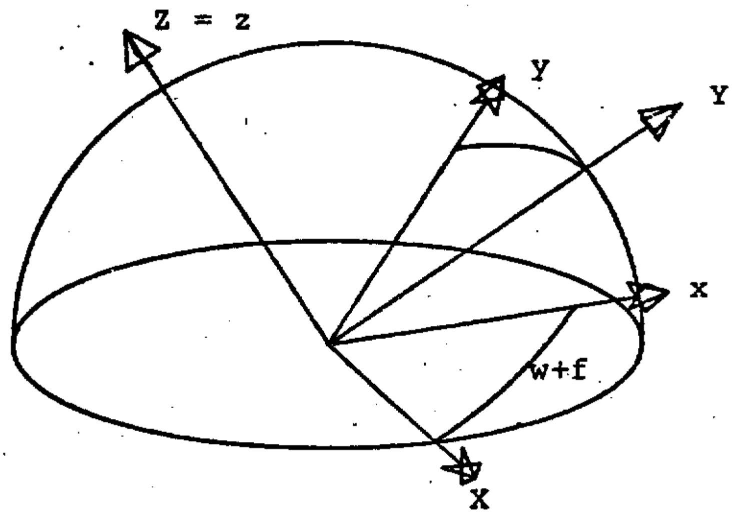

Fig. 2.3. Orbital system (xyz) and the orbit plane system (XYZ). The angle between X and x is the sum of the perigee argument w and the true anomaly f.

5- Spacecraft system at t=0. This system coincides with the spacecraft system at the origin of the time and remains inertially fixed, despite the satellite angular motion. It can be related to any one of the preceedings systems, through a X-Y-Z rotation as in Figure 2.4, with angles provided as input parameters.

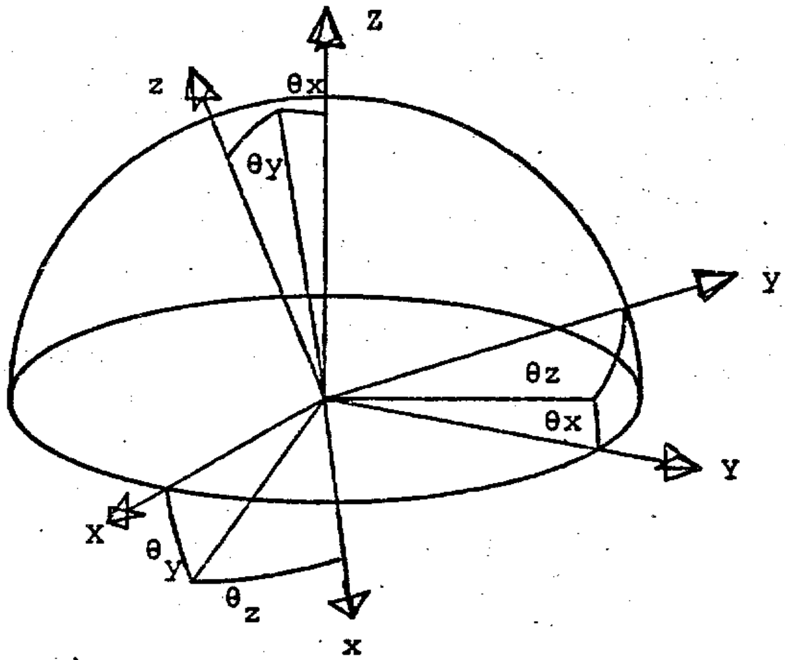

Fig. 2.4. Spacecraft system (xyz) at T=0 and the attitude related system (XYZ). The angles θx, θy and θz define the relation among the systems.

6- <u>Spacecraft system</u>. This system is fixed to the spacecraft structure and the satellite geometry, as well as the geometry of the appendages, must be described in it. The spacecraft system can also be related to all of the preceeding four systems. The relationship is a X-Y-Z rotation as in Figure 2.4, but it doesn't remain inertially fixed since the related system is not inertial (orbital system).

Systems 1 to 4 are useful for the presentation of the forces; systems 5 and 6 are prefered for the torques. The program user must specify the system in which the aerodynamic and solar radiation forces and torques are to be output.

3.0 THE PROGRAM STRUCTURE

The program was structured in a way so as to utilize only data files for both input and output. All the input parameters to the program are given in two files, containing the spacecraft geometry and the orbital data. The outputs are printed in several files, containing the results of the aerodynamic and solar radiation forces and torques, orbit propagation data, atmospheric properties, sun-angles related to the satellite body, spacecraft composition in terms of its surface elements and a resume of the linear and angular impulses over the satellite in each orbit. The inputs and outputs will be described with more detail at Section 4.

Initially, the program reads the spacecraft geometry from the appropriate data files and stores all the surface elements in arrays. Because large memory is consumed by these arrays, the program is limited to a maximum of 50 surface elements. All the necessary rotation matrices are calculated and the orbit propagation is initialized. The program uses an analytical orbit propagator which takes into account only the Earth oblateness effects. Due to the normally short time period of the orbit propagation in a typical run, this simplification of the orbit pertubations is acceptable.

For each point, the program computes the sun position, atmospheric density, mean molecular weight, and the velocity of the atmosphere. The sun position is obtained by the SUN subroutine (Kuga [8]), that employs an analytical Earth orbit propagator without corrections for the Earth-sun distance due to eccentricity. This causes an error less than 7% in the radiation forces.

The atmospheric properties are calculated by the ASDAMO subroutine (from Analytical Static and Dynamic Atmosphere MOdels), an analytical version (Lafontaine [9]) of the Jacchia's J77 model [10]. All the necessary parameters for the atmospheric model are calculated internally with exception of the exospheric temperature, a function of the daily 10.7 cm wavelength solar flux. The user must provide this data through the input file, as the other input parameters.

The sun position and the satellite velocity vectors are then rotated to the spacecraft system and a summation of the aerodynamic and solar radiation forces is made over the spacecraft main body. These vectors are rotated again to each appendage system and additional summations are performed over each appendage. The output values for this point in time are then evaluated and printed. Once a whole orbit is completed, the program outputs the net impulse per orbit. The program then continues calculations for the next orbit until the desired time period has been processed.

Care must be taken with the aerodynamic and solar radiation shadowing on the spacecraft, since the program doesn't automatically eliminate the shadowed areas from the summation. This is particularly important on concave-shape spacecrafts (i. e. when one spacecraft external surface sees others). The expressions for the elementary aerodynamic force are obtained from the assumption of total surface exposure by the flow, meaning that any other element can be in its field of view (the hemisphere above the surface), independent of the flux direction. Nevertheless, the resulting force is affected more with shadowing in the flux direction than in any other direction. For that reason it is a good aproximation to consider the aerodynamic shadowing like a solar radiation shadowing, removing the surfaces which are behind the others in the flow direction from integration. It can be done by properly eliminating the shadowed surfaces in the spacecraft geometry data file: those in the satellite velocity direction when computing the aerodynamic forces and those in the sun direction when calculating the solar radiation forces.

The main program is stored in the ARFTS.FTN file (from Aerodynamic and solar Radiation Forces and Torques on Satellites). Almost all the auxiliary routines are in the AUROT.FTN file. The atmospheric model routines are stored in the ANATM.FTN file (ANalytical ATmospheric Model). The program also utilizes some orbit propagation routines, provided by the ORBIT.FTN file and described in Kuga [8].

The default names of the input files and the extension of the output file names can be changed during the running command:

```
ARFTS,<INPUT.FILE1>,<INPUT.FILE2>,<OUTPUT EXT>
```

INPUT.FILE1 is a NASTRAN file containing all the spacecraft definition surfaces. Its default name is SATGE.DAT, from SATellite GEometry. The INPUT.FILE2 is an input file with several parameters, like orbital elements, date, the composition and properties of the surfaces in the spacecraft, the position of the satellite centre of mass, etc. Its default name is INELE.DAT (from INput ELEments). The output file extension has the DAT string as default. Nevertheless, it is useful sometimes to change the output extension, to avoid overwriting previous results when running the program. The new extension string is passed to the program by the <OUTPUT EXT> parameter of the runstring.

Figure 3.1 represents the subroutines hierarchy of the ARFTS program. Some of these routines (CONSTP, DJM, VARELK, KEPLER and SUN) came from the ORBIT.FTN file [8]. The atmospheric model comprises the ASDAMO, ASMADE, DIVARA, GEOACA, SEALAT, SEMIAN, TEMLO and AMOWEI subroutines.

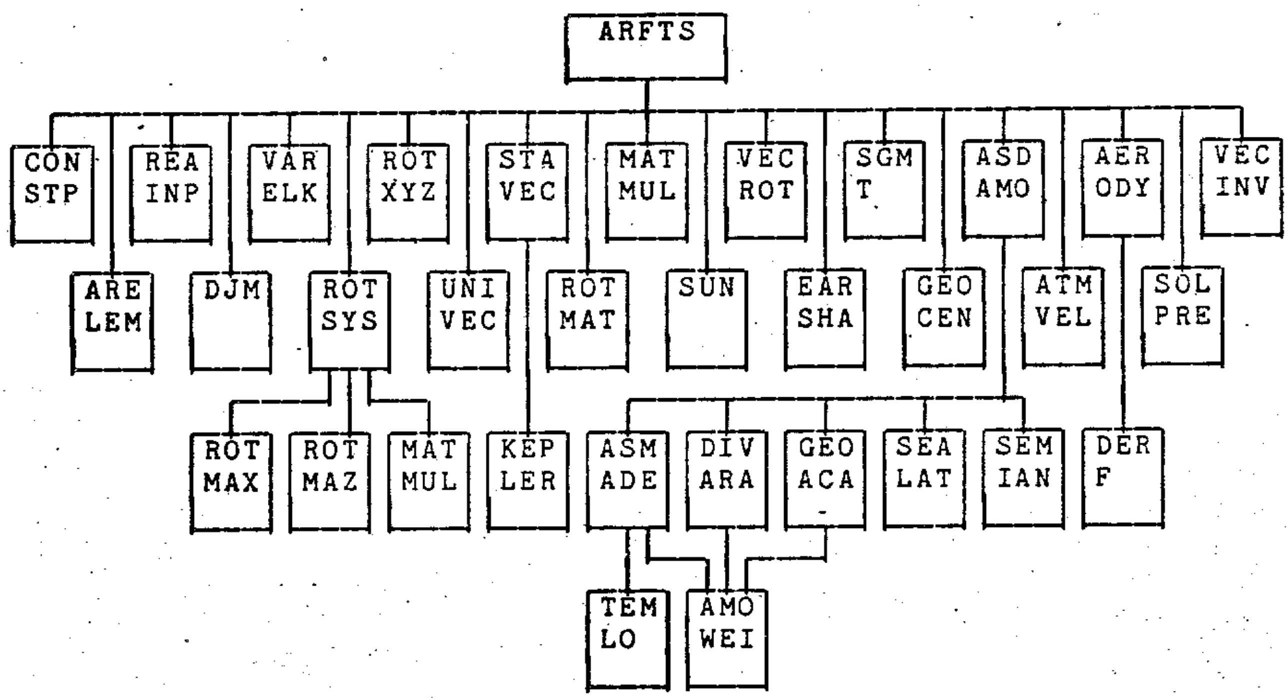

Figure 3.1. ARFTS structure.

4.0 INPUT AND OUTPUT DATA FILES

4.1 INPUT FILES DESCRIPTION

The inputs for the program are stored in two files: SATGE.DAT and INELE.DAT are the default names.

The SATGE.DAT file contains a NASTRAN description of the spacecraft geometry. The NASTRAN is a widely used language to perform structural analysis. It was chosen because it is easy to employ and it decreases the user's spent time to create a geometry description file or subroutine (as a NASTRAN file is often already available or can easily be created using CAD utilities).

As the program is interested only in the spacecraft geometry description, there are few NASTRAN commands (or cards) recognized by the program: GRID, CTRIA3, CQUAD4 and ENDDATA - the remainder are ignored. If the file contains surface definition cards other than the CTRIA3 and CQUAD4 commands, the user must modify the ARELEM subroutine in such a way as to accept the new cards.

GRID A GRID card gives the program information about the position of a spacecraft node, i. e. the three coordinates of a characteristic point of the satellite structure. A GRID card is identified by the program in the format: A8, 2I8, 3F8.2. The last variable in the 2I8 field and all the variables after the 3F8.2 field positions will be ignored, as they have no useful meaning to this program (only to the NASTRAN program). The first field, A8, must contain the "GRID" character string, starting on column 1 and filled with blanks until column 8, inclusive. The first integer in the 2I8 field is the identification number of the node, and will be used by the surface definition cards, CTRIA3 and CQUAD4. The 3F8.2 position contains the rectangular XYZ coordinates in millimeters of the node given in the spacecraft system. All the node elements are stored in an array by the program. Although the program capacity has been limited to 50 nodes, it is possible to alter this value by changing the NGRD variable of the PARAMETER statement in the ARELEM subroutine. A message error will be printed if there are more than the maximum number of nodes in the data file.

CTRIA3 A card with the string "CTRIA3" starting at column 1 is recognized by the program as a triangular surface definition. It's format must be A8 (for the alphanumeric string) and 5I8. The first integer is the identification surface number, used in the BODYAP cards of the INELE.DAT file. The second is unused. The 3 remaining values are the node identification numbers of a GRID definition card, which fix the corners of the triangular surface. Attention should be given to the sequence in which the numbers appear: the program calculates the external normal by the right-hand rule of the first, second and third node points.

CQUAD4 This card defines a quadrilateral surface of the spacecraft structure, and has the same format of a CTRIA3 card, except than a fourth node identification number must be given. The read format is then A8, 6I8. The second integer number and the numbers after the last integer field (which sometimes appears in NASTRAN files) are ignored. The surface external normal is defined, as a CTRIA3 card, by the right-hand rule of the first, second and third node points.

ENDDATA This card, with the string "ENDDATA" starting on column 1, informs the program that the end of data has been reached. It causes the program to end the surface computations or rewind the file if there are more data to be read.

Appendix A lists a sample of a SATGE.DAT file, with a NASTRAN definition geometry for the RADARSAT configuration. Nevertheless it is not a typical NASTRAN file: NASTRAN has many other commands not given there.

The surface elements are also stored in arrays as the node points. Consequently, the program capacity has been limited to 50 surface elements maximum. If more than 50 surfaces are needed to describe the spacecraft geometry, the program can be altered so as to accept additional nodes by changing the NSUR variable of the PARAMETER statement to the desired value.

The second input file, INELE.DAT, defines several input variables, described below. To make it easy for the user, the INELE.DAT definition cards have total compatibility with the NASTRAN cards. It was separated into a different file, however, as the SATGE.DAT can be the actual NASTRAN file (without change). The file comprises 10 different command cards: ORBIT, DATE, SOLFLUX, BARICEN, PROAREA, MAINSYS, APPSYS, OUTSYS, BODYAP and ENDDATA. All these cards, except the APPSYS and BODYAP cards, may appear only once in the file. If more than one card is encountered by the program, subsequent cards will be ignored. The APPSYS card, which informs the existence of spacecraft appendages to the program, appears once for each appendage. BODYAP cards define the spacecraft surface composition and properties, having as many cards as necessary to define the satellite geometry. All the cards without these names are ignored by the program, allowing the insertion of comments to the file as well as to permit data to be added or deleted by simply changing a character in the card name.

Unlike the SATGE.DAT file, all the data in the INELE.DAT file are in free format. Therefore, it isn't necessary to comment on the format of the data, only its meaning to the program. Nevertheless, the command name must be in A8 format (starting on column 1), as in SATGE.DAT file.

ORBIT — This command contains the orbital elements of the satellite. They are, respectively: perigee and apogee altitudes, in km and range of 100 to 2000 km (limit imposed by the atmospheric model constraints); orbit inclination, in degrees; right ascension of the ascending node, in degrees; perigee argument, in degrees and mean anomaly at the date, in degrees. The semi-major axis is calculated with the perigee and apogee values, using an Earth's radius of 6,378.16 km.

DATE — This card gives to the program the time for the orbital elements: month, day, year, hour, minute (integers) and second (decimal). The two last values are the time step size and the total time for the orbit propagation, both in seconds.

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SOLFLUX	The values that this card must contain are the daily solar flux at a 10.7 cm wavelength (adjusted for the correct Earth-sun distance), the averaged flux over six solar rotations (162 days approximately) and the geomagnetic activity index Kp. These values are utilized in the atmospheric properties computations. More details of how to get and utilize this data can be found in refs. [10] and [11]. In case of simulation, the same value for both the daily and the averaged solar flux must be used. Mean values are: 70 ($x10^{-22}$ $W/m^2/Hz$) at minimum solar activity and 240 ($x10^{-22}$ $W/m^2/Hz$) at maximum solar activity. The geomagnetic activity index depends on the activity in the solar corona, increasing during the solar storms (which are more frequent near the maximum activity periods). It can vary from 0.0 (during quiet days) to 9.7 (during strong solar storms), in steps of 1/3.
BARICEN	This command gives the three rectangular coordinates of the spacecraft's center of mass, in meters, in the spacecraft system.
PROAREA	This card must contain a spacecraft characteristic area in square meters to compute the aerodynamic drag coefficients. If the area is equal to the projected satellite area in the velocity direction, then the drag coefficient will be approximately 2 for high speed ratio values (low altitudes).
MAINSYS	The spacecraft system must be related to one of the frames described on Section 2, to find the spacecraft's attitude by the program. The related spacecraft frame is the first parameter in this card, corresponding to the number of the system described on Section 2. As the related frame can't be the spacecraft system itself, it is restricted to the first four systems: 1- Inertial system. 2- Ascending node system. 3- Orbit plane system. 4- Orbital system. The next parameters are, respectively: the three components of a X-Y-Z rotation relating the frame to the spacecraft system (see Fig. 2.4), in degrees and the three components of the spacecraft angular velocity relative to that system, in revolutions per minute, in the spacecraft system.

APPSYS These cards provide the relation between the spacecraft body and the appendages. For each appendage (corresponding one APPSYS card), the command must contain: the identification structure number (corresponding to that in the BODYAP cards), the three coordinates of the position, in meters, of the origin of the appendage-fixed system; the three components of the angular velocity of the appendage, in revolutions per minute and the three components of a X-Y-Z rotation, in degrees, relating the spacecraft system to the appendage orientation.

The position of the appendage-fixed system origin informs the program that the appendage is articulated at this point, with three degrees of freedom (the orientation of the appendage). As the program understands that the articulation point is fixed in both the appendage and the spacecraft's body, care must be taken if one wants to change the appendage position by simply altering the articulation point position in the APPSYS card. Sometimes is necessary to alter also the geometry description data file (SATGE.DAT) as the program adopts that geometry at the initial time (T=0).

The angular velocity of each appendage tells the program that the appendage must rotate with time. This information must be given when the spacecraft is composed by rotating counter-parts (as dual-spin) or when an Earth-pointing satellite has sun-oriented solar arrays, for example.

The last three components of the APPSYS instruct the program to reorient the appendage through a X-Y-Z rotation applied to the articulation point as shown in Figure 4.1. These angles can be used to direct the solar arrays to the sun direction before starting calculations (as a phase angle), to introduce misalignments in the appendage positions or even to reorient them for a new spacecraft's geometry.

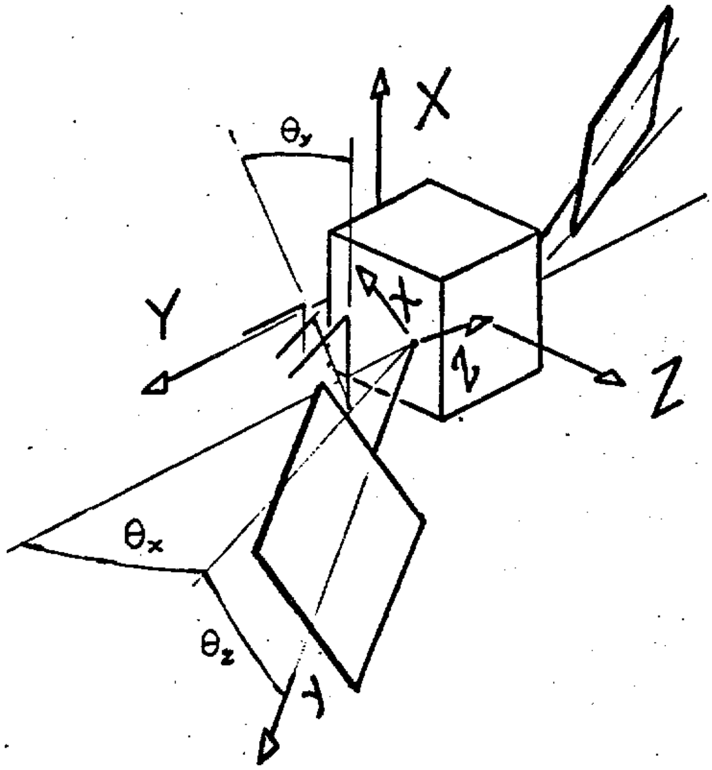

Fig. 4.1 Spacecraft body-fixed system X-Y-Z and appendage-fixed frame x-y-z with origin at the articulation point.

These parameters define a new system of coordinates (x-y-z in Figure 4.1) fixed at each appendage, with origin at the articulation point. Both the position of the articulation point and the angular velocity of the appendage must be in spacecraft system coordinates. The appendage-fixed system is then found by a translation of the spacecraft system to the articulation point, a rotation about the angular velocity direction until the calculated appendage direction and, finally, a X-Y-Z rotation to the desired appendage orientation.

Note that the appendage position is fixed in the spacecraft body, when the SATGE.DAT file is created. However, it can be oriented in other positions and rotated without changing the geometry file, by simply altering the APPSYS commands. It is useful to simulate the appendage rotation in geo-pointing satellites with sun-oriented arrays. Other applications include appendage misalignment studies and analysis of the appendage and structure composition, with the aim of minimizing disturbance torques.

OUTSYS — The OUTSYS card defines the coordinate system in which the user wants the results printed. Its parameters are, respectively, the system number for the aerodynamic force, aerodynamic torque, solar radiation force and solar radiation torque. The output systems can be (see Section 2 for frame definitions):

1- Inertial system.
2- Ascending node system.
3- Orbit plane system.
4- Orbital system.
5- Spacecraft system at t=0.
6- Spacecraft system.

BODYAP — These cards give the surface composition of the spacecraft to the program. The first parameter is the identification structure number (0 is reserved for the main body or the spacecraft itself, 1 is for the first appendage, 2 for the second and so on until 10 appendages, maximum). The second is the surface element identification number, as described in the CTRIA3 and CQUAD4 commands of the SATGE.DAT file. If the number is negative, then the surface normal will be considered to be in the opposite direction to that given in the SATGE.DAT file. The back-side of some structures like solar arrays can be composed easily in this manner. Note that each BODYAP command corresponds to one satellite surface, meaning that the surface identification number can't appear more than once in BODYAP card, except for a back-side composition (one positive and one negative). The next 7 values are the surface properties, respectively: the tangential and normal aerodynamic coefficients (see refs. [4], [6] and [7] for more details); the specular reflectivity, diffuse reflectivity and the absortion coefficient in the solar spectrum; the infra-red emissivity; and the surface temperature, in Kelvin degrees.

There is no fixed sequence for the command cards. They can be placed anywhere in the INELE.DAT file. However, the name must start in column 1 and be completed with blanks up to column 9.

4.2 OUTPUT FILES DESCRIPTION

All the most important results are printed in separated files, in order to simplify the user's analysis. The files are: "PLANE.DAT", "EXTSE.DAT", "AEROF.DAT", "AEROT.DAT", "SORAF.DAT", "SORAT.DAT", "ORBPR.DAT", "ADRAG.DAT", "SUNAN.DAT" and "ORBMO.DAT". The first and second files are the internal results computed from the SATGE.DAT file.

After reading the surface definition commands (CTRIA3 and CQUAD4), the program creates the PLANE.DAT file, storing values of the surface identification number, unit external normal, position of the center and area.

The second file, EXTSE.DAT, shows the spacecraft composition, after the BODYAP commands (see the INELE.DAT file description, in Section 4.1). The printed values are the structure number (spacecraft body must always have the 0 number), element number, unit external normal, position of the center of pressure and the element area. These results can be used to check the correct understanding of the input data.

The AEROF.DAT, AEROT.DAT, SORAF.DAT and SORAT.DAT files are, respectively, results of the: aerodynamic forces, aerodynamic torques, solar radiation forces and solar radiation torques. Just after the title, the program prints the coordinate system where the forces, torques and impulses were calculated. The first column is the time, in seconds, for all the files. The next three are the force (in N) or the torque (in Nm) and the last three are the linear (in Ns) or angular (in Nms) impulse components.

ORBPR.DAT contains data from the orbit propagation as function of the time: the orbit mean anomaly, the spacecraft geocentric distance and velocity, the longitude and latitude of the sub-satellite point, the geocentric height, and the right ascension and declination of the sun. The sun position is calculated from the date and hour of the day, using the SUN subroutine, implemented by Kuga [8,12]. This file contains also printed values of the ORBIT, DATE, SOLFLUX, BARICEN, MAINSYS, APPSYS and PROAREA commands.

The ADRAG.DAT is a table with some intermediate results of the aerodynamic force computations: the local atmospheric temperature and density, the speed ratio (the ratio between the spacecraft velocity and the most probable speed of the molecules of the atmosphere). The direction of the satellite velocity relative to the velocity of the atmosphere in the spacecraft system coordinates is also printed. Here, ALPHA is the angle between the YZ plane and the velocity direction and BETA the angle between the Y axis and the projection of the velocity direction in the plane YZ. These angles are useful to check the satellite attitude. The other values are: the spacecraft system components of the drag coefficient and the drag coefficient itself. This file also contains a resume of the input elements, as in the ORBPR.DAT file.

The SUNAN.DAT file has the sun aspect angles for each structure of the spacecraft, as a function of the time. These angles are defined in the same way as in the ADRAG.DAT file (with ALPHA being the angle between the YZ plane and the sun direction and BETA the angle between the Y axis and the projection of the sun direction in the YZ plane). These angles are in spacecraft system coordinates. They are useful to check the satellite attitude and also the appendage orientation. As for the two last files, the SUNAN.DAT contains the printed values of the input parameters.

The last output file, ORBMO.DAT is a per orbit evaluation of the forces, torques and momenta variations (the accumulated impulse over one orbit). It contains these values for each completed orbit during the propagation time, identified by the orbit number and the time when the results were calculated. For the aerodynamic and solar radiation, the minimum and maximum force and torque intensities encountered at this orbit, as well as its mean values, are printed in the coordinate system given by the OUTSYS command card. The same system is used to print the minimum, maximum, the difference between the minimum and maximum, the build-up and the total accumulated values of the linear and angular momentum variations (impulses). The minimum and maximum are the lower and the higher impulse values encountered at this orbit. Note that the impulse is always made equal zero at the beginning of a new orbit. Its difference is the maximum variation of the momentum during each orbit. The build-up values are the impulse at the end of the orbit. A small value for the build-up for impulse (relative to the difference value) means a symmetrical force or torque on this axis and, consequently, a small change in the spacecraft attitude about this axis. The accumulated value is total momentum change since the start of the simulation.

The output files are listed in Appendix A, an example of application to RADARSAT.

5.0 CONCLUSION

The aerodynamic and solar radiation are the most important low Earth orbit perturbations acting on satellites. However, depending on the spacecraft geometry, the other pertubations - gravity gradient torque, magnetic torque, etc. - can supplant the first ones. The user should compare the magnitude of these forces before making any judgement, in order to avoid neglecting important results.

As the program gives instantaneous values of the forces and torques, sometimes it will be necessary to change some of the input parameters (like the starting date, solar flux, orbital elements, etc.) so as to assure a reasonable sample of the perturbations during the mission duration.

The inability of the program to automatically remove the shadowed surfaces from integration precludes its application to some highly convex satellites. Also, the NASTRAN is not a good format to implement a shadow analysis, because it takes too much computer time to evaluate the forces for a single orbit point (it could be better to describe the spacecraft geometry by means of a subroutine, where the shadowed areas were removed from integration by the user, during the subroutine construction).

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APPENDIX A

APPLICATION TO RADARSAT

The program was applied to the dawn-dusk configuration of RADARSAT satellite [13]. It has two large solar arrays fixed on the spacecraft structure, as shown in Figure A-1, drawn with points extracted from the SATGE.DAT file. For that configuration the main origin of the torques are the spacecraft assymetry due to the Synthetic Aperture Radar (SAR) positioning, the solar array misalignments and changes in the spacecraft center of mass due to fuel consumption.

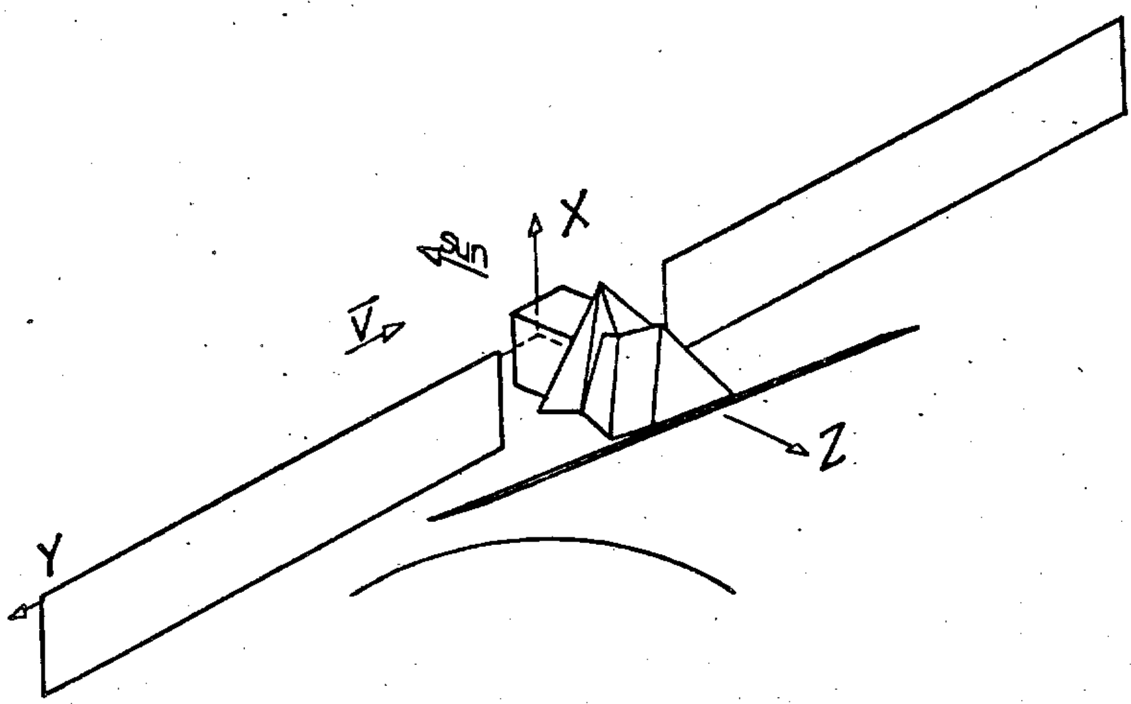

Figure A-1. RADARSAT geometry.

The input files, SATGE.DAT and INELE.DAT, are listed in Tables A-1 and A-2, respectively. The SATGE.DAT is an original NASTRAN file for RADARSAT intended for calculating solar fluxes on external surfaces. Note that the program doesn't use all the spacecraft surfaces defined in the SATGE.DAT file. In fact, as can be seen in the INELE.DAT file, the surface identification numbers 1101, 1041, 1141 and 1161 don't appear in the BODYAP commands, as they are internal surfaces. Note also that is necessary to define both sides of the solar arrays and the SAR (the 1121 and 1131 surfaces are negatives because its normal was defined as internal in the NASTRAN file). It was assumed that all the surfaces have a normal and tangential aerodynamic coefficients of 0.9 and, with exception of the solar array, a specular reflectivity of 0.8, no diffuse reflection, absorption coefficient equals to 0.2 (no transmitted radiation) and infra-red emissivity equals to 1. The specular and diffuse reflectivity of the solar array were, respectively, 0.21 and 0.0 [4]. The surface temperature was admitted to be equal to 350 K for all the surfaces (solar arrays including). Although they are fixed in the spacecraft, the solar arrays were considered as appendages, for misalignment study purposes.

Table A-1. SATGE.DAT file (obtained from a NASTRAN file).

BEGIN BULK

GRID	1000	01400.000-2875.001328.190	0
GRID	1010	0-1400.00-2875.001328.190	0
GRID	1020	0-1400.00-18915.01328.190	0
GRID	1030	01400.000-18915.01328.190	0
GRID	1040	01400.0002875.0001328.190	0
GRID	1050	01400.00018915.001328.190	0
GRID	1060	0-1400.0018915.001328.190	0
GRID	1070	0-1400.002875.0001328.190	0
GRID	1080	0-949.405-7432.445490.793	0
GRID	1090	0174.47787510.4814822.949	0
GRID	1100	0-693.9557510.4813361.504	0
GRID	1110	0-1817.84-7432.444029.347	0
GRID	1120	01050.000875.00001807.190	0
GRID	1130	01050.000875.0000-162.810	0
GRID	1140	0-1050.00875.0000-162.810	0
GRID	1150	0-1050.00875.00001807.190	0
GRID	1160	01050.000-875.0001807.190	0
GRID	1170	0-1050.00-875.0001807.190	0
GRID	1180	01050.000-875.000-162.810	0
GRID	1190	0-1050.00-875.000-162.810	0
GRID	1200	02358.972+0.0E+002057.190	0
GRID	1210	0-413.5072338.6892057.190	0
GRID	1220	0-1050.00875.00002057.190	0
GRID	1230	0-1050.00-875.0002057.190	0
GRID	1240	0-413.507-2338.692057.190	0
GRID	1250	0863.3638+0.0E+002057.190	0
GRID	1260	0-1007.671412.7943548.807	0
GRID	1270	0893.6788-135.8622418.970	0
GRID	1280	0-1209.97-1276.933669.018	0
GRID	1290	0-341.537-1276.935130.464	0
GRID	1300	01762.112-135.8623880.416	0
GRID	1310	0-139.2381412.7945010.252	0
GRID	1320	0-1050.00850.00002057.190	0
GRID	1330	0-1050.00-850.0002057.190	0

Table A-1. SATGE.DAT file (cont'd).

```
CQUAD4      1001       1    1000    1010    1020    1030+0.0E+00  +10001
+10001                +0.0E+00
CQUAD4      1011       1    1040    1050    1060    1070+0.0E+00  +10002
+10002                +0.0E+00
CQUAD4      1021       1    1080    1090    1100    1110+0.0E+00  +10003
+10003                +0.0E+00
CQUAD4      1031       1    1120    1130    1140    1150+0.0E+00  +10004
+10004                +0.0E+00
CQUAD4      1041       1    1160    1120    1150    1170+0.0E+00  +10005
+10005                +0.0E+00
CQUAD4      1051       1    1160    1180    1130    1120+0.0E+00  +10006
+10006                +0.0E+00
CQUAD4      1061       1    1130    1180    1190    1140+0.0E+00  +10007
+10007                +0.0E+00
CQUAD4      1071       1    1180    1160    1170    1190+0.0E+00  +10008
+10008                +0.0E+00
CQUAD4      1081       1    1140    1190    1170    1150+0.0E+00  +10009
+10009                +0.0E+00
CTRIA3      1091       1    1200    1210    1220+0.0E+00          +10010
+10010                +0.0E+00
CTRIA3      1101       1    1200    1220    1230+0.0E+00          +10011
+10011                +0.0E+00
CTRIA3      1111       1    1230    1240    1200+0.0E+00          +10012
+10012                +0.0E+00
CQUAD4      1121       1    1280    1290    1300    1270+0.0E+00  +10013
+10013                +0.0E+00
CQUAD4      1131       1    1270    1300    1310    1260+0.0E+00  +10014
+10014                +0.0E+00
CQUAD4      1141       1    1310    1260    1280    1290+0.0E+00  +10015
+10015                +0.0E+00
CTRIA3      1151       1    1300    1310    1290+0.0E+00          +10016
+10016                +0.0E+00
CTRIA3      1161       1    1270    1280    1260+0.0E+00          +10017
+10017                +0.0E+00
CQUAD4      1171       1    1320    1260    1270    1250+0.0E+00  +10018
+10018                +0.0E+00
CQUAD4      1181       1    1250    1270    1280    1330+0.0E+00  +10019
+10019                +0.0E+00
CQUAD4      1191       1    1330    1280    1260    1320+0.0E+00  +10020
+10020                +0.0E+00
PSHELL         1       11.000000      11.000000      1.8333330+0.0E+00
ENDDATA
```

Table A-2. INELE.DAT file for RADARSAT.

```
ORBIT     777.5 777.5 98.5 11.6 0.0 0.0
DATE      1. 1. 1993. 0. 0. 0. 60.00 6120.
SOLFLUX   180. 180. 5.
BARICEN   0.0  0.0 2.56
PROAREA   11.907
MAINSYS   4 180. 0. 0. 0. 0. 0.
APPESYS   1 0. -0.875 1.328190  0. 0. 0.  0.0  0.0  0.0
APPESYS   2 0.  0.875 1.328190  0. 0. 0.  0.0  0.0  0.0
OUTSYS    4 6 3 6
BODYAP    0  1021 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0 -1021 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1031 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1051 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1061 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1071 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1081 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1091 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1111 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0 -1121 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0 -1131 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1151 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1171 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1181 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    0  1191 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    1  1001 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    1 -1001 0.90 0.90 0.21 0.00 0.79 1.0 350.
BODYAP    2  1011 0.90 0.90 0.80 0.00 0.20 1.0 350.
BODYAP    2 -1011 0.90 0.90 0.21 0.00 0.79 1.0 350.
ENDDATA
```

The RADARSAT orbit is circular and sunsynchronous (98.5 degrees inclination) at 777.5 km altitude. An equator crossing time of 18:00 hs was adopted , with resulting right ascention of the ascending node of 11.6 degrees, at 0:00 of 1/1/1993. The RADARSAT attitude is Earth pointing, so that the orbit system best relates to the spacecraft attitude (MAINSYS command equals to 4). Nevertheless, the spacecraft system must be rotated 180 degrees about the X axis, to direct the spacecraft Y axis in the opposite direction of its velocity (the Y direction of the orbit system) as Figure A-1 shows. As there is no relative motion between the spacecraft and the orbital system, the last three components of the MAINSYS card are nulls.

For the APPSYS commands, a frame translated to the point where the solar arrays are articulated during deployment was used so that it would be possible to impose the solar array misalignments at these points. Two cases were analysed: first a nominal geometry and secondly a misaligned solar array geometry. Note that the solar arrays are fixed (i. e. non-rotating) due to the orbit geometry and hence the components of the appendage angular velocity (5th, 6th and 7th parameters of the APPSYS command) are also nulls.

Tables A-3 to A-13 list the output files for the nominal geometry. Table A-3 is the PLASE.DAT file, which contains the coordinates and size of each surface defined in the SATGE.DAT file. Table A-4, EXTSE.DAT, gives the number of each surface defined by the BODYAP commands. The 4 next tables are the aerodynamic and solar radiation forces and torques, as well as the impulses (linear for the forces and angular for the torques) equal to the summation of the product of the forces or torques and the time step.

The input variables in the INELE.DAT file are printed in a common header for the ORBPR, ADRAG and SUNAN files. As the header is strictly the same in all the files, it is shown only once, in Table A-9. ORBPR.DAT contains data from the orbit propagation, as the mean anomaly, spacecraft geocentric coordinates, etc., as indicated in Table A-10. The ADRAG.DAT output file is shown in Table A-11 with the local atmospheric properties and the drag coefficient. The sun-angles are printed in the SUNAN.DAT file, for the main body and each solar array (Table A-12). In this case the angles are the same, as the spacecraft body and the appendages coordinate system have the same orientation. Finally, Table A-13 presents the orbit resume file, ORBMO.DAT, with the maximum and minimum values for the forces, torques and impulses.

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Table A-3. PLASE.DAT file.

SPACECRAFT SURFACE ELEMENTS

INT NBR	IDENT NUMBR	EXT. NORMAL VECTOR X	Y	Z	ELEMENT POSITION (M) X	Y	Z	AREA (M2)
1	1001	0.0000	0.0000	1.0000	.0000E+00	-.1090E+02	.1328E+01	.4491E+02
2	1011	0.0000	0.0000	1.0000	.0000E+00	.1090E+02	.1328E+01	.4491E+02
3	1021	-.8564	.0872	.5089	-.8217E+00	.3902E-01	.4426E+01	.2550E+02
4	1031	0.0000	1.0000	0.0000	.0000E+00	.8750E+00	.8222E+00	.4137E+01
5	1041	0.0000	0.0000	1.0000	.0000E+00	.0000E+00	.1807E+01	.3675E+01
6	1051	1.0000	0.0000	0.0000	.1050E+01	.0000E+00	.8222E+00	.3448E+01
7	1061	0.0000	0.0000	-1.0000	.0000E+00	.0000E+00	-.1628E+00	.3675E+01
8	1071	0.0000	-1.0000	0.0000	.0000E+00	-.8750E+00	.8222E+00	.4137E+01
9	1081	-1.0000	0.0000	0.0000	-.1050E+01	.0000E+00	.8222E+00	.3448E+01
10	1091	0.0000	0.0000	1.0000	.2985E+00	.1071E+01	.2057E+01	.2773E+01
11	1101	0.0000	0.0000	1.0000	.8632E-01	.0000E+00	.2057E+01	.2983E+01
12	1111	0.0000	0.0000	1.0000	.2985E+00	-.1071E+01	.2057E+01	.2773E+01
13	1121	-.3633	.9063	.2159	.2761E+00	-.7064E+00	.3775E+01	.4590E+01
14	1131	-.4931	-.8192	.2930	.3772E+00	.6385E+00	.3715E+01	.4590E+01
15	1141	-.8564	.0872	.5089	-.6746E+00	.6793E-01	.4340E+01	.4590E+01
16	1151	.5108	.0000	.8597	.4271E+00	.6667E-06	.4674E+01	.3157E+01
17	1161	-.5108	.0000	-.8597	-.4413E+00	.6667E-06	.3212E+01	.3157E+01
18	1171	.4752	.8187	-.3224	-.7516E-01	.5317E+00	.2521E+01	.2158E+01
19	1181	.2717	-.8932	-.3582	-.1257E+00	-.5657E+00	.2551E+01	.2169E+01
20	1191	-.9943	.0712	-.0798	-.1079E+01	.3397E-01	.2833E+01	.3423E+01

Table A-5. AEROF.DAT file.

AERODYNAMIC FORCES (N) AND IMPULSES (N*S)
ORBITAL SYSTEM

TIME	FORCES			IMPULSES		
(S)	X	Y	Z	X	Y	Z
0	-.4644E-05	-.1088E-03	-.1518E-04	-.2786E-03	-.6530E-02	-.9109E-03
60	-.4508E-05	-.1052E-03	-.1471E-04	-.5491E-03	-.1284E-01	-.1794E-02
120	-.4345E-05	-.1010E-03	-.1411E-04	-.8098E-03	-.1890E-01	-.2640E-02
180	-.4159E-05	-.9627E-04	-.1341E-04	-.1059E-02	-.2468E-01	-.3445E-02
240	-.3958E-05	-.9126E-04	-.1262E-04	-.1297E-02	-.3015E-01	-.4202E-02
300	-.3746E-05	-.8610E-04	-.1179E-04	-.1522E-02	-.3532E-01	-.4909E-02
360	-.3531E-05	-.8093E-04	-.1093E-04	-.1733E-02	-.4018E-01	-.5565E-02
420	-.3319E-05	-.7593E-04	-.1007E-04	-.1933E-02	-.4473E-01	-.6169E-02
480	-.3119E-05	-.7130E-04	-.9251E-05	-.2120E-02	-.4901E-01	-.6724E-02
540	-.2941E-05	-.6723E-04	-.8496E-05	-.2296E-02	-.5304E-01	-.7234E-02
600	-.2793E-05	-.6390E-04	-.7829E-05	-.2464E-02	-.5688E-01	-.7704E-02
660	-.2679E-05	-.6139E-04	-.7258E-05	-.2624E-02	-.6056E-01	-.8139E-02
720	-.2600E-05	-.5973E-04	-.6780E-05	-.2780E-02	-.6415E-01	-.8546E-02
780	-.2553E-05	-.5884E-04	-.6379E-05	-.2934E-02	-.6768E-01	-.8929E-02
840	-.2534E-05	-.5861E-04	-.6036E-05	-.3086E-02	-.7119E-01	-.9291E-02
900	-.2537E-05	-.5889E-04	-.5725E-05	-.3238E-02	-.7473E-01	-.9634E-02
960	-.2552E-05	-.5950E-04	-.5424E-05	-.3391E-02	-.7830E-01	-.9960E-02
1020	-.2573E-05	-.6026E-04	-.5112E-05	-.3545E-02	-.8191E-01	-.1027E-01
⋮	⋮	⋮	⋮	⋮	⋮	⋮
5580	-.4349E-05	-.1042E-03	-.1309E-04	-.1252E-01	-.3159E+00	-.1273E-01
5640	-.4515E-05	-.1079E-03	-.1388E-04	-.1279E-01	-.3224E+00	-.1356E-01
5700	-.4650E-05	-.1109E-03	-.1456E-04	-.1307E-01	-.3290E+00	-.1443E-01
5760	-.4751E-05	-.1130E-03	-.1509E-04	-.1336E-01	-.3358E+00	-.1534E-01
5820	-.4812E-05	-.1142E-03	-.1547E-04	-.1365E-01	-.3427E+00	-.1627E-01
5880	-.4832E-05	-.1143E-03	-.1567E-04	-.1394E-01	-.3495E+00	-.1721E-01
5940	-.4811E-05	-.1134E-03	-.1569E-04	-.1423E-01	-.3563E+00	-.1815E-01
6000	-.4750E-05	-.1116E-03	-.1553E-04	-.1451E-01	-.3630E+00	-.1908E-01
6060	-.4653E-05	-.1088E-03	-.1520E-04	-.1479E-01	-.3695E+00	-.1999E-01
6120	-.4523E-05	-.1053E-03	-.1473E-04	-.1506E-01	-.3759E+00	-.2088E-01

Table A-6. AEROT.DAT file.

AERODYNAMIC TORQUES (N*M) AND ANGULAR IMPULSES (N*M*S)
SPACECRAFT SYSTEM

TIME	TORQUES			ANGULAR IMPULSES		
(S)	X	Y	Z	X	Y	Z
0	.3471E-04	-.4901E-05	-.8766E-05	.2083E-02	-.2941E-03	-.5260E-03
60	.3375E-04	-.4765E-05	-.8496E-05	.4108E-02	-.5800E-03	-.1036E-02
120	.3256E-04	-.4601E-05	-.8172E-05	.6062E-02	-.8560E-03	-.1526E-02
180	.3121E-04	-.4414E-05	-.7806E-05	.7934E-02	-.1121E-02	-.1994E-02
240	.2973E-04	-.4211E-05	-.7410E-05	.9717E-02	-.1374E-02	-.2439E-02
300	.2816E-04	-.3997E-05	-.6997E-05	.1141E-01	-.1613E-02	-.2859E-02
360	.2657E-04	-.3778E-05	-.6579E-05	.1300E-01	-.1840E-02	-.3254E-02
420	.2499E-04	-.3563E-05	-.6169E-05	.1450E-01	-.2054E-02	-.3624E-02
480	.2351E-04	-.3359E-05	-.5784E-05	.1591E-01	-.2255E-02	-.3971E-02
540	.2218E-04	-.3177E-05	-.5439E-05	.1724E-01	-.2446E-02	-.4297E-02
600	.2108E-04	-.3027E-05	-.5151E-05	.1851E-01	-.2628E-02	-.4606E-02
660	.2024E-04	-.2913E-05	-.4925E-05	.1972E-01	-.2802E-02	-.4902E-02
720	.1967E-04	-.2837E-05	-.4765E-05	.2090E-01	-.2973E-02	-.5188E-02
780	.1935E-04	-.2796E-05	-.4663E-05	.2206E-01	-.3140E-02	-.5467E-02
840	.1925E-04	-.2786E-05	-.4612E-05	.2322E-01	-.3308E-02	-.5744E-02
900	.1933E-04	-.2799E-05	-.4597E-05	.2438E-01	-.3476E-02	-.6020E-02
960	.1953E-04	-.2827E-05	-.4606E-05	.2555E-01	-.3645E-02	-.6296E-02
1020	.1980E-04	-.2862E-05	-.4624E-05	.2674E-01	-.3817E-02	-.6574E-02
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
5580	.3188E-04	-.4612E-05	-.8157E-05	.1081E+00	-.1408E-01	-.2246E-01
5640	.3321E-04	-.4777E-05	-.8493E-05	.1101E+00	-.1437E-01	-.2297E-01
5700	.3432E-04	-.4912E-05	-.8768E-05	.1122E+00	-.1467E-01	-.2350E-01
5760	.3516E-04	-.5012E-05	-.8972E-05	.1143E+00	-.1497E-01	-.2404E-01
5820	.3572E-04	-.5073E-05	-.9098E-05	.1164E+00	-.1527E-01	-.2458E-01
5880	.3595E-04	-.5093E-05	-.9139E-05	.1186E+00	-.1558E-01	-.2513E-01
5940	.3587E-04	-.5072E-05	-.9096E-05	.1207E+00	-.1588E-01	-.2568E-01
6000	.3548E-04	-.5011E-05	-.8973E-05	.1229E+00	-.1618E-01	-.2622E-01
6060	.3481E-04	-.4914E-05	-.8776E-05	.1250E+00	-.1648E-01	-.2674E-01
6120	.3388E-04	-.4785E-05	-.8515E-05	.1270E+00	-.1676E-01	-.2725E-01

Table A-7. SORAF.DAT file

RADIATION FORCES (N) AND IMPULSES (N*S)
ORBIT PLANE SYSTEM

TIME	FORCES			IMPULSES		
(S)	X	Y	Z	X	Y	Z
0	-.4066E-04	.9045E-04	-.5276E-03	-.2440E-02	.5427E-02	-.3165E-01
60	-.3886E-04	.8786E-04	-.5260E-03	-.4771E-02	.1070E-01	-.6322E-01
120	-.3693E-04	.8547E-04	-.5245E-03	-.6987E-02	.1583E-01	-.9469E-01
180	-.3492E-04	.8328E-04	-.5231E-03	-.9082E-02	.2082E-01	-.1261E+00
240	-.3283E-04	.8131E-04	-.5216E-03	-.1105E-01	.2570E-01	-.1574E+00
300	-.3070E-04	.7954E-04	-.5203E-03	-.1289E-01	.3047E-01	-.1886E+00
360	-.2854E-04	.7798E-04	-.5189E-03	-.1461E-01	.3515E-01	-.2197E+00
420	-.2638E-04	.7662E-04	-.5177E-03	-.1619E-01	.3975E-01	-.2508E+00
480	-.2423E-04	.7544E-04	-.5165E-03	-.1764E-01	.4428E-01	-.2818E+00
540	-.2212E-04	.7446E-04	-.5153E-03	-.1897E-01	.4874E-01	-.3127E+00
600	-.2005E-04	.7364E-04	-.5142E-03	-.2017E-01	.5316E-01	-.3435E+00
660	-.1804E-04	.7298E-04	-.5132E-03	-.2126E-01	.5754E-01	-.3743E+00
720	-.1611E-04	.7247E-04	-.5123E-03	-.2222E-01	.6189E-01	-.4051E+00
780	-.1426E-04	.7208E-04	-.5114E-03	-.2308E-01	.6621E-01	-.4358E+00
840	-.1250E-04	.7182E-04	-.5105E-03	-.2383E-01	.7052E-01	-.4664E+00
900	-.1084E-04	.7165E-04	-.5098E-03	-.2448E-01	.7482E-01	-.4970E+00
960	-.9283E-05	.7157E-04	-.5091E-03	-.2503E-01	.7912E-01	-.5275E+00
1020	-.7823E-05	.7155E-04	-.5086E-03	-.2550E-01	.8341E-01	-.5580E+00
⋮	⋮	⋮	⋮	⋮	⋮	⋮
5580	-.4956E-04	.1159E-03	-.5405E-03	.1660E-01	.6091E+00	-.2999E+01
5640	-.4918E-04	.1120E-03	-.5388E-03	.1364E-01	.6159E+00	-.3031E+01
5700	-.4854E-04	.1082E-03	-.5370E-03	.1073E-01	.6224E+00	-.3064E+01
5760	-.4767E-04	.1046E-03	-.5353E-03	.7872E-02	.6286E+00	-.3096E+01
5820	-.4657E-04	.1012E-03	-.5335E-03	.5078E-02	.6347E+00	-.3128E+01
5880	-.4529E-04	.9788E-04	-.5318E-03	.2361E-02	.6406E+00	-.3160E+01
5940	-.4382E-04	.9478E-04	-.5301E-03	-.2687E-03	.6463E+00	-.3191E+01
6000	-.4221E-04	.9186E-04	-.5284E-03	-.2801E-02	.6518E+00	-.3223E+01
6060	-.4046E-04	.8915E-04	-.5268E-03	-.5229E-02	.6571E+00	-.3255E+01
6120	-.3860E-04	.8665E-04	-.5253E-03	-.7545E-02	.6623E+00	-.3286E+01

Table A-8. SORAT.DAT file

RADIATION TORQUES (N*M) AND ANGULAR IMPULSES (N*M*S)
SPACECRAFT SYSTEM

TIME	TORQUES			ANGULAR IMPULSES		
(S)	X	Y	Z	X	Y	Z
0	-.8945E-04	-.4507E-04	.1891E-05	-.5367E-02	-.2704E-02	.1135E-03
60	-.8944E-04	-.4812E-04	.1860E-05	-.1073E-01	-.5592E-02	.2251E-03
120	-.8908E-04	-.5128E-04	.1817E-05	-.1608E-01	-.8668E-02	.3341E-03
180	-.8838E-04	-.5452E-04	.1761E-05	-.2138E-01	-.1194E-01	.4398E-03
240	-.8732E-04	-.5783E-04	.1695E-05	-.2662E-01	-.1541E-01	.5415E-03
300	-.8592E-04	-.6120E-04	.1620E-05	-.3178E-01	-.1908E-01	.6387E-03
360	-.8417E-04	-.6460E-04	.1538E-05	-.3683E-01	-.2296E-01	.7310E-03
420	-.8208E-04	-.6801E-04	.1448E-05	-.4175E-01	-.2704E-01	.8178E-03
480	-.7966E-04	-.7142E-04	.1352E-05	-.4653E-01	-.3132E-01	.8990E-03
540	-.7690E-04	-.7479E-04	.1251E-05	-.5114E-01	-.3581E-01	.9740E-03
600	-.7384E-04	-.7812E-04	.1146E-05	-.5557E-01	-.4050E-01	.1043E-02
660	-.7046E-04	-.8136E-04	.1038E-05	-.5980E-01	-.4538E-01	.1105E-02
720	-.6680E-04	-.8450E-04	.9272E-06	-.6381E-01	-.5045E-01	.1161E-02
780	-.6286E-04	-.8753E-04	.8139E-06	-.6758E-01	-.5570E-01	.1210E-02
840	-.5866E-04	-.9040E-04	.6988E-06	-.7110E-01	-.6113E-01	.1252E-02
900	-.5422E-04	-.9312E-04	.5825E-06	-.7435E-01	-.6671E-01	.1286E-02
960	-.4958E-04	-.9564E-04	.4682E-06	-.7733E-01	-.7245E-01	.1315E-02
1020	-.4475E-04	-.9797E-04	.3533E-06	-.8001E-01	-.7833E-01	.1336E-02
⋮	⋮	⋮	⋮	⋮	⋮	⋮
5580	-.7939E-04	-.2531E-04	.1593E-05	-.9500E-03	-.3089E+00	-.1191E-01
5640	-.8170E-04	-.2757E-04	.1688E-05	-.5852E-02	-.3105E+00	-.1181E-01
5700	-.8373E-04	-.2995E-04	.1768E-05	-.1088E-01	-.3123E+00	-.1170E-01
5760	-.8547E-04	-.3244E-04	.1833E-05	-.1600E-01	-.3143E+00	-.1159E-01
5820	-.8690E-04	-.3505E-04	.1878E-05	-.2122E-01	-.3164E+00	-.1148E-01
5880	-.8803E-04	-.3777E-04	.1904E-05	-.2650E-01	-.3186E+00	-.1137E-01
5940	-.8883E-04	-.4060E-04	.1910E-05	-.3183E-01	-.3211E+00	-.1125E-01
6000	-.8930E-04	-.4351E-04	.1901E-05	-.3719E-01	-.3237E+00	-.1114E-01
6060	-.8946E-04	-.4651E-04	.1877E-05	-.4255E-01	-.3265E+00	-.1103E-01
6120	-.8928E-04	-.4961E-04	.1840E-05	-.4791E-01	-.3294E+00	-.1092E-01

Table A-9. Header of the ORBPR.DAT, ADRAG.DAT and SUNAN.DAT files.

ORBITAL ELEMENTS:			
SEMI MAJOR AXIS (M)	7155660.000		
ECCENTRICITY	0.00000000		
INCLINATION (DEG)	98.500		
ASCENDING NODE (DEG)	11.600		
PERIGEE ARG. (DEG)	0.000		
MEAN ANOMALY (DEG)	0.000		
ORBITAL PERIOD (MIN)	100.400		
START TIME:			
MONTH	1		
DAY	1		
YEAR	1993		
MODIFIED JULIAN DATE	48988.5		
HOUR	0		
MINUTES	0		
SECONDS	0.000		
TIME STEP (SECONDS)	60.000		
CALCULATION TIME (S)	6120.000		
SOLAR FLUX DATA:			
SOLAR FLUX F10.7	180.00		
AVERAGED SOLAR FLUX	180.00		
GEOMAG. ACTIVITY KP	5.00		
SATELLITE CENTER OF MASS IN BODY FRAME COORDINATES:			
X AXIS (METERS)	0.00000		
Y AXIS (METERS)	0.00000		
Z AXIS (METERS)	2.56000		
REFERENCE AREA FOR DRAG COEFFICIENT:			
SATELLITE AREA (M2)	11.90700		
ATTITUDE RELATED FRAME:			
FRAME NUMBER	4 - SPACECRAFT SYSTEM		
X-Y-Z ROTATION (DEG)	180.00000	0.00000	0.00000
ANGULAR VELOCITY (RPM)	0.00000	0.00000	0.00000
APPENDAGE NUMBER 1			
APPENDAGE POSITION (M)	0.00000	-.87500	1.32819
ANGULAR VELOCITY (RPM)	0.00000	0.00000	0.00000
X-Y-Z ROTATION (DEG)	0.00000	0.00000	0.00000
APPENDAGE NUMBER 2			
APPENDAGE POSITION (M)	0.00000	.87500	1.32819
ANGULAR VELOCITY (RPM)	0.00000	0.00000	0.00000
X-Y-Z ROTATION (DEG)	0.00000	0.00000	0.00000

Table A-10. ORBPR.DAT file.

ORBIT TIME (S)	MEAN ANOM. (DEG)	GEOCENTR. DISTANCE (KM)	SATEL. VELOC. (KM/S)	ORBIT DATA LONGITUDE (DEG)	LATITUDE (DEG)	GEOCENTR. ALTITUDE (KM)	SUN R. ASCEN. (DEG)	SUN DECLI. (DEG)
0	0.00	7155.660	7.464	270.95	0.00	777.500	281.59	-23.01
60	3.58	7155.660	7.464	270.17	3.54	777.582	281.59	-23.01
120	7.17	7155.660	7.464	269.38	7.08	777.827	281.59	-23.01
180	10.75	7155.660	7.464	268.59	10.62	778.231	281.59	-23.01
240	14.33	7155.660	7.464	267.79	14.17	778.787	281.59	-23.01
300	17.92	7155.660	7.464	266.96	17.70	779.487	281.59	-23.01
360	21.50	7155.660	7.464	266.12	21.24	780.319	281.60	-23.01
420	25.08	7155.660	7.464	265.24	24.78	781.271	281.60	-23.01
480	28.67	7155.660	7.464	264.33	28.31	782.328	281.60	-23.01
540	32.25	7155.660	7.464	263.37	31.84	783.472	281.60	-23.01
600	35.83	7155.660	7.464	262.36	35.36	784.687	281.60	-23.01
660	39.42	7155.660	7.464	261.28	38.88	785.952	281.60	-23.01
720	43.00	7155.660	7.464	260.11	42.39	787.248	281.60	-23.01
780	46.59	7155.660	7.464	258.83	45.90	788.555	281.60	-23.01
840	50.17	7155.660	7.464	257.41	49.39	789.852	281.60	-23.01
900	53.75	7155.660	7.464	255.81	52.87	791.119	281.60	-23.01
960	57.34	7155.660	7.464	253.98	56.34	792.337	281.60	-23.01
1020	60.92	7155.660	7.464	251.83	59.77	793.486	281.60	-23.01
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
5580	333.26	7155.660	7.464	251.99	-26.61	781.807	281.66	-23.01
5640	336.85	7155.660	7.464	251.10	-23.07	780.799	281.66	-23.01
5700	340.43	7155.660	7.464	250.24	-19.54	779.903	281.66	-23.01
5760	344.02	7155.660	7.464	249.40	-16.00	779.132	281.66	-23.01
5820	347.60	7155.660	7.464	248.59	-12.46	778.500	281.66	-23.01
5880	351.18	7155.660	7.464	247.79	-8.92	778.017	281.66	-23.01
5940	354.77	7155.660	7.464	247.00	-5.38	777.689	281.66	-23.01
6000	358.35	7155.660	7.464	246.22	-1.84	777.522	281.67	-23.01
6060	1.93	7155.660	7.464	245.44	1.71	777.519	281.67	-23.01
6120	5.52	7155.660	7.464	244.66	5.25	777.680	281.67	-23.01

Table A-11. ADRAG.DAT file.

ORBIT TIME (S)	ATM. TEMP (K)	LOCAL DENSITY (KG/M3)	SPEED RATIO	ATMOSPHERIC DATA ANG. ALPHA (DEG)	ANG. BETA (DEG)	DRAG COMPONENTS X	Y	Z	DRAG COEFF.
0	1161	.762E-13	5.92	-.00	-176.1	-.179	4.202	.586	4.232
60	1161	.732E-13	5.84	-.00	-176.1	-.181	4.224	.591	4.255
120	1161	.699E-13	5.76	-.00	-176.1	-.183	4.247	.593	4.277
180	1161	.663E-13	5.67	.00	-176.2	-.184	4.268	.594	4.299
240	1161	.626E-13	5.58	.00	-176.2	-.186	4.288	.593	4.318
300	1161	.588E-13	5.51	-.00	-176.3	-.187	4.306	.590	4.335
360	1161	.551E-13	5.44	0.00	-176.4	-.188	4.320	.583	4.348
420	1161	.516E-13	5.38	-.00	-176.5	-.189	4.329	.574	4.357
480	1161	.484E-13	5.34	.00	-176.6	-.190	4.334	.562	4.360
540	1161	.457E-13	5.31	.00	-176.7	-.190	4.332	.547	4.357
600	1161	.435E-13	5.29	.00	-176.8	-.189	4.326	.530	4.349
660	1161	.419E-13	5.28	.00	-177.0	-.188	4.315	.510	4.336
720	1161	.409E-13	5.28	.00	-177.1	-.187	4.301	.488	4.320
780	1161	.405E-13	5.28	.00	-177.3	-.186	4.284	.465	4.301
840	1161	.405E-13	5.29	-.00	-177.5	-.184	4.266	.439	4.281
900	1161	.409E-13	5.30	0.00	-177.7	-.183	4.249	.413	4.262
960	1161	.415E-13	5.30	.00	-177.9	-.182	4.232	.386	4.244
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1020	1161	.421E-13	5.30	.00	-178.1	-.180	4.219	.358	4.228
5580	1161	.759E-13	6.36	.00	-176.5	-.169	4.037	.507	4.060
5640	1161	.782E-13	6.32	-.00	-176.4	-.170	4.060	.522	4.084
5700	1161	.799E-13	6.27	.00	-176.3	-.171	4.082	.536	4.108
5760	1161	.810E-13	6.22	0.00	-176.2	-.173	4.103	.548	4.131
5820	1161	.814E-13	6.17	.00	-176.2	-.174	4.125	.559	4.153
5880	1161	.811E-13	6.11	-.00	-176.1	-.175	4.146	.568	4.175
5940	1161	.800E-13	6.04	-.00	-176.1	-.177	4.168	.576	4.198
6000	1161	.783E-13	5.96	.00	-176.1	-.178	4.190	.583	4.220
6060	1161	.759E-13	5.88	0.00	-176.1	-.180	4.213	.589	4.244
6120	1161	.731E-13	5.80	-.00	-176.1	-.182	4.237	.592	4.267

Table A-12. SUNAN.DAT file.

SUN ASPECT ANGLE (DEGREES)

ORBIT TIME (S)	SPACECRAFT MAIN BODY ALPHA	SPACECRAFT MAIN BODY BETA	APPENDAGE NUMBER 1 ALPHA	APPENDAGE NUMBER 1 BETA	APPENDAGE NUMBER 2 ALPHA	APPENDAGE NUMBER 2 BETA	APPENDAGE NUMBER 3 ALPHA	APPENDAGE NUMBER 3 BETA	APPENDAGE NUMBER 4 ALPHA	APPENDAGE NUMBER 4 BETA
0	-.0	-75.5	-.0	-75.5	-.0	-75.5				
60	-.9	-75.5	-.9	-75.5	-.9	-75.5				
120	-1.8	-75.6	-1.8	-75.6	-1.8	-75.6				
180	-2.7	-75.7	-2.7	-75.7	-2.7	-75.7				
240	-3.6	-75.9	-3.6	-75.9	-3.6	-75.9				
300	-4.4	-76.2	-4.4	-76.2	-4.4	-76.2				
360	-5.3	-76.5	-5.3	-76.5	-5.3	-76.5				
420	-6.1	-76.8	-6.1	-76.8	-6.1	-76.8				
480	-6.9	-77.2	-6.9	-77.2	-6.9	-77.2				
540	-7.7	-77.7	-7.7	-77.7	-7.7	-77.7				
600	-8.4	-78.2	-8.4	-78.2	-8.4	-78.2				
660	-9.2	-78.7	-9.2	-78.7	-9.2	-78.7				
720	-9.8	-79.3	-9.8	-79.3	-9.8	-79.3				
780	-10.5	-79.9	-10.5	-79.9	-10.5	-79.9				
840	-11.1	-80.6	-11.1	-80.6	-11.1	-80.6				
900	-11.7	-81.3	-11.7	-81.3	-11.7	-81.3				
960	-12.2	-82.0	-12.2	-82.0	-12.2	-82.0				
1020	-12.6	-82.8	-12.6	-82.8	-12.6	-82.8				
⋮	⋮	⋮	⋮	⋮	⋮	⋮				
5580	6.5	-77.0	6.5	-77.0	6.5	-77.0				
5640	5.7	-76.6	5.7	-76.6	5.7	-76.6				
5700	4.9	-76.3	4.9	-76.3	4.9	-76.3				
5760	4.0	-76.0	4.0	-76.0	4.0	-76.0				
5820	3.1	-75.8	3.1	-75.8	3.1	-75.8				
5880	2.2	-75.7	2.2	-75.7	2.2	-75.7				
5940	1.4	-75.6	1.4	-75.6	1.4	-75.6				
6000	.5	-75.5	.5	-75.5	.5	-75.5				
6060	-.4	-75.5	-.4	-75.5	-.4	-75.5				
6120	-1.3	-75.6	-1.3	-75.6	-1.3	-75.6				

Table A-13. ORBMO.DAT file.

ORBIT NUMBER 1 T = 6060 S

AERODYNAMIC FORCES AND TORQUES:

	ORBITAL SYSTEM	SPACECRAFT SYSTEM
AERODYNAMIC	FORCE	TORQUE
MINIMUM	.294183E-04 N	.119103E-04 N*M
MAXIMUM	.115465E-03 N	.374445E-04 N*M
X MEAN	-.244060E-05 N	.206209E-04 N*M
Y MEAN	-.609816E-04 N	-.271885E-05 N*M
Z MEAN	-.329892E-05 N	-.441317E-05 N*M
AEROD. IMPULSE	LINEAR	ANGULAR
X MINIMUM	-.147900E-01 N*S	.000000E+00 N*M*S
X MAXIMUM	.000000E+00 N*S	.124962E+00 N*M*S
X DIFF.	.147900E-01 N*S	.124962E+00 N*M*S
X BUILD-UP	-.147900E-01 N*S	.124962E+00 N*M*S
X ACCUM.	-.147900E-01 N*S	.124962E+00 N*M*S
Y MINIMUM	-.369548E+00 N*S	-.164762E-01 N*M*S
Y MAXIMUM	.000000E+00 N*S	.000000E+00 N*M*S
Y DIFF.	.369548E+00 N*S	.164762E-01 N*M*S
Y BUILD-UP	-.369548E+00 N*S	-.164762E-01 N*M*S
Y ACCUM.	-.369548E+00 N*S	-.164762E-01 N*M*S
Z MINIMUM	-.199915E-01 N*S	-.267438E-01 N*M*S
Z MAXIMUM	.000000E+00 N*S	.000000E+00 N*M*S
Z DIFF.	.199915E-01 N*S	.267438E-01 N*M*S
Z BUILD-UP	-.199915E-01 N*S	-.267438E-01 N*M*S
Z ACCUM.	-.199915E-01 N*S	-.267438E-01 N*M*S

Table A-13. ORBMO.DAT file (cont'd).

SOLAR RADIATION FORCES AND TORQUES:

	ORBIT PLANE SYSTEM	SPACECRAFT SYSTEM
SOLAR RADIATION	FORCE	TORQUE
MINIMUM	.511612E-03 N	.115285E-04 N*M
MAXIMUM	.585884E-03 N	.107771E-03 N*M
X MEAN	-.862856E-06 N	-.702226E-05 N*M
Y MEAN	.108437E-03 N	-.538721E-04 N*M
Z MEAN	-.537071E-03 N	-.181943E-05 N*M
S. RAD. IMPULSE	LINEAR	ANGULAR
X MINIMUM	-.267705E-01 N*S	-.901591E-01 N*M*S
X MAXIMUM	.560858E-01 N*S	.526704E-01 N*M*S
X DIFF.	.828563E-01 N*S	.142830E+00 N*M*S
X BUILD-UP	-.522891E-02 N*S	-.425549E-01 N*M*S
X ACCUM.	-.522891E-02 N*S	-.425549E-01 N*M*S
Y MINIMUM	.000000E+00 N*S	-.326465E+00 N*M*S
Y MAXIMUM	.657130E+00 N*S	.000000E+00 N*M*S
Y DIFF.	.657130E+00 N*S	.326465E+00 N*M*S
Y BUILD-UP	.657130E+00 N*S	-.326465E+00 N*M*S
Y ACCUM.	.657130E+00 N*S	-.326465E+00 N*M*S
Z MINIMUM	-.325465E+01 N*S	-.124062E-01 N*M*S
Z MAXIMUM	.000000E+00 N*S	.135757E-02 N*M*S
Z DIFF.	.325465E+01 N*S	.137637E-01 N*M*S
Z BUILD-UP	-.325465E+01 N*S	-.110257E-01 N*M*S
Z ACCUM.	-.325465E+01 N*S	-.110257E-01 N*M*S

Except the spacecraft's geometry files PLASE.DAT, EXTSE.DAT and the orbit resume output ORBMO.DAT all the other files are difficult to analyse, due to the large amount of printed results. Therefore, as they are in a table in function of the time, it is preferable to plot those values. They are shown in Figures A-2 to A-11.

Figure A-2 shows the atmospheric density as printed in the ADRAG.DAT file. The dynamic model and the satellite polar orbit are responsible for the high variation in the density with time. The drag coefficient suffers the same effect, as can be seen in Figure A-3. The high value of the drag coefficient is caused by the large solar arrays, which contribute to a significant drag but have no projected area in the velocity direction.

Figures A-4 and A-5 are plots of the aerodynamic and solar radiation forces, respectively. Note that the forces aren't in the same coordinate system. The aerodynamic are weaker than the solar radiation forces, basically due to the orbit geometry: the sun radiation impinges on the entire solar arrays while the atmospheric molecules do not. The orbit inclination and the date chosen for the simulation are responsible for the lack of an eclipse period during the orbit, and thus the non-pulsating shape of the solar radiation forces (and torques) that are typical of these type of perturbations.

The torques, shown in Figures A-6 and A-7 show a similar behavior as the forces, with the aerodynamic and solar radiation effects causing a torque principally about the spacecraft's X and Y axes, respectively. Both are due to the SAR positioning.

Figures A-8 and A-9 show the linear impulse during the propagation period. Again, the solar radiation is the most important effect, giving an impulse of almost 3.3 Ns in the orbit normal direction per orbit period. The angular impulses (Figures A-10 and A-11), present high values in the X and Y axis, spacecraft's yaw and roll axis respectively.

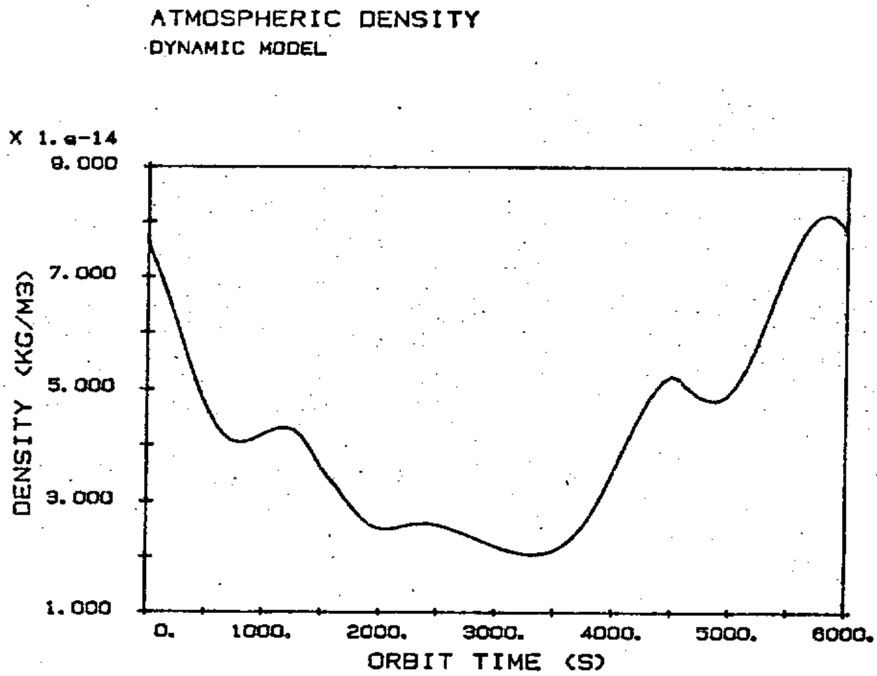

Fig. A-2. Local atmospheric density for the RADARSAT orbit.

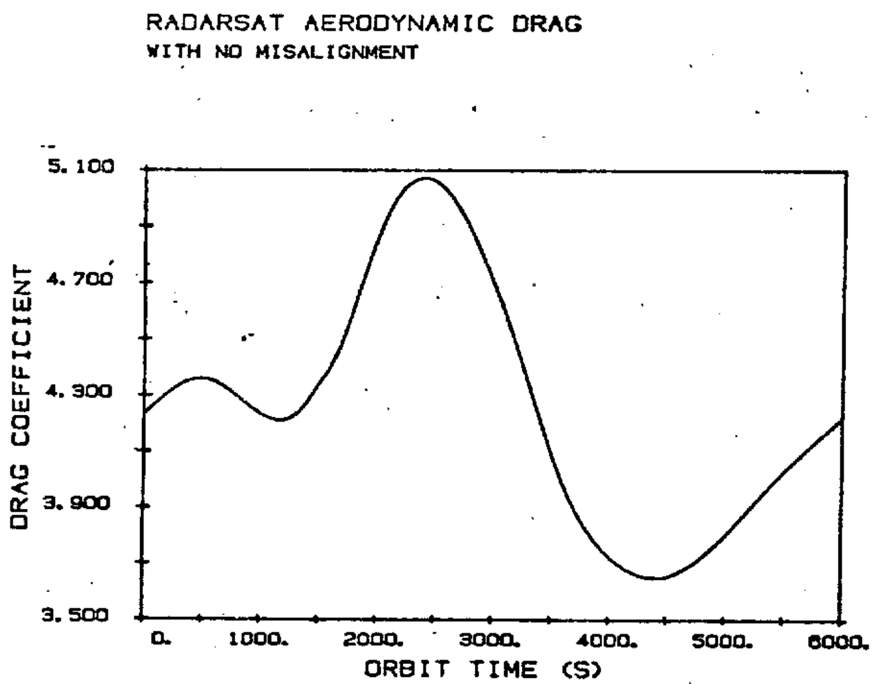

Fig A-3. RADARSAT drag coefficient variation during the orbit.

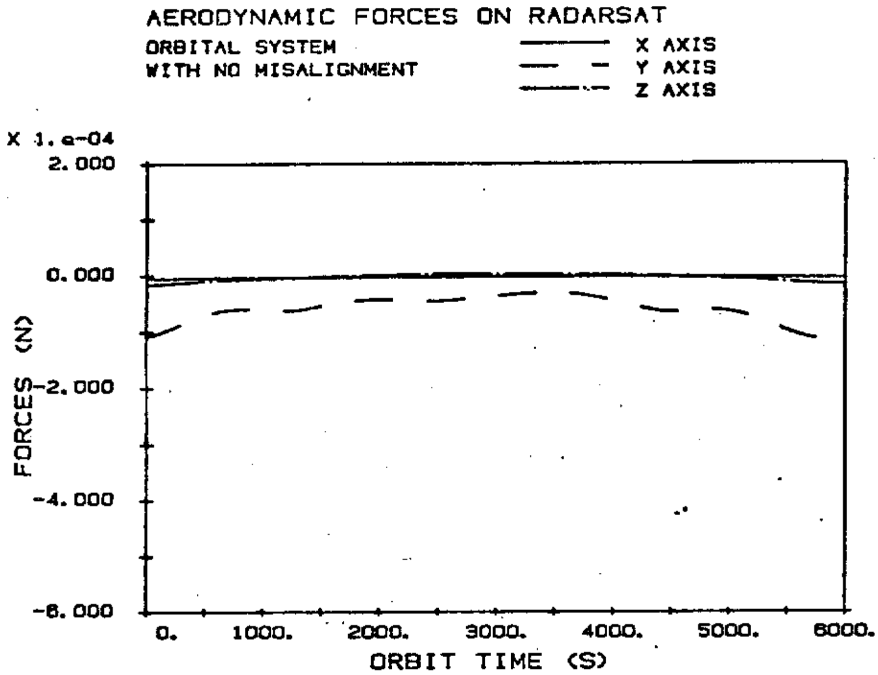

Fig. A-4. Aerodynamic forces on RADARSAT without misalignment.

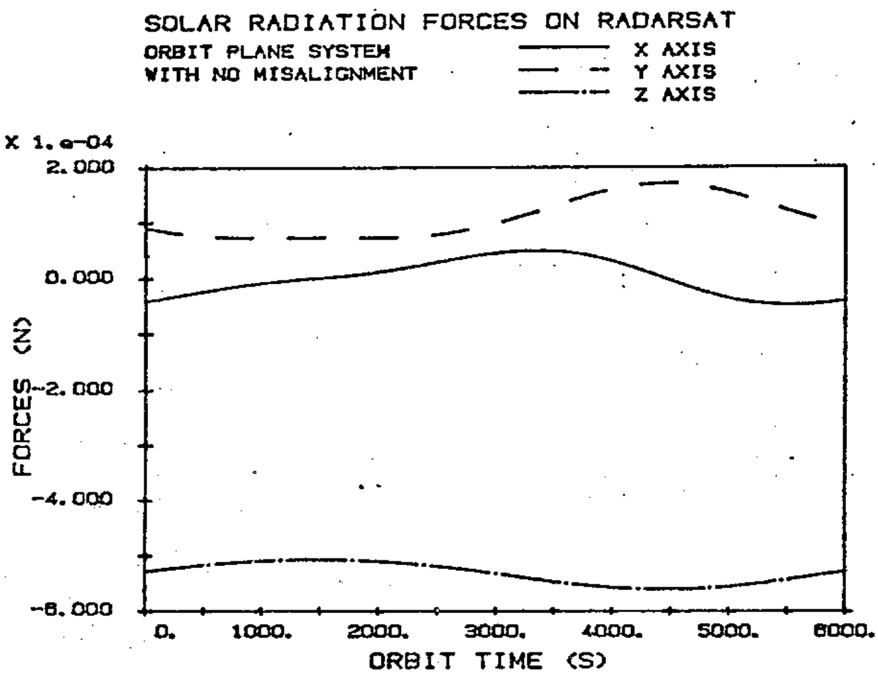

Fig A-5. Solar radiation forces on RADARSAT without misalignment.

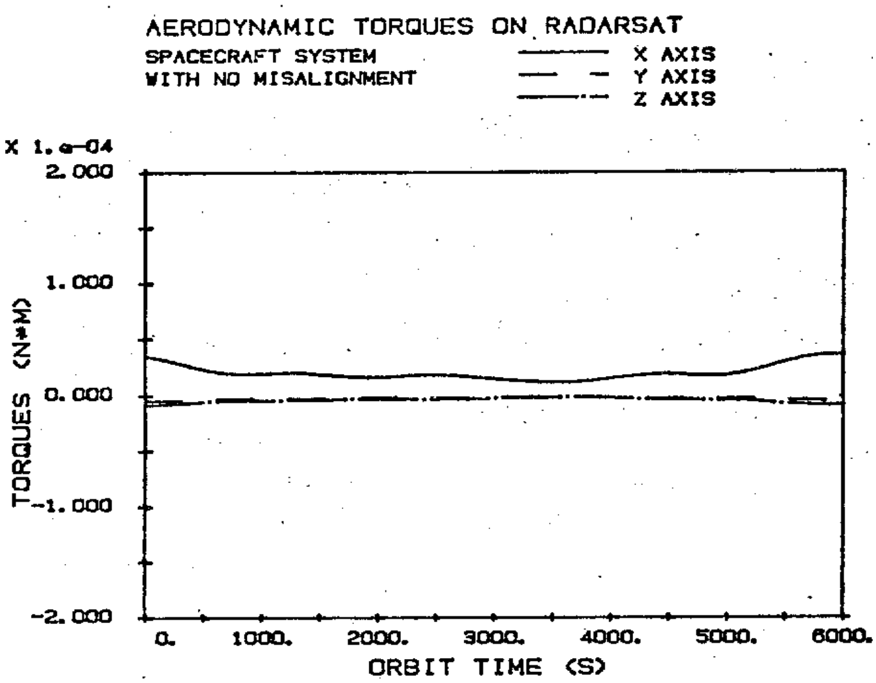

Fig. A-6. Aerodynamic torques on RADARSAT without misalignment.

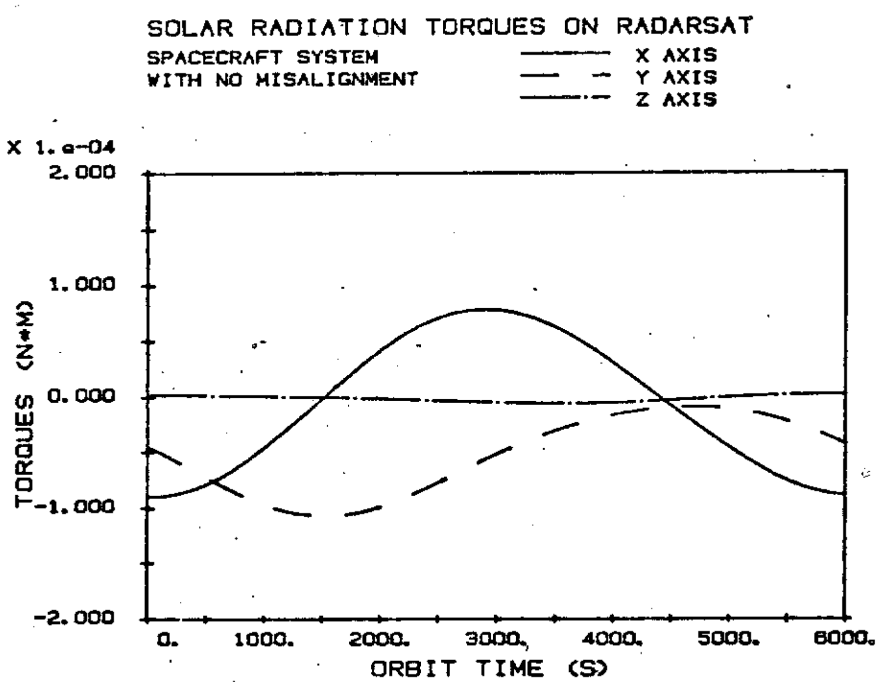

Fig A-7. Solar radiation torques on RADARSAT without misalignment.

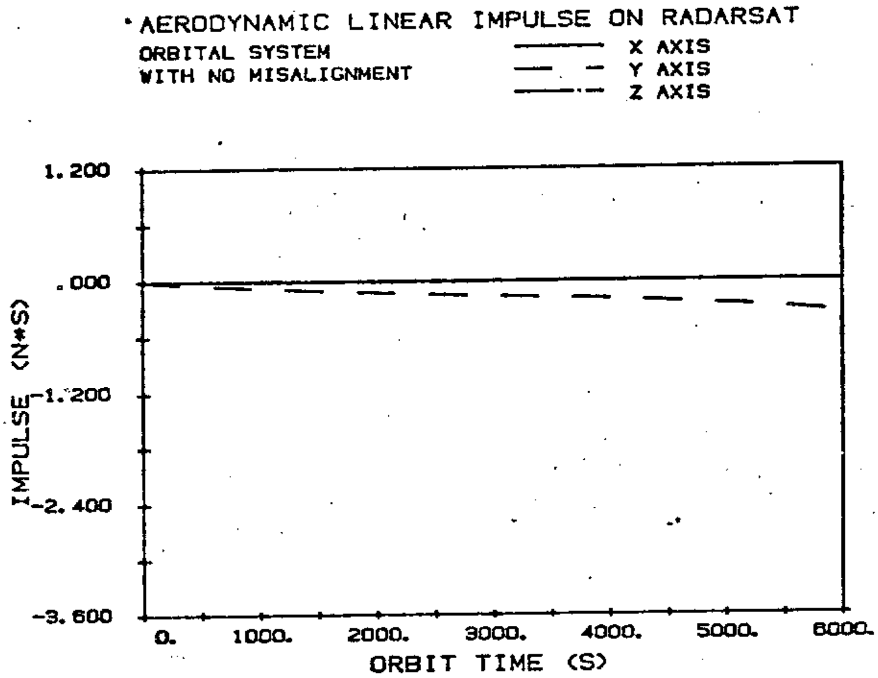

Fig. A-8. Aerodynamic linear impulse variation.

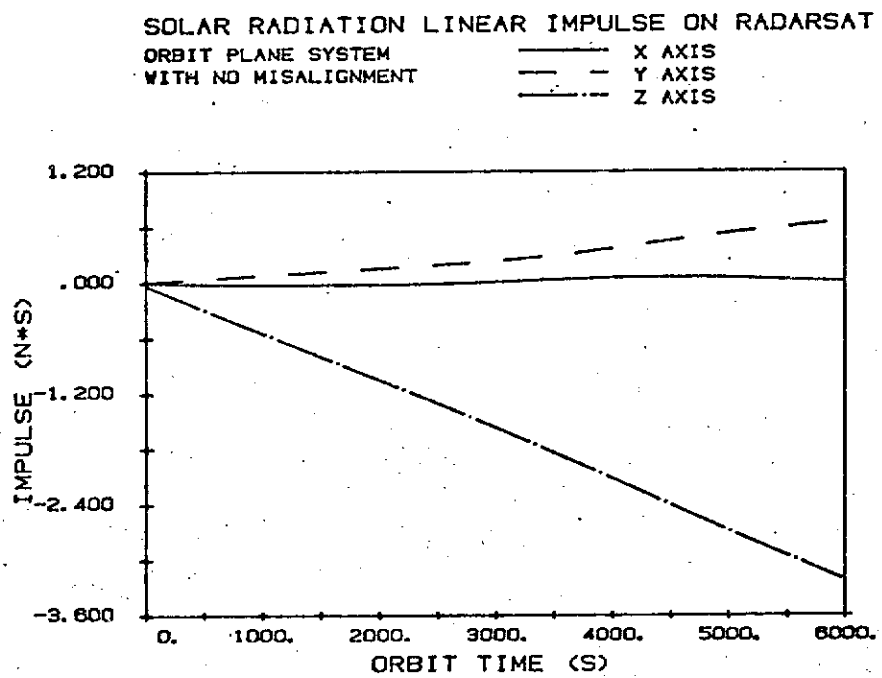

Fig A-9. Solar radiation linear impulse variation.

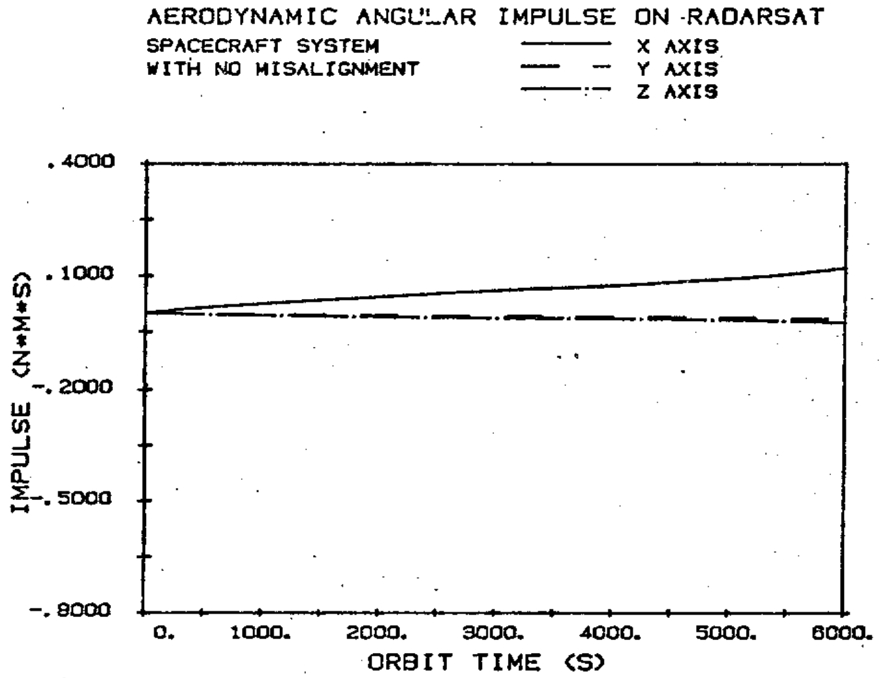

Fig. A-10. Aerodynamic angular impulse variation during a single orbit.

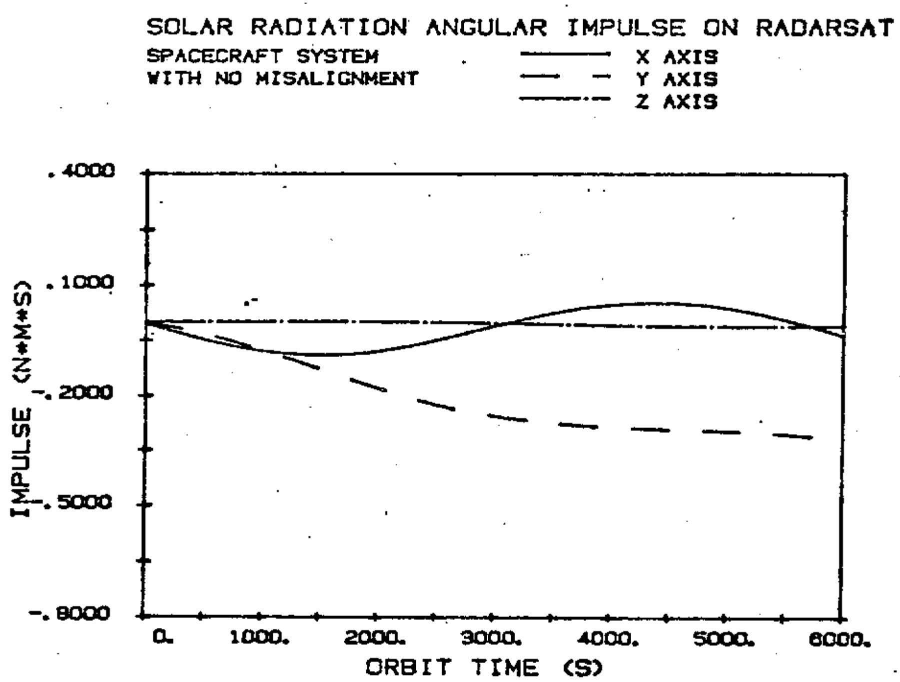

Fig A-11. Solar radiation angular impulse variation during a single orbit.

It was assumed, based on ref. [4], that for each solar array the misalignment angles could be in the range: 1.2 deg, 0.1 deg and 0.2 deg in the spacecraft X, Y and Z direction, respectively. These angles can be visualized (exaggerated) in Figure A-12. The RADARSAT center of mass offsets were considered equal to 0.1 m maximum for all three axes.

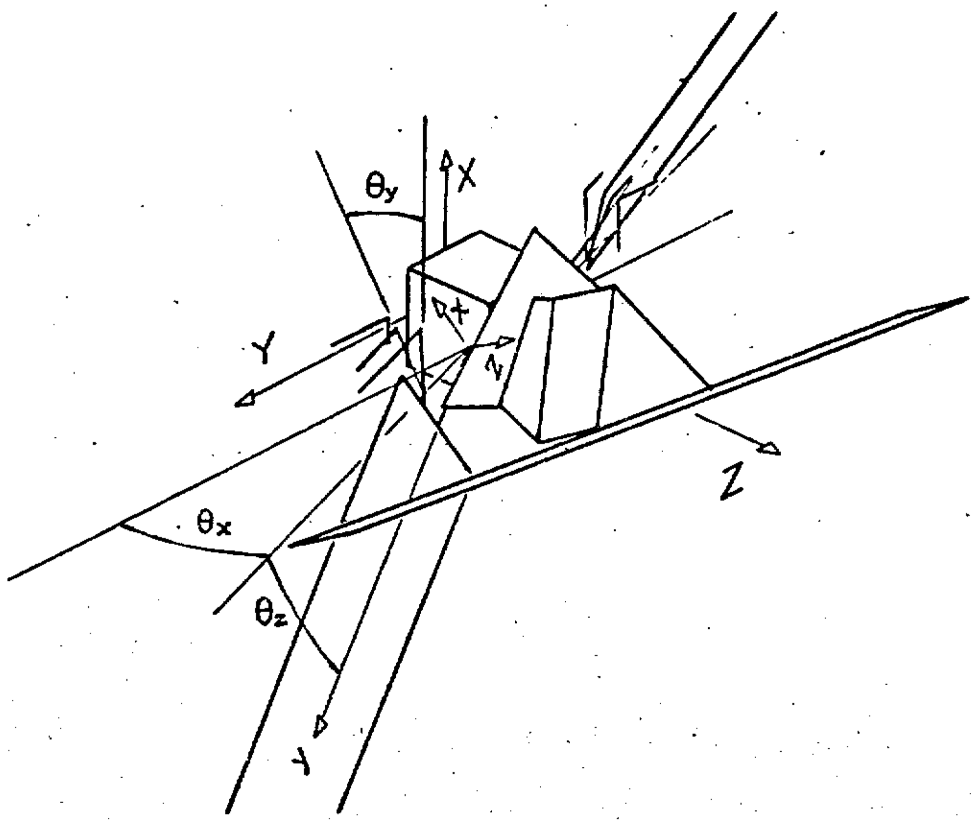

Figure A-12. RADARSAT misalignment angles (largely exaggerated).

To compare the results with and without misalignment, the angles were chosen in the possible range for the worst case, in order to maximize the resulting build-up angular impulse. As the torques and, consequently, the impulses are almost linear for small array angles, it was necessary to test only the maximum values. Table A-14 shows the altered cards of INELE.DAT file which caused the highest angular impulse build-up for the RADARSAT dawn-dusk configuration.

Table A-14. INELE.DAT cards with the misaligned angles and the center of mass offset.

```
BARICEN   -0.1 -0.1 2.46
APPESYS   1 0. -0.875 1.328190  0. 0. 0.  1.2  0.1  0.2
APPESYS   2 0.  0.875 1.328190  0. 0. 0. -1.2  0.1 -0.2
```

The resulting torques and impulses due to the misalignments are shown in Figures A-13, A-14 (aerodynamic and solar radiation torques), A-15 and A-16 (aerodynamic and solar radiation angular impulses).

By comparing these results with Figures A-6 to A-9, it is seen that the misalignments cause a greater change in the solar radiation torque than in the aerodynamic. In fact, the solar radiation torque in the spacecraft's Y axis (roll) is strongly dependent on the center of mass position in the X axis. The center of mass offset in the X axis alone raises the angular build-up impulse from .33 to .65 Nms in the Y axis. The other misalignments are responsible for the increase in this value to .78 Nms, or 94% of the total solar radiation angular momentum build-up and 84% of the total angular momentum build-up (aerodynamic and solar radiation effects together). A change in the negative X axis direction of 0.1 m position of the spacecraft's center of mass causes a increasing of 35% in the angular momentum build-up.

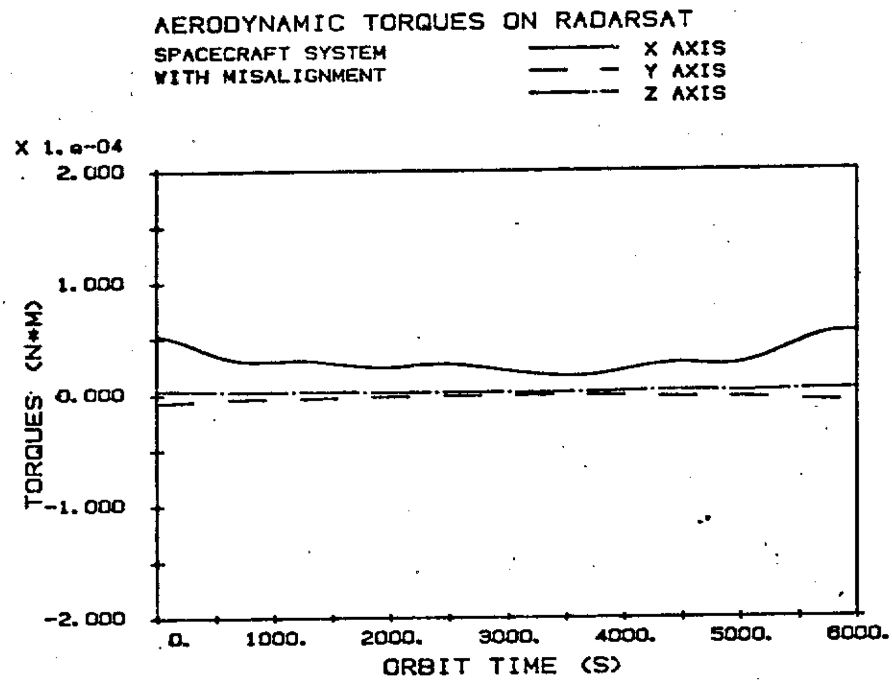

Fig. A-13. Aerodynamic torque on RADARSAT with misalignment included.

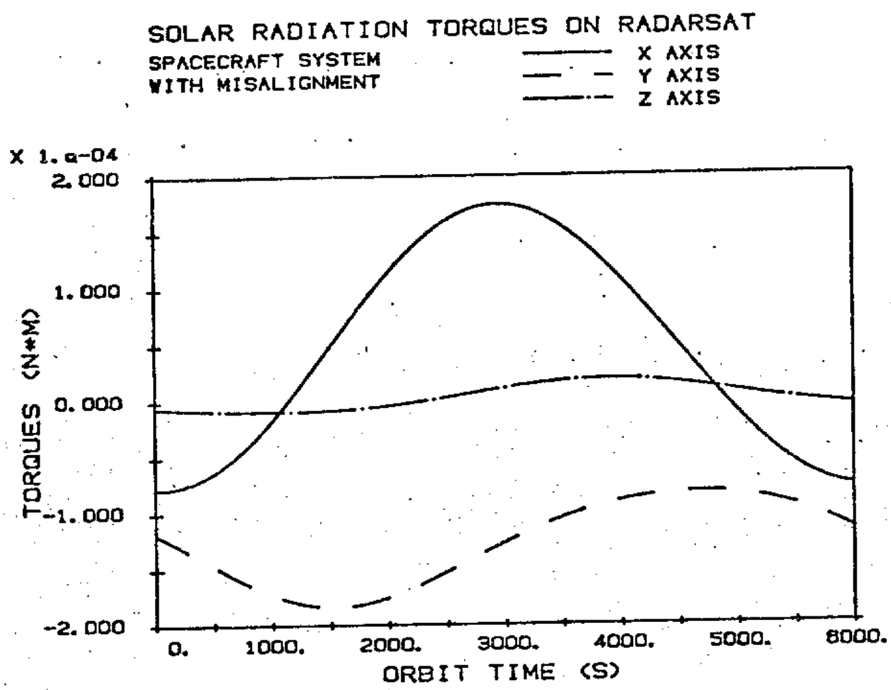

Fig. A-14. Solar radiation torques on RADARSAT with misalignments included.

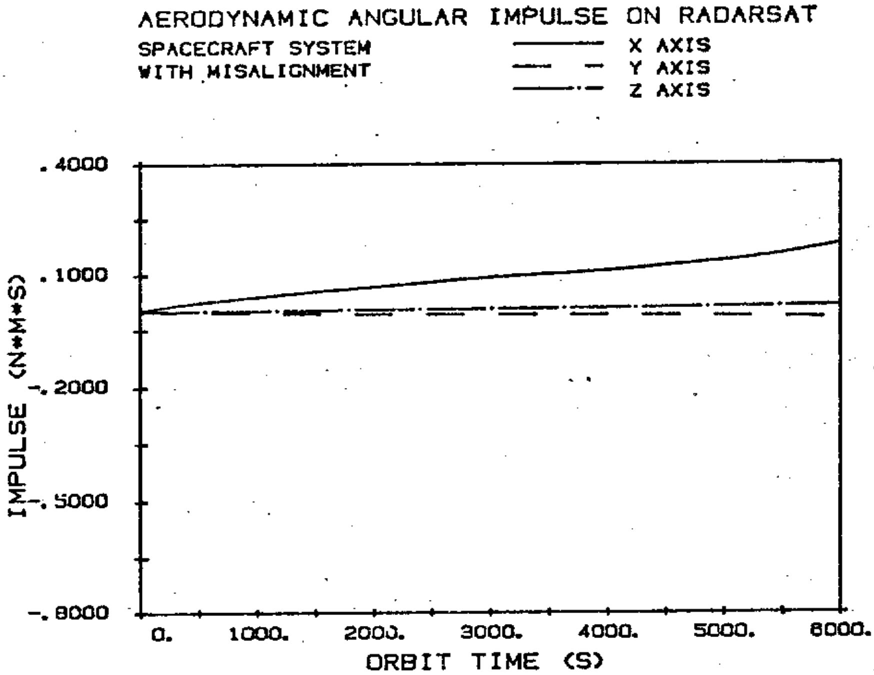

Fig. A-15. Aerodynamic angular impulse build-up with misalignments included.

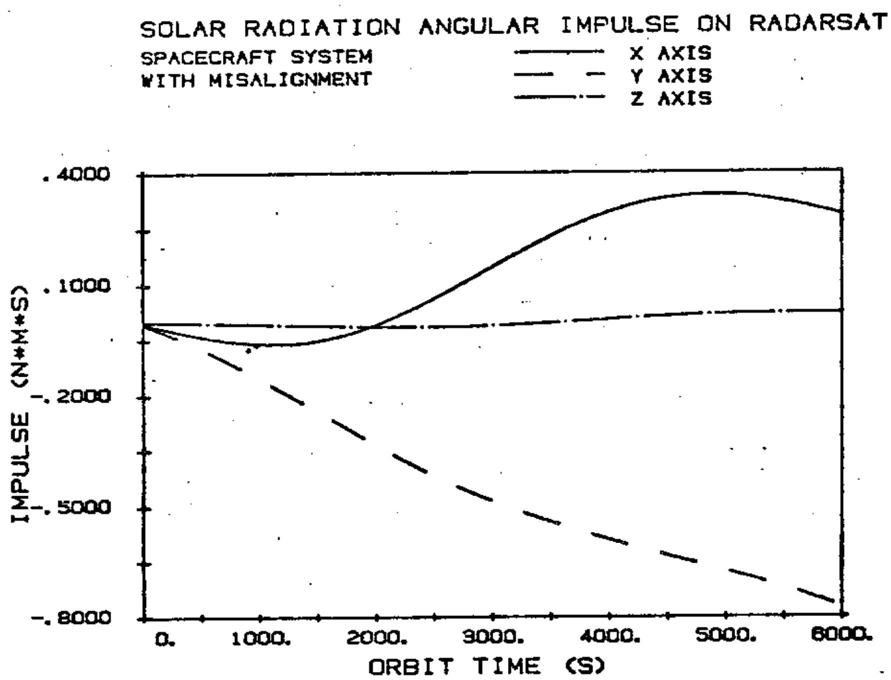

Fig. A-16. Solar radiation angular impulse build-up with misalignments included.

APPENDIX B

MAIN PROGRAM AND SUBROUTINES LISTING

SPAR

FILE ARFTS.FTN

```
FTN77,J
$CDS ON
$FILES 0,15
      PROGRAM ARFTS
C
C     THE MAIN ARFTS (AERODYNAMIC AND  RADIATION  FORCES AND
C     TORQUES ACTUATING ON SATELLITES) CALCULATES THE FORCES
C     AND TORQUES ON LOW EARTH ORBIT SATELLITES, DUE  TO THE
C     ATMOSPHERIC AND SOLAR RADIATION PRESSURE EFFECTS.
C
C     THE INPUT PARAMETERS ARE GIVEN  TO  THE PROGRAM BY TWO
C     INPUT FILES:
C
C       SATGE.DAT  CONTAINS  A  NASTRAN  DESCRIPTION OF  THE
C                  SPACECRAFT GEOMETRY, WITH THE GRID  NODES
C                  AND THE SURFACES. THE PROGRAM UNDERSTANDS
C                  TWO TYPES OF SURFACE DEFINITION: TRIANGLE
C                  (CTRIA3) AND QUADRILATERAL (CQUAD4)  ELE-
C                  MENTS.
C
C       INELE.DAT  CONTAIS SEVERAL DATA TO THE PROGRAM, WITH
C                  CARDS IDENTIFIED BY ITS FIRST WORD,  LIKE
C                  A NASTRAN CARD.  THE FILE MUST CONTAINS:
C
C         ORBIT    CARD, WITH THE ORBITAL ELEMENTS,  RESPEC-
C                  TIVELY: PERIGEE ALTITUDE (KM), APOGEE AL-
C                  TITUDE (KM), INCLINATION (DEGRESS),   RI-
C                  GHT ASCENTION OF ASCENDING  NODE  (DEG.),
C                  PERIGEE ARGUMENT (DEG.) AND MEAN  ANOMALY
C                  (DEG.). EXAMPLE:
C                  ORBIT    777.5 777.5 98.5 11.6 0.0 0.0
C
C         DATE     CARD WITH THE TIME OF THE ELEMENTS: MONTH
C                  DAY, YEAR, HOUR, MINUTE AND SECOND IN THE
C                  GREENWITCH TIME (UT), TIME STEP  FOR  THE
C                  ORBIT PROPAGATION AND  TOTAL  PROPAGATION
C                  TIME, BOTH IN SECONDS. EXAMPLE:
C                  DATE      7 16 1993 8 52 31.5 60.0 6000.0
C
C         SOLFLUX  CARD, WITH THE DAILY SOLAR FLUX INDEX  AT
C                  10.7 CM, THE AVERAGED SOLAR FLUX OVER SIX
C                  SOLAR ROTATIONS AND THE GEOMAGNETIC ACTI-
C                  VITY INDEX KP (0.0 TO 9.7). EXAMPLE:
C                  SOLFLUX  180. 180. 5.3
C
C         BARICEN  CARD, GIVES THE POSITION OF THE SATELLITE
C                  CENTER OF MASS, IN METERS, IN THE  SPACE-
C                  CRAFT SYSTEM. EXAMPLE:
C                  BARICEN  0.102 0.0 1.33
```

```
C          SUNAN.DAT   CONTAINS PRINTED VALUES OF THE SUN ASPECT
C                      ANGLE, DEFINED AS THE ANGLE  BETWEEN  THE
C                      SUN DIRECTION IN  THE  SPACECRAFT  SYSTEM
C                      (FOR THE  MAIN  BODY)  OR  THE  APPENDAGE
C                      SYSTEMS (FOR  THE  APPENDAGES),  AND  THE
C                      PLANE YZ (ALPHA). THE ANGLE  BETA IS  THE
C                      ANGLE BETWEEN THE PROJECTION  OF  THE SUN
C                      DIRECTION IN THE PLANE YZ AND THE Y AXIS.
C
C          ORBMO.DAT   CONTAINS ORBIT EVALUATIONS OF THE  FORCES
C                      (MINIMUM  AND  MAXIMUM  INTENSITIES  AND
C                      MEAN VALUES)  AND THE IMPULSES  (MINIMUM,
C                      AND MAXIMUM VALUES  ENCOUNTERED  AT  THAT
C                      ORBIT, ITS DIFFERENCE, THE IMPULSE BUILD-
C                      UP - DIFFERENCE BETWEEN  THE  ACCUMULATED
C                      IMPULSE AT THE END AND  THE  BEGINING  OF
C                      THE ORBIT - AND THE ACCUMULATED IMPULSE).
C
C        SUBROUTINES UTILISED BY THIS PROGRAM:
C          RCPAR     - HP 1000 INTERNAL ROUTINE.
C          CONSTP    - SETS CONSTANT VALUES (ORBIT.FTN FILE).
C          ARELEM    - READS THE SATGE.DAT FILE
C          REAINP    - READS SOME INELE.DAT FILE CARDS.
C          DJM       - MODIFIED JULIAN DATE (ORBIT.FTN FILE).
C          VARELK    - TIME VARIATIONS OF THE KEPLERIAN ELEMENTS
C                      (ORBIT.FTN FILE).
C          ROTSYS    - OBTAINS SOME ROTATION MATRIX.
C          ROTXYZ    - OBTAINS THE MATRIX FOR A XYZ ROTATION.
C          UNIVEC    - CALCULATES THE UNIT OF A VECTOR.
C          STAVEC    - CALCULATES THE POSITION AND VELOCITY OF A
C                      SATELLITE BY ITS KEPLERIAN ELEMENTS.
C          ROTMAT    - OBTAINS THE ROTATION MATRIX OF A ROTATION
C                      ABOUT A GIVEN AXIS.
C          MATMUL    - OBTAINS THE PRODUCT OF TWO MATRIX.
C          SUN       - SUN POSITION (ORBIT.FTN FILE).
C          VECROT    - OBTAINS  THE  COMPONENTS  OF A  VECTOR IN
C                      OTHER SYSTEM.
C          EARSHA    - VERIFIES IF THE SATELLITE IS IN THE EARTH
C                      SHADOW.
C          SGMT      - OBTAINS THE GREENWICH SIDERAL TIME AT OH
C                      (ORBIT.FTN FILE).
C          GEOCEN    - CALCULATES THE GEOCENTRIC COORDINATES.
C          ASDAMO    - OBTAINS THE ATMOSPHERIC PROPERTIES.
C          ATMVEL    - CALCULATES THE ATMOSPHERIC VELOCITY.
C          AERODY    - COMPUTES THE AERODYNAMIC FORCE AND TORQUE
C                      IN A FLAT PLATE.
C          SOLPRE    - COMPUTES THE SOLAR  RADIATION  FORCE  AND
C                      TORQUE IN A FLAT PLATE.
C          VECINV    - OBTAINS THE INVERSE ROTATION OF A VECTOR.
C
```

```
C      NOTES:      THE CARDS WITHOUT THESE NAMES STARTING ON
C                  COLUMN 1 AND NUMBERS STARTING ON COLUMN 9
C                  WILL BE IGNORED BY THE PROGRAM. THE CARDS
C                  CAN APPEAR  IN  ANY  ORDER  BUT  ONCE  AT
C                  LEAST,   EXCEPT  THE  APPSYS  AND  BODYAP
C                  CARDS, THAT APPEARS  AS  MANY TIMES AS TO
C                  GIVE THE SPACECRAFT EXTERNAL GEOMETRY.
C
C
C    THE OUTPUT PARAMETERS ARE PRINTED IN SEVERAL FILES:
C
C      PLASE.DAT   CONTAINS THE SURFACE  ELEMENTS  GIVEN  BY
C                  THE SATGE.DAT FILE, AS  ITS  UNIT NORMAL,
C                  POSITION AND AREA.
C
C      EXTSE.DAT   CONTAINS ALL THE ELEMENTS THAT REALY WILL
C                  BE UTILIZED IN THE COMPUTATIONS, AS GIVEN
C                  BY THE  BODYAP  CARDS, ITS IDENTIFICATION
C                  NUMBER (0 FOR THE MAIN BODY),  UNIT  NOR-
C                  MAL, POSITION OF THE CENTER OF  THE  ELE-
C                  MENT AND ITS AREA.
C
C      AEROF.DAT   CONTAINS THE  AERODYNAMIC  FORCES AND IM-
C                  PULSES, IN THE SYSTEM SET BY  THE  OUTSYS
C                  CARD, IN FUNCTION OF THE TIME.
C
C      AEROT.DAT   CONTAINS THE AERODYNAMIC TORQUES  AND IM-
C                  PULSES IN THE  SYSTEM SET BY  THE  OUTSYS
C                  CARD, IN FUNCTION OF THE TIME.
C
C      SORAF.DAT   CONTAINS THE SOLAR  RADIATION  FORCES AND
C                  IMPULSES IN THE SYSTEM SET BY  THE OUTSYS
C                  CARD, IN FUNCTION OF THE TIME.
C
C      SORAT.DAT   CONTAINS THE SOLAR  RADIATION TORQUES AND
C                  IMPULSES IN THE SYSTEM SET BY  THE OUTSYS
C                  CARD, IN FUNCTION OF THE TIME.
C
C      ORBPR.DAT   CONTAINS DATA FROM  THE PROPAGATED ORBIT:
C                  MEAN ANOMALY, GEOCENTRIC DISTANCE, SATEL-
C                  LITE VELOCITY,  LONGITUDE,  LATITUDE  AND
C                  ALTITUDE OF THE SUB-SATELLITE  POINT  AND
C                  THE RIGHT ASCENTION  AND  DECLINATION  OF
C                  THE SUN.
C
C      ADRAG.DAT   CONTAINS THE ATMOSPHERIC DATA IN TERMS OF
C                  ITS TEMPERATURE, DENSITY AND SPEED RATIO,
C                  AS WELL AS THE ANGLE OF INCIDENCE OF  THE
C                  MOLECULES, THE DRAG COEFFICIENT  AND  ITS
C                  COMPONENTS, IN BODY COORDINATES.
C
```

```
C         OUTSYS    CARD CONTAINS INFORMATION ABOUT THE COOR-
C                   DINATE SYSTEM IN WHICH THE USER WANTS THE
C                   RESULTS, RESPECTIVELY  THE  AERODYNAMIC
C                   FORCE, AERODYNAMIC TORQUE, SOLAR RADIATI-
C                   ON FORCE AND SOLAR RADIATION TORQUE.  THE
C                   OUTPUT SYSTEMS CAN BE:
C                   1- INERTIAL SYSTEM
C                   2- ASCENDING NODE SYSTEM
C                   3- ORBIT PLANE SYSTEM
C                   4- ORBITAL SYSTEM
C                   5- SPACECRAFT SYSTEM AT T=0
C                   6- SPACECRAFT SYSTEM
C                   EXAMPLE:
C                   OUTSYS    4 6 3 6
C
C          BODYAP   CARDS GIVES THE SPACECRAFT COMPOSITION IN
C                   TERMS OF THE SURFACE ELEMENTS AS WELL  AS
C                   THE PROPERTIES AND TEMPERATURE OF EACH E-
C                   LEMENT. THE PARAMETERS ARE: BODY AND  AP-
C                   PENDAGE IDENTIFICATION  NUMBER  (0  MEANS
C                   THE MAIN BODY OR THE  SPACECRAFT ITSELF);
C                   ELEMENT IDENTIFICATION NUMBER, CORRESPON-
C                   DING TO THAT USED IN THE NASTRAN GEOMETRY
C                   DESCRIPTION FILE (IF  NEGATIVE  THE  ELE-
C                   MENT NORMAL WILL BE IN  THE  OPPOSITE DI-
C                   RECTION); THE SURFACE TANGENTIAL AND NOR-
C                   MAL AERODYNAMIC COEFFICIENTS; THE  SPECU-
C                   LAR REFLECTIVITY; THE DIFFUSE REFLECTIVI-
C                   TY; THE SURFACE  ABSORPTION  COEFFICIENT;
C                   THE INFRA-RED EMISSIVITY AND THE  SURFACE
C                   TEMPERATURE, IN KELVIN. EXAMPLE:
C                   BODYAP    0  1031 .9 .9 .80 .0 .20 1. 350.
C                   BODYAP    0  1041 .9 .9 .80 .0 .20 1. 350.
C                   BODYAP    0  1051 .9 .9 .80 .0 .20 1. 350.
C                   BODYAP    0  1061 .9 .9 .80 .0 .20 1. 350.
C                   BODYAP    0  1071 .9 .9 .80 .0 .20 1. 350.
C                   BODYAP    0  1081 .9 .9 .80 .0 .20 1. 350.
C                   BODYAP    1  1001 .9 .9 .21 .0 .79 1. 350.
C                   BODYAP    1 -1001 .9 .9 .80 .0 .20 1. 350.
C                   BODYAP    2  1011 .9 .9 .21 .0 .79 1. 350.
C                   BODYAP    2 -1011 .9 .9 .80 .0 .20 1. 350.
C
C          ENDDATA  CARD INFORMS TO THE PROGRAM  THE  END  OF
C                   DATA. EXAMPLE:
C                   ENDDATA
C
```

```
C
C         PROAREA  REFERENCE AREA USED TO CALCULATE THE DRAG
C                  COEFFICIENT, IN SQUARE METERS.  WHEN THIS
C                  AREA IS EQUAL TO THE SATELLITE AREA  PRO-
C                  JECTED IN  THE  VELOCITY  DIRECTION,  THE
C                  DRAG COEFFICIENT TENDS TO 2. EXAMPLE:
C                  PROAREA  11.907
C
C         MAINSYS  CARD GIVES INFORMATION ABOUT THE ATTITUDE
C                  RELATED FRAME OF THE  SPACECRAFT,  I. E.,
C                  THE SYSTEM WHERE THE SPACECRAFT FRAME  IS
C                  RELATED:
C                  1- INERTIAL SYSTEM
C                  2- ASCENDING NODE SYSTEM
C                  3- ORBIT PLANE SYSTEM
C                  4- ORBITAL SYSTEM
C                  THE OTHER  PARAMETERS ARE,  RESPECTIVELY:
C                  THE THREE COMPONENTS OF A X-Y-Z , ROTATION
C                  BETWEEN THE RELATED FRAME AND THE  SPACE-
C                  CRAFT SYSTEM, IN DEGREES  AND  THE  THREE
C                  COMPONENTS OF THE SPACECRAFT  ANGULAR VE-
C                  LOCITY (IN REVOLUTIONS PER MINUTE). EX:
C                  MAINSYS  4 0. 0. 0. 0. 0. 0.
C
C         APPSYS   CARD CONTAINS THE POSITION OF EACH APPEN-
C                  DAGE POSITION AND ORIENTATION. ITS  PARA-
C                  METERS ARE, RESPECTIVELY: APPENDAGE IDEN-
C                  TIFICATION (1-10),  THREE  COMPONENTS  OF
C                  THE APPENDAGE ORIENTATION IN DEGREES, THE
C                  THREE COMPONENTS OF THE APPENDAGE ANGULAR
C                  VELOCITY (IN RPM  AND  SPACECRAFT  SYSTEM
C                  COORDINATES) AND  THE  THREE  COMPONTENTS
C                  OF THE POSITION, IN SPACECRAFT FRAME,  IN
C                  WHICH THE APPENDAGE  WILL  ROTATE,  IN M.
C                  EXAMPLE:
C                  APPESYS  1 0.  2. 0. 0. 0. 0. 0. -0.9 1.3
C                  APPESYS  2 0. -2. 0. 0. 0. 0. 0. -0.9 1.3
C                  NOTE THAT WILL BE AS MANY APPESYS CARD AS
C                  THE NUMBER OF APPENDAGES IN THE SATELLITE
C
```

```
C
C      AUTHOR:     VALDEMIR CARRARA     MAY/87
C
C
       IMPLICIT REAL*8 (A-H,O-Z)

       PARAMETER (NSUR=50)

       DIMENSION SU(2)
       DIMENSION AH(3),AP(3),AS(3),AV(3),AW(3)
       DIMENSION BA(3),BR(3),DA(3),DR(3),EA(3),EB(3)
       DIMENSION FA(3),FR(3),F1(3),F2(3),F5(3),F6(3)
       DIMENSION GA(3),GC(3),HA(3),HR(3),PV(3)
       DIMENSION RG(3),RH(3),RV(3),SF(3),SP(3)
       DIMENSION TA(3),TR(3),T1(3),T2(3),T5(3),T6(3)
       DIMENSION US(3),UV(3),VN(3),WA(3),WU(3),WV(3)
       DIMENSION AD(6),CA(6),CR(6),DE(6),EL(6),ER(6)
       DIMENSION SA(6),SC(7),SV(6),TE(6)
       DIMENSION AB(10),AM(40),AA(20),AL(50),SM(40),WM(10)
       DIMENSION RA(3,3),RC(3,3),RI(3,3),RL(3,3),RN(3,3)
       DIMENSION RP(3,3),RS(3,3),RT(3,3),RZ(3,3)
       DIMENSION R1(3,3),R2(3,3)
       DIMENSION PL(NSUR,3),PP(10,3),SL(NSUR,7),VL(NSUR,3)
       DIMENSION WS(10,3),QR(10,3,3)
       DIMENSION NF(11)
       CHARACTER *20 FD(6),OD(6)
       CHARACTER *10 FN(14)
       CHARACTER *8  CQUE
       CHARACTER     RFIL*3,FILI*14

       COMMON /CONSTA/ PI,PIT2,PID2,RAD,DEG
       COMMON /CEARTH/ RE,GM,FLAT,TETP
       COMMON /ANGSUN/ ALSU,DESU,ROSU,ELSU,ECLI
       COMMON /CTSSUN/ ASTU,DSUN

       DATA BOAV /8314.3298D0/
       DATA SUNC /1.011D+17/
       DATA AMAX /1.D+32/
       DATA AMIN /1.D-32/
       DATA FD/'INERTIAL SYSTEM     ','ASC. NODE SYSTEM    ',
      1        'ORBIT PLANE SYSTEM  ','SPACECRAFT SYSTEM   ',
      2        '                    ','                    '/
       DATA OD/'  INERTIAL SYSTEM   ','  ASC. NODE SYSTEM  ',
      1        ' ORBIT PLANE SYSTEM ','   ORBITAL SYSTEM   ',
      2        'SPACECRAF SYS AT T=0',' SPACECRAFT SYSTEM  '/
```

```
C
C          OPEN FILES
C

      FN(1)   = 'SATGE.DAT'
      FN(2)   = 'INELE.DAT'
      FN(3)   = '         '
      FN(4)   = 'PLASE'
      FN(5)   = 'EXTSE'
      FN(6)   = 'AEROF'
      FN(7)   = 'AEROT'
      FN(8)   = 'SORAF'
      FN(9)   = 'SORAT'
      FN(10)  = 'ORBPR'
      FN(11)  = 'ADRAG'
      FN(12)  = 'SUNAN'
      FN(13)  = 'ORBMO'
      FN(14)  = '     '

      FILI    = FN(1)
      CALL RCPAR(1I,FILI)
      OPEN(UNIT=3;FILE=FILI)

      FILI    = FN(2)
      CALL RCPAR(2I,FILI)
      OPEN(UNIT=4,FILE=FILI)

      RFIL    = 'DAT'

      CALL RCPAR(3I,RFIL)

      DO 10 I = 4, 13
      FILI    = FN(I)//'.'//RFIL
      NFIL    = I + 2
      OPEN(UNIT=NFIL,FILE=FILI)
   10 CONTINUE

C
C          COMMON VALUES INITIALIZATION
C

      CALL CONSTP

C
C          READ THE SURFACE ELEMENTS AND ITS PROPERTIES  FROM
C          SATGE.DAT FILE
C

      CALL ARELEM(NF,VL,PL,SL,AL)
```

```
C
C       READ THE INPUT ELEMENTS FROM INELE.DAT FILE
C

      CALL REAINP('ORBIT   ',4,6,EL)
      PERI   = EL(1)
      APOG   = EL(2)
      SEMA   = (EL(1) + EL(2))*.5D+03 + RE
      EXCE   = (EL(2) - EL(1))*.5E+03/SEMA
      EL(1)  = SEMA
      EL(2)  = DABS(EXCE)
      PERI   = PIT2*DSQRT(EL(1)/GM)*EL(1)
      CALL REAINP('DATE    ',4,8,AB)
      AMO    = AB(1)
      DAY    = AB(2)
      YEA    = AB(3)
      HOU    = AB(4)
      AMI    = AB(5)
      SEC    = AB(6)
      DTI    = AB(7)
      TEN    = AB(8)
      CALL REAINP('SOLFLUX ',4,3,SF)
      CALL REAINP('BARICEN ',4,3,GC)
      CALL REAINP('MAINSYS ',4,7,AB)
      IFRA   = AB(1)
      IF(IFRA.LT.1.OR.IFRA.GT.4) GOTO 920

      DO 20 I = 1, 3
      EB(I)  = AB(I+1)
      WV(I)  = AB(I+4)
   20 CONTINUE

      CALL REAINP('PROAREA ',4,1,AB)
      SBA    = AB(1)
      CALL REAINP('OUTSYS  ',4,4,AB)
      IOFA   = AB(1)
      IOTA   = AB(2)
      IOFR   = AB(3)
      IOTR   = AB(4)
      IF(IOFA.LT.1.OR.IOFA.GT.6) IOFA    = 1
      IF(IOTA.LT.1.OR.IOTA.GT.6) IOTA    = 1
      IF(IOFR.LT.1.OR.IOFR.GT.6) IOFR    = 1
      IF(IOTR.LT.1.OR.IOTR.GT.6) IOTR    = 1

      DJUL  = DJM(YEA,AMO,DAY)
      YFRA  = (DJUL - DJM(YEA,1.D0,1.D0))/3.6525D02
      DFRA  = SEC + 60.D0*(AMI + 60.D0*HOU)
      SBAS  = SBA
```

SPAR

```
C
C        WRITE HEADER OF THE ORBPR.DAT, ADRAG.DAT AND
C        SUNAN.DAT FILES
C

      DO 30 I = 12, 14
      WRITE(I,1000) EL,PERI/60.D0
      WRITE(I,1001) AMO,DAY,YEA,DJUL,HOU,AMI,SEC,DTI,TEN
      WRITE(I,1002) SF
      WRITE(I,1003) GC
      WRITE(I,1004) SBA
      WRITE(I,1005) IFRA,FD(IFRA),EB,WV
   30 CONTINUE

C
C        READ THE APPSYS COMMANDS FROM INELE.DAT FILE
C

      NBOD    = 0
      NELE    = 0

   40 CONTINUE
      REWIND 4
      NBOD    = NBOD + 1
      IF(NBOD.GT.10) GOTO 910
      IF(NF(NBOD+1).EQ.0) GOTO 80
      NELE    = NELE + NF(NBOD)

   50 CONTINUE
      READ(4,*,END=950) CQUE
      IF(CQUE.EQ.'ENDDATA ') GOTO 950
      IF(CQUE.NE.'APPESYS ') GOTO 50
      BACKSPACE 4
      READ(4,*) CQUE,INAP,AP,AW,EA
      IF(INAP.NE.NBOD) GOTO 50

      WRITE(12,1006) INAP,AP,AW,EA
      WRITE(13,1006) INAP,AP,AW,EA
      WRITE(14,1006) INAP,AP,AW,EA

      DO 60 I = 1, 3
      EA(I)   = EA(I)*RAD
      AW(I)   = AW(I)*PIT2/60.D0
   60 CONTINUE

      CALL UNIVEC(AW,WA,WAPP)
      CALL ROTXYZ(EA,R1)
      WM(NBOD)     = WAPP
```

SPAR

```
      DO 70 I = 1, 3
      WS(NBOD,I)  = WA(I)
      PP(NBOD,I)  = AP(I)
      QR(NBOD,I,1)= R1(I,1)
      QR(NBOD,I,2)= R1(I,2)
      QR(NBOD,I,3)= R1(I,3)
   70 CONTINUE

      DO 78 I = 1, NF(NBOD+1)
      INAP    = NELE + I
      DO 72 J = 1, 3
      PL(INAP,J) = PL(INAP,J) - PP(NBOD,J)
   72 CONTINUE

   78 CONTINUE

      GOTO 40

   80 CONTINUE
      NBAP    = NBOD

      WRITE( 8,3000) OD(IOFA)
      WRITE(10,4000) OD(IOFR)
      WRITE( 9,5000) OD(IOTA)
      WRITE(11,6000) OD(IOTR)
      WRITE(12,7000)
      WRITE(13,8000)
      WRITE(14,9000)

C
C          ORBIT AND ATTITUDE CONSTANTS
C

      AM(1)   = AMAX
      AM(2)   = AMAX
      AM(3)   = AMIN
      AM(4)   = AMIN
      SM(1)   = AMAX
      SM(2)   = AMAX
      SM(3)   = AMIN
      SM(4)   = AMIN

      DO 85 I=5, 40
      AM(I)   = 0.D0
      SM(I)   = 0.D0
   85 CONTINUE
```

```
      EL(3)   = EL(3)*RAD
      EL(4)   = EL(4)*RAD
      EL(5)   = EL(5)*RAD
      EL(6)   = EL(6)*RAD
      EB(1)   = EB(1)*RAD
      EB(2)   = EB(2)*RAD
      EB(3)   = EB(3)*RAD
      WV(1)   = WV(1)*PI/30.DO
      WV(2)   = WV(2)*PI/30.DO
      WV(3)   = WV(3)*PI/30.DO

      CALL VARELK(EL,DE)

      ER(1)   = EL(1)
      ER(2)   = EL(2)
      ER(3)   = EL(3)

      CALL ROTSYS(1,EL,RI)
      CALL ROTSYS(2,EL,RN)
      CALL ROTSYS(3,EL,RL)

      IF(IFRA.NE.4) CALL ROTSYS(IFRA,EL,RS)

      CALL ROTXYZ(EB,RA)
      CALL UNIVEC(WV,WU,WBOD)

      ICON    = 0
      NORB    = 0
      TIST    = 0.DO

      DO 90 I = 1, 3
      HA(I)   = 0.DO
      HR(I)   = 0.DO
      AH(I)   = 0.DO
      BA(I)   = 0.DO
      BR(I)   = 0.DO
   90 CONTINUE
```

```
C
C         ORBIT AND ATTITUDE PROPAGATION
C

  100 CONTINUE
      TIME    = ICON*DTI
      ICON    = ICON + 1
      DTIM    = DFRA + TIME
      IF(TIME.GT.TEN) GOTO 900

      ER(4)   = DMOD(EL(4)+DE(4)*TIME,PIT2)
      ER(5)   = DMOD(EL(5)+DE(5)*TIME,PIT2)
      ER(6)   = DMOD(EL(6)+DE(6)*TIME,PIT2)

      CALL STAVEC(ER,SV,RP)

      IF(IFRA.NE.4) GOTO 120
      DO 110 I=1,3
      DO 110 J=1,3
      RS(I,J) = RP(I,J)
  110 CONTINUE
  120 CONTINUE

      ANGL    = DMOD(WBOD*TIME,PIT2)
      CALL ROTMAT(ANGL,WU,R1)
      CALL MATMUL(RA,RS,RZ)
      CALL MATMUL(R1,RZ,RT)

C
C         SUN POSITION
C

      CALL SUN(DJUL,DTIM,SP)
      SU(1)   = ALSU
      SU(2)   = DESU
      PRAD    = SUNC/ROSU/ROSU

      CALL UNIVEC(SP,RV,DIST)
      CALL VECROT(RT,RV,US)

      AA(1)   = DASIN (US(1))*DEG
      AA(2)   = DATAN2(US(3),US(2))*DEG

      CALL EARSHA(SV,SP,SHAD)
      SUPR    = PRAD*SHAD
```

```
C
C          ATMOSPHERIC PROPERTY COMPUTATIONS
C

      GWST    = SGMT(DJUL,DTIM)

      CALL GEOCEN(SV,SA)

      CALL ASDAMO(SA,SU,SF,DJUL,DTIM,GWST,TE,AD,WMOL,RHOD)

      CALL ATMVEL(SV,AV)

      UV(1)   = SV(4) - AV(1)
      UV(2)   = SV(5) - AV(2)
      UV(3)   = SV(6) - AV(3)

      CALL UNIVEC(UV,RV,VREL)
      CALL VECROT(RT,RV,UV)

      TEMP    = TE(2)
      SPRT    = VREL/DSQRT(2.D0*BOAV*TEMP/WMOL)
      AEPR    = VREL*VREL*RHOD*.5D0

C
C          SPACECRAFT MAIN BODY LOOP
C

      DO 140 J=1,3
      FA(J)   = 0.D0
      TA(J)   = 0.D0
      FR(J)   = 0.D0
      TR(J)   = 0.D0
  140 CONTINUE

      DO 170 I=1,NF(1)

      DO 150 J = 1, 3
      VN(J)   = VL(I,J)
      PV(J)   = PL(I,J)
      SC(J)   = SL(I,J)
      SC(J+3)= SL(I,J+3)
      RG(J)   = PV(J) - GC(J)
  150 CONTINUE
      SC(7)   = SL(I,7)
      AREA    = AL(I)

      TWTI    = SC(7)/TEMP
```

```
C
C        AERODYNAMIC FORCE AND TORQUE ON A PLANE ELEMENT
C

      CALL AERODY(AEPR,UV,VN,RG,SPRT,TWTI,SC,AREA,F1,T1)

C
C        SOLAR RADIATION FORCE AND TORQUE COMPUTATION
C

      CALL SOLPRE(SUPR,US,VN,RG,SC,AREA,F5,T5)

      DO 160 J=1,3
      FA(J)   = FA(J) + F1(J)
      TA(J)   = TA(J) + T1(J)
      FR(J)   = FR(J) + F5(J)
      TR(J)   = TR(J) + T5(J)
  160 CONTINUE
  170 CONTINUE

C
C        APPENDAGE LOOP
C

      NBOD = 0
      NELE = 0

  190 CONTINUE

      NBOD    = NBOD + 1
      IF(NF(NBOD+1).EQ.0) GOTO 400

      NELE    = NELE + NF(NBOD)
      WAPP    = WM(NBOD)
      DO 200 J = 1, 3
      AW(J)   = WS(NBOD,J)
      F1(J)   = GC(J) - PP(NBOD,J)
      R1(J,1)= QR(NBOD,J,1)
      R1(J,2)= QR(NBOD,J,2)
      R1(J,3)= QR(NBOD,J,3)
      F2(J)   = 0.DO
      T2(J)   = 0.DO
      F6(J)   = 0.DO
      T6(J)   = 0.DO
  200 CONTINUE
```

```
      ANGL     = DMOD(WAPP*TIME,PIT2)
      CALL ROTMAT(ANGL,AW,R2)
      CALL MATMUL(R1,R2,RC)
      CALL VECROT(RC,UV,RV)
      CALL VECROT(RC,US,AS)
      CALL VECROT(RC,F1,GA)

      AA(2*NBOD+1) = DASIN(AS(1))*DEG
      AA(2*NBOD+2) = DATAN2(AS(3),AS(2))*DEG

      DO 300 I=1,NF(NBOD+1)

      INAP     = NELE + I

      DO 210 J=1,3
      VN(J)   = VL(INAP,J)
      PV(J)   = PL(INAP,J)
      SC(J)   = SL(INAP,J)
      SC(J+3)= SL(INAP,J+3)
      RG(J)   = PV(J) - GA(J)
  210 CONTINUE
      SC(7)   = SL(INAP,7)
      AREA    = AL(INAP)

      TWTI    = SC(7)/TEMP

C
C         AERODYNAMIC FORCE AND TORQUE
C

      CALL AERODY(AEPR,RV,VN,RG,SPRT,TWTI,SC,AREA,F1,T1)

C
C         SOLAR RADIATION FORCE AND TORQUE
C

      CALL SOLPRE(SUPR,AS,VN,RG,SC,AREA,F5,T5)

      DO 220 J=1,3
      F2(J)   = F2(J) + F1(J)
      T2(J)   = T2(J) + T1(J)
      F6(J)   = F6(J) + F5(J)
      T6(J)   = T6(J) + T5(J)
  220 CONTINUE
  300 CONTINUE
```

```
C
C        MAIN BODY + APPENDAGE
C

      CALL VECINV(RC,F2,F1)
      CALL VECINV(RC,T2,T1)
      CALL VECINV(RC,F6,F5)
      CALL VECINV(RC,T6,T5)

      DO 310 J=1,3
      FA(J)  = FA(J) + F1(J)
      TA(J)  = TA(J) + T1(J)
      FR(J)  = FR(J) + F5(J)
      TR(J)  = TR(J) + T5(J)
  310 CONTINUE

      GOTO 190

  400 CONTINUE

C
C        ROTATE THE FORCE AND TORQUE TO THE OUTPUT SYSTEM
C

      CALL VECINV(RT,FA,F1)
      CALL VECINV(RT,TA,T1)
      CALL VECINV(RT,FR,F5)
      CALL VECINV(RT,TR,T5)

      IF(IOFA.EQ.1) CALL VECROT(RI,F1,F2)
      IF(IOFA.EQ.2) CALL VECROT(RN,F1,F2)
      IF(IOFA.EQ.3) CALL VECROT(RL,F1,F2)
      IF(IOFA.EQ.4) CALL VECROT(RP,F1,F2)
      IF(IOFA.EQ.5) CALL VECROT(RZ,F1,F2)
      IF(IOFA.EQ.6) CALL VECROT(RT,F1,F2)

      IF(IOFR.EQ.1) CALL VECROT(RI,F5,F6)
      IF(IOFR.EQ.2) CALL VECROT(RN,F5,F6)
      IF(IOFR.EQ.3) CALL VECROT(RL,F5,F6)
      IF(IOFR.EQ.4) CALL VECROT(RP,F5,F6)
      IF(IOFR.EQ.5) CALL VECROT(RZ,F5,F6)
      IF(IOFR.EQ.6) CALL VECROT(RT,F5,F6)

      IF(IOTA.EQ.1) CALL VECROT(RI,T1,T2)
      IF(IOTA.EQ.2) CALL VECROT(RN,T1,T2)
      IF(IOTA.EQ.3) CALL VECROT(RL,T1,T2)
      IF(IOTA.EQ.4) CALL VECROT(RP,T1,T2)
      IF(IOTA.EQ.5) CALL VECROT(RZ,T1,T2)
      IF(IOTA.EQ.6) CALL VECROT(RT,T1,T2)
```

```
      IF(IOTR.EQ.1) CALL VECROT(RI,T5,T6)
      IF(IOTR.EQ.2) CALL VECROT(RN,T5,T6)
      IF(IOTR.EQ.3) CALL VECROT(RL,T5,T6)
      IF(IOTR.EQ.4) CALL VECROT(RP,T5,T6)
      IF(IOTR.EQ.5) CALL VECROT(RZ,T5,T6)
      IF(IOTR.EQ.6) CALL VECROT(RT,T5,T6)

C
C         LINEAR AND ANGULAR MOMENTUM COMPUTATIONS
C

      DO 450 I = 1, 3
      HA(I)   = HA(I) + F2(I)*DTI
      HR(I)   = HR(I) + F6(I)*DTI
      AH(I)   = AH(I) + T2(I)*DTI
      RH(I)   = RH(I) + T6(I)*DTI
      J       = 10*I
      IF(HA(I).LT.AM(J+1)) AM(J+1)    = HA(I)
      IF(HA(I).GT.AM(J+3)) AM(J+3)    = HA(I)
      IF(AH(I).LT.AM(J+2)) AM(J+2)    = AH(I)
      IF(AH(I).GT.AM(J+4)) AM(J+4)    = AH(I)
      IF(HR(I).LT.SM(J+1)) SM(J+1)    = HR(I)
      IF(HR(I).GT.SM(J+3)) SM(J+3)    = HR(I)
      IF(RH(I).LT.SM(J+2)) SM(J+2)    = RH(I)
      IF(RH(I).GT.SM(J+4)) SM(J+4)    = RH(I)
  450 CONTINUE

C
C         AEROF, AEROT, SORAF AND SORAT TABLES
C

      WRITE(1,1120) TIME

      WRITE( 8,1320) TIME,F2,HA
      WRITE(10,1320) TIME,F6,HR
      WRITE( 9,1320) TIME,T2,AH
      WRITE(11,1320) TIME,T6,RH
```

```
C
C         ORBPR.DAT FILE RESULTS
C

      ANME     = ER(6)*DEG
      VLCT     = DSQRT(SV(4)*SV(4)+SV(5)*SV(5)+SV(6)*SV(6))
      VLCT     = VLCT*1.D-03
      RAIO     = DSQRT(SV(1)*SV(1)+SV(2)*SV(2)+SV(3)*SV(3))
      RAIO     = RAIO*1.D-03
      ALON     = DMOD(SA(1)-GWST,PIT2)*DEG
      IF(ALON.LT.0.D0) ALON    = ALON + 360.D0
      ALAT     = SA(2)*DEG
      ALTU     = SA(3)/1.D+03
      SURA     = DMOD(SU(1),PIT2)*DEG
      SUDL     = SU(2)*DEG
      WRITE(12,1720) TIME,ANME,RAIO,VLCT,
     1               ALON,ALAT,ALTU,SURA,SUDL

C
C         ADRAG.DAT FILE RESULTS
C

      ALPH     = DASIN(UV(1))*DEG
      BETA     = DMOD(DATAN2(UV(3),UV(2)),PIT2)*DEG
      F1(1)    = FA(1)/AEPR/SBAS
      F1(2)    = FA(2)/AEPR/SBAS
      F1(3)    = FA(3)/AEPR/SBAS
      CDAR     = FA(1)*UV(1)+FA(2)*UV(2)+FA(3)*UV(3)
      CDAR     = -CDAR/AEPR/SBAS
      WRITE(13,1820) TIME,TEMP,RHOD,SPRT,ALPH,BETA,F1,CDAR

C
C         SUNAN.DAT FILE RESULTS
C

      WRITE(14,9020) TIME,(AA(I),I=1,2*NBAP)

C
C         ORBMO.DAT FILE RESULTS
C

      FMOD     = DSQRT(F2(1)*F2(1)+F2(2)*F2(2)+F2(3)*F2(3))
      TMOD     = DSQRT(T2(1)*T2(1)+T2(2)*T2(2)+T2(3)*T2(3))
      IF(FMOD.LT.AM(1)) AM(1)     = FMOD
      IF(FMOD.GT.AM(3)) AM(3)     = FMOD
      IF(TMOD.LT.AM(2)) AM(2)     = TMOD
      IF(TMOD.GT.AM(4)) AM(4)     = TMOD
```

```
      FMOD    = DSQRT(F6(1)*F6(1)+F6(2)*F6(2)+F6(3)*F6(3))
      TMOD    = DSQRT(T6(1)*T6(1)+T6(2)*T6(2)+T6(3)*T6(3))
      IF(FMOD.LT.SM(1)) SM(1)     = FMOD
      IF(FMOD.GT.SM(3)) SM(3)     = FMOD
      IF(TMOD.LT.SM(2)) SM(2)     = TMOD
      IF(TMOD.GT.SM(4)) SM(4)     = TMOD

      DPER    = TIME - TIST

      IF(DPER.LT.PERI) GOTO 880
      TIST    = TIME
      NORB    = NORB + 1

      DO 850 I = 1, 3
      AM(3+2*I) = (HA(I) - DA(I))/DPER
      AM(4+2*I) = (AH(I) - BA(I))/DPER
      SM(3+2*I) = (HR(I) - DR(I))/DPER
      SM(4+2*I) = (RH(I) - BR(I))/DPER
      J         = 10*I
      AM(J+1)   = AM(J+1) - DA(I)
      AM(J+3)   = AM(J+3) - DA(I)
      AM(J+2)   = AM(J+2) - BA(I)
      AM(J+4)   = AM(J+4) - BA(I)
      SM(J+1)   = SM(J+1) - DR(I)
      SM(J+3)   = SM(J+3) - DR(I)
      SM(J+2)   = SM(J+2) - BR(I)
      SM(J+4)   = SM(J+4) - BR(I)
      AM(J+5)   = AM(J+3) - AM(J+1)
      AM(J+6)   = AM(J+4) - AM(J+2)
      SM(J+5)   = SM(J+3) - SM(J+1)
      SM(J+6)   = SM(J+4) - SM(J+2)
      AM(J+7)   = HA(I) - DA(I)
      AM(J+8)   = AH(I) - BA(I)
      SM(J+7)   = HR(I) - DR(I)
      SM(J+8)   = RH(I) - BR(I)
      AM(J+9)   = HA(I)
      AM(J+10)  = AH(I)
      SM(J+9)   = HR(I)
      SM(J+10)  = RH(I)
      DA(I)     = HA(I)
      BA(I)     = AH(I)
      DR(I)     = HR(I)
      BR(I)     = RH(I)
  850 CONTINUE
```

```
      WRITE(15,3110) NORB,TIME
      WRITE(15,3120) OD(IOFA),OD(IOTA),AM

      WRITE(15,3140) OD(IOFR),OD(IOTR),SM

      AM(1)   = AMAX
      AM(2)   = AMAX
      AM(3)   = AMIN
      AM(4)   = AMIN
      SM(1)   = AMAX
      SM(2)   = AMAX
      SM(3)   = AMIN
      SM(4)   = AMIN

      DO 860 I = 1, 3
      J          = 10*I
      AM(J+1)    = HA(I)
      AM(J+3)    = HA(I)
      AM(J+2)    = AH(I)
      AM(J+4)    = AH(I)
      SM(J+1)    = HR(I)
      SM(J+3)    = HR(I)
      SM(J+2)    = RH(I)
      SM(J+4)    = RH(I)
  860 CONTINUE

  880 CONTINUE

      GOTO 100
```

```
C
C         TERMINATION
C

  900 CONTINUE
      CLOSE(UNIT=3)
      CLOSE(UNIT=4)

      DO 902 I = 6, 15
      CLOSE(UNIT=I)
  902 CONTINUE

      STOP

C
C         ERROR MESSAGES
C

  910 CONTINUE
      WRITE(1,*) ' TOO MANY APPENDAGES (>10)'
      GOTO 900

  920 CONTINUE
      WRITE(1,*) ' ATTITUDE RELATED SYSTEM ',
     1           'INDEX OUT OF RANGE (1-4)'
      GOTO 900
  950 CONTINUE
      WRITE(1,*) ' APPENDAGE SYSTEM DEFINITION CARD ',
     1           'NOT FOUND'
      GOTO 900
```

```
1000 FORMAT(' ORBITAL ELEMENTS:',/,
     1      '   SEMI MAJOR AXIS (M)      ',F15.3,/,
     2      '   ECCENTRICITY             ',F15.8,/,
     3      '   INCLINATION     (DEG)    ',F15.3,/,
     4      '   ASCENDING NODE  (DEG)    ',F15.3,/,
     5      '   PERIGEE ARG.    (DEG)    ',F15.3,/,
     6      '   MEAN ANOMALY    (DEG)    ',F15.3,/,
     7      '   ORBITAL PERIOD  (MIN)    ',F15.3,/)
1001 FORMAT(' START TIME:',/,
     1      '   MONTH                    ',I11,/,
     2      '   DAY                      ',I11,/,
     3      '   YEAR                     ',I11,/,
     4      '   MODIFIED JULIAN DATE     ',F13.1,/,
     5      '   HOUR                     ',I11,/,
     6      '   MINUTES                  ',I11,/,
     7      '   SECONDS                  ',F15.3,/,
     8      '   TIME STEP (SECONDS)      ',F15.3,/,
     9      '   CALCULATION TIME (S)     ',F15.3,/)
1002 FORMAT(' SOLAR FLUX DATA:',/,
     1      '   SOLAR FLUX F10.7         ',F15.2,/,
     2      '   AVERAGED SOLAR FLUX      ',F15.2,/,
     1      '   GEOMAG. ACTIVITY KP      ',F15.2,/)
1003 FORMAT(' SATELLITE CENTER OF MASS IN BODY',
     1      ' FRAME COORDINATES:',/,
     2      '   X  AXIS  (METERS)        ',F15.5,/,
     3      '   Y  AXIS  (METERS)        ',F15.5,/,
     4      '   Z  AXIS  (METERS)        ',F15.5,/)
1004 FORMAT(' REFERENCE AREA FOR DRAG COEFFICIENT:',/,
     1      '   SATELLITE AREA     (M2)',F15.5,/)
1005 FORMAT(' ATTITUDE RELATED FRAME:',/,
     1      '   FRAME NUMBER             ',I9,' - ',A20,/,
     2      '   X-Y-Z ROTATION    (DEG)',3F15.5,/,
     3      '   ANGULAR VELOCITY  (RPM)',3F15.5,/)
1006 FORMAT(' APPENDAGE NUMBER ',I2,/,
     1      '   APPENDAGE POSITION (M)',3F15.5,/,
     2      '   ANGULAR VELOCITY (RPM)',3F15.5,/,
     3      '   X-Y-Z ROTATION   (DEG)',3F15.5,/)

3000 FORMAT(16X,'AERODYNAMIC FORCES (N) AND IMPULSES',
     1' (N*S)',/,26X,A20,/,
     2'  TIME                    FORCES',26X,'IMPULSES',/,
     3'   (S)        X          Y            Z               ',
     4'X          Y          Z')
4000 FORMAT(16X,'RADIATION FORCES (N) AND IMPULSES',
     1' (N*S)',/,26X,A20,/,
     2'  TIME                    FORCES',26X,'IMPULSES',/,
     3'   (S)        X          Y            Z               ',
     4'X          Y          Z')
5000 FORMAT('          AERODYNAMIC TORQUES (N*M) AND',
     1' ANGULAR IMPULSES (N*M*S)',/,26X,A20,/,
     2'  TIME',15X,'TORQUES',21X,'ANGULAR IMPULSES',/,
     3'   (S)        X          Y            Z               ',
     4'X          Y          Z')
```

```
6000 FORMAT('              RADIATION TORQUES (N*M) AND'
    1' ANGULAR IMPULSES (N*M*S)',/,26X,A20,/,
    2'  TIME',15X,'TORQUES',21X,'ANGULAR IMPULSES',/,
    3'   (S)           X             Y            Z           ',
    4'X            Y            Z')
7000 FORMAT('                                              ORBIT DATA',/,
    1' ORBIT   MEAN GEOCENTR. SATEL. LONGI-  LATI- ',
    2'GEOCENTR. SUN R.    SUN',/,
    3'  TIME  ANOM.  DISTANCE VELOC.   TUDE   TUDE ',
    4' ALTITUDE ASCEN. DECLI.',/,
    5'   (S)  (DEG)      (KM) (KM/S)  (DEG)  (DEG) ',
    6'     (KM)  (DEG)  (DEG)')
8000 FORMAT(29X,'ATMOSPHERIC DATA',/,
    1' ORBIT ATM.     LOCAL SPEED   ANG.   ANG.     ',
    2'DRAG COMPONENTS       DRAG',/,
    3'  TIME TEMP   DENSITY RATIO  ALPHA   BETA      ',
    4'                    COEFF.',/,
    5'   (S)  (K)   (KG/M3)        (DEG)  (DEG)    X',
    6'        Y        Z          ')
9000 FORMAT(22X,'SUN ASPECT ANGLE (DEGREES)',/,
    1' ORBIT  SPACECRAFT   APPENDAGE   APPENDAGE   ',
    2'APPENDAGE   APPENDAGE',/,
    3'  TIME  MAIN  BODY    NUMBER 1    NUMBER 2   ',
    4' NUMBER 3    NUMBER 4',/,
    5'   (S) ALPHA  BETA ALPHA  BETA ALPHA  BETA ALPHA',
    6'  BETA ALPHA  BETA')

1120 FORMAT(20X,I6)

1320 FORMAT(I6,1X,5(E10.4,1X),E10.4)

1720 FORMAT(I6,1X,F6.2,1X,F9.3,1X,F6.3,1X,F6.2,1X,
    1       F6.2,1X,F9.3,1X,F6.2,1X,F6.2)

1820 FORMAT(I6,1X,I4,1X,E9.3,1X,F5.2,1X,F6.2,1X,F6.2,1X,
    1       3(F7.3,1X),F6.3)

9020 FORMAT(I6,10(1X,F5.1,1X,F5.1))

3110 FORMAT(' ORBIT NUMBER ',I4,'   T = ',I6,' S',/)
```

```
3120 FORMAT(' AERODYNAMIC FORCES AND TORQUES:',/,
    1'                ',A20,1X,A20,//,
    2' AERODYNAMIC           FORCE                  TORQUE',/,
    3'  MINIMUM     ',E12.6,' N        ',E12.6,' N*M  ',/,
    4'  MAXIMUM     ',E12.6,' N        ',E12.6,' N*M  ',/,
    5'  X MEAN      ',E12.6,' N        ',E12.6,' N*M  ',/,
    6'  Y MEAN      ',E12.6,' N        ',E12.6,' N*M  ',/,
    7'  Z MEAN      ',E12.6,' N        ',E12.6,' N*M  ',//,
    8' AEROD. IMPULSE     LINEAR               ANGULAR',/,
    9'  X MINIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    A'  X MAXIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    1'  X DIFF.     ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    2'  X BUILD-UP  ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    3'  X ACCUM.    ',E12.6,' N*S      ',E12.6,' N*M*S',//,
    4'  Y MINIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    5'  Y MAXIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    6'  Y DIFF.     ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    7'  Y BUILD-UP  ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    8'  Y ACCUM.    ',E12.6,' N*S      ',E12.6,' N*M*S',//,
    9'  Z MINIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    B'  Z MAXIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    1'  Z DIFF.     ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    2'  Z BUILD-UP  ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    3'  Z ACCUM.    ',E12.6,' N*S      ',E12.6,' N*M*S',/)

3140 FORMAT(' SOLAR RADIATION FORCES AND TORQUES:',/,
    1'                ',A20,1X,A20,//,
    2' SOLAR RADIATION       FORCE                  TORQUE',/,
    3'  MINIMUM     ',E12.6,' N        ',E12.6,' N*M  ',/,
    4'  MAXIMUM     ',E12.6,' N        ',E12.6,' N*M  ',/,
    5'  X MEAN      ',E12.6,' N        ',E12.6,' N*M  ',/,
    6'  Y MEAN      ',E12.6,' N        ',E12.6,' N*M  ',/,
    7'  Z MEAN      ',E12.6,' N        ',E12.6,' N*M  ',//,
    8' S. RAD. IMPULSE    LINEAR               ANGULAR',/,
    9'  X MINIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    A'  X MAXIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    1'  X DIFF.     ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    2'  X BUILD-UP  ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    3'  X ACCUM.    ',E12.6,' N*S      ',E12.6,' N*M*S',//,
    4'  Y MINIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    5'  Y MAXIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    6'  Y DIFF.     ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    7'  Y BUILD-UP  ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    8'  Y ACCUM.    ',E12.6,' N*S      ',E12.6,' N*M*S',//,
    9'  Z MINIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    B'  Z MAXIMUM   ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    1'  Z DIFF.     ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    2'  Z BUILD-UP  ',E12.6,' N*S      ',E12.6,' N*M*S',/,
    3'  Z ACCUM.    ',E12.6,' N*S      ',E12.6,' N*M*S',/)

     END
```

```
      SUBROUTINE ARELEM(NF,VU,VQ,SG,AE)
C
C     THE SUBROUTINE ARELEM  READS  THE  GRID  ELEMENTS DATA
C     FILE AND CALCULATES ITS NORMAL, AREA AND THE  POSITION
C     OF ITS CENTER OF PRESSURE. ALL THE ELEMENTS ARE STORED
C     IN ARRAYS, TO BE USED IN THE MAIN PROGRAM.
C
C     OUTPUTS:
C       NF(10)    ARRAY  CONTAINING  THE  NUMBER  OF  SURFACE
C                 ELEMENTS OF THE SPACECRAFT BODY (NF(1)) AND
C                 EACH APPENDAGE (NF(2) ... NF(10) -  MAXIMUM
C                 9 APPENDAGES).
C       VU(50,3)  COMPONENTS OF THE SURFACE NORMAL,  FOR EACH
C                 ELEMENT (MAXIMUM 50 ELEMENTS).
C       VQ(50,3)  POSITION, IN METERS, OF THE ELEMENT  CENTER
C                 OF PRESSURE,  RELATIVE  TO  THE  SPACECRAFT
C                 SYSTEM.
C       SG(50,7)  SURFACE CHARACTERISTICS, RESPECTIVELY:
C                 TANGENTIAL AERODYNAMIC COEFFICIENT.
C                 NORMAL AERODYNAMIC COEFFICIENT.
C                 SOLAR SPECULAR REFLECTION COEFFICIENT.
C                 SOLAR DIFFUSE REFLECTION COEFFICIENT.
C                 SOLAR ABSORPTION COEFFICIENT.
C                 INFRA-RED EMMITANCE COEFFICIENT.
C                 ABSOLUTE TEMPERATURE OF THE ELEMENT IN K.
C       AE(50)    AREA OF EACH ELEMENT IN M**2.
C
C     AUTHOR:     VALDEMIR CARRARA,  MAY 1987.
C
      IMPLICIT REAL*8 (A-H,O-Z)

      PARAMETER (NSUR=50, NGRD=50)

      DIMENSION GR(NGRD,3),VV(NSUR,3),VP(NSUR,3),AR(NSUR)
      DIMENSION SG(NSUR,7),VU(NSUR,3),VQ(NSUR,3),AE(NSUR)
      DIMENSION IG(NGRD),NS(NSUR),NF(11)
      DIMENSION EG(6),VN(3),PV(3),SC(7)
      DIMENSION KG(4)

      CHARACTER *8 CQ

      WRITE(6,1600)

      WRITE(7,1500)

      NG     = 0
```

```
C
C         READ THE GRID ELEMENTS FROM SATGE.DAT FILE
C

  100 CONTINUE
      READ(3,1400,END=200) CQ
 1400 FORMAT(A8,2I8,4F8.2)
      IF(CQ.EQ.'ENDDATA ') GOTO 200
      IF(CQ.NE.'GRID    ') GOTO 100

      BACKSPACE 3
      READ(3,1400) CQ,EG
      NG      = NG + 1
      IF(NG.GT.NGRD) GOTO 920
      GR(NG,1) = EG(3)
      GR(NG,2) = EG(4)
      GR(NG,3) = EG(5)
      IG(NG)   = EG(1)
      GOTO 100

  200 CONTINUE
      IF(NG.LT.3) GOTO 900
      REWIND 3
      IELE    = 0

C
C         READ THE SURFACE DEFINITION CARDS FROM SATGE.DAT
C

  250 CONTINUE
      READ(3,1410,END=600) CQ
      IF(CQ.EQ.'ENDDATA ') GOTO 600
      IF(CQ.NE.'CTRIA3  ') GOTO 300

C
C         TRIANGLE ELEMENT COMPUTATIONS
C

      BACKSPACE 3
      READ(3,1410) CQ,EG
      IELE    = IELE + 1
      IF(IELE.GT.NSUR) GOTO 930

      DO 270 I = 1, 3
      JG      = 0
  260 CONTINUE
      JG      = JG + 1
      IF(JG.GT.NG) GOTO 270
      IF(IG(JG).EQ.EG(2+I)) KG(I)  = JG
      GOTO 260
  270 CONTINUE
```

```
      XD21    =   GR(KG(2),1) - GR(KG(1),1)
      XD31    =   GR(KG(3),1) - GR(KG(1),1)
      YD21    =   GR(KG(2),2) - GR(KG(1),2)
      YD31    =   GR(KG(3),2) - GR(KG(1),2)
      ZD21    =   GR(KG(2),3) - GR(KG(1),3)
      ZD31    =   GR(KG(3),3) - GR(KG(1),3)

      XVTC    =   YD21*ZD31 - ZD21*YD31
      YVTC    =   ZD21*XD31 - XD21*ZD31
      ZVTC    =   XD21*YD31 - YD21*XD31

      ARMO    =   DSQRT(XVTC*XVTC + YVTC*YVTC + ZVTC*ZVTC)
      AREA    =   ARMO*.5D-06
      VN(1)   =   XVTC/ARMO
      VN(2)   =   YVTC/ARMO
      VN(3)   =   ZVTC/ARMO

      PV(1)   =   (GR(KG(1),1)+GR(KG(2),1)+GR(KG(3),1))/3.D3
      PV(2)   =   (GR(KG(1),2)+GR(KG(2),2)+GR(KG(3),2))/3.D3
      PV(3)   =   (GR(KG(1),3)+GR(KG(2),3)+GR(KG(3),3))/3.D3

      NS(IELE) = EG(1)
      AR(IELE) = AREA

      DO 280 I = 1, 3
      VV(IELE,I) = VN(I)
      VP(IELE,I) = PV(I)
  280 CONTINUE

      GOTO 250

  300 CONTINUE
      IF(CQ.NE.'CQUAD4  ') GOTO 400
C
C        QUADRILATERAL ELEMENT COMPUTATIONS
C

      BACKSPACE 3
      READ(3,1410) CQ,EG
      IELE     = IELE + 1
      IF(IELE.GT.NSUR) GOTO 930

      DO 320 I = 1, 4
      JG       = 0
  310 CONTINUE
      JG       = JG + 1
      IF(JG.GT.NG) GOTO 320
      IF(IG(JG).EQ.EG(2+I)) KG(I)  = JG
      GOTO 310
  320 CONTINUE
```

```
      XD21   =  GR(KG(2),1) - GR(KG(1),1)
      XD31   =  GR(KG(3),1) - GR(KG(1),1)
      YD21   =  GR(KG(2),2) - GR(KG(1),2)
      YD31   =  GR(KG(3),2) - GR(KG(1),2)
      ZD21   =  GR(KG(2),3) - GR(KG(1),3)
      ZD31   =  GR(KG(3),3) - GR(KG(1),3)

      XVTC   =  YD21*ZD31 - ZD21*YD31
      YVTC   =  ZD21*XD31 - XD21*ZD31
      ZVTC   =  XD21*YD31 - YD21*XD31

      ARMO   =  DSQRT(XVTC*XVTC + YVTC*YVTC + ZVTC*ZVTC)
      AREA   =  ARMO*.5D-06

      VN(1)  =  XVTC/ARMO
      VN(2)  =  YVTC/ARMO
      VN(3)  =  ZVTC/ARMO

      XD21   =  GR(KG(3),1) - GR(KG(1),1)
      XD31   =  GR(KG(4),1) - GR(KG(1),1)
      YD21   =  GR(KG(3),2) - GR(KG(1),2)
      YD31   =  GR(KG(4),2) - GR(KG(1),2)
      ZD21   =  GR(KG(3),3) - GR(KG(1),3)
      ZD31   =  GR(KG(4),3) - GR(KG(1),3)

      XVTC   =  YD21*ZD31 - ZD21*YD31
      YVTC   =  ZD21*XD31 - XD21*ZD31
      ZVTC   =  XD21*YD31 - YD21*XD31

      ARMO   =  DSQRT(XVTC*XVTC + YVTC*YVTC + ZVTC*ZVTC)
      AREA   =  AREA + ARMO*.5D-06

      PV(1)  =  (GR(KG(1),1) + GR(KG(2),1) +
     1           GR(KG(3),1) + GR(KG(4),1))/4.D3
      PV(2)  =  (GR(KG(1),2) + GR(KG(2),2) +
     1           GR(KG(3),2) + GR(KG(4),2))/4.D3
      PV(3)  =  (GR(KG(1),3) + GR(KG(2),3) +
     1           GR(KG(3),3) + GR(KG(4),3))/4.D3

      NS(IELE) = EG(1)
      AR(IELE) = AREA

      DO 340 I = 1, 3
      VV(IELE,I) = VN(I)
      VP(IELE,I) = PV(I)
  340 CONTINUE

      GOTO 250

  400 CONTINUE

      GOTO 250
```

```
C
C         PLASE.DAT FILE OUTPUTS
C
  600 CONTINUE
      DO 605 J = 1, IELE
      WRITE(6,1610) J,NS(J),(VV(J,I),I=1,3),
     1              (VP(J,I),I=1,3),AR(J)
  605 CONTINUE

C
C         READ THE BODYAP COMMANDS FROM THE INELE.DAT FILE
C

      IELE    = 0
      NBOD    = -1
      IFLA    = 1

  610 CONTINUE
      IF(IFLA.EQ.0) GOTO 660
      IELA    = 0
      NBOD    = NBOD + 1
      IF(NBOD.GE.10) GOTO 950
      IFLA    = 0
      REWIND 4

  620 CONTINUE
      READ(4,*,END=610) CQ
      IF(CQ.EQ.'ENDDATA ') GOTO 610
      IF(CQ.NE.'BODYAP  ') GOTO 620
      BACKSPACE 4
      READ(4,*) CQ,INBO,NUEL,SC
      IF(INBO.NE.NBOD) GOTO 620
      IFLA    = 1
      NUEA    = IABS(NUEL)
      IELE    = IELE + 1
      IELA    = IELA + 1
      NF(NBOD+1) = IELA
      SNUE    = 1.D0
      IF(NUEL.LT.0) SNUE    = -1.D0
      NG      = 0

  630 CONTINUE
      NG      = NG + 1
      IF(NG.GT.NSUR) GOTO 940
      IF(NUEA.NE.NS(NG)) GOTO 630

      AE(IELE)      = AR(NG)
```

```
      DO 640 I = 1, 3
      SG(IELE,I)     = SC(I)
      SG(IELE,I+3)   = SC(I+3)
      VQ(IELE,I)     = VP(NG,I)
      VU(IELE,I)     = SNUE*VV(NG,I)
  640 CONTINUE
      SG(IELE,7)     = SC(7)

C
C        EXTSE.DAT FILE OUTPUTS
C

      WRITE(7,1510) NBOD,IELA,(VU(IELE,I),I=1,3),
     1               (VQ(IELE,I),I=1,3),AE(IELE)
      GOTO 620

  660 CONTINUE

      RETURN

C
C        ERROR MESSAGES
C

  900 CONTINUE
      WRITE(1,*) ' TOO FEW GRID ELEMENTS IN DATA FILE'
      GOTO 990
  920 CONTINUE
      WRITE(1,*) ' TOO MANY GRID ELEMENTS (>50) ',
     1           'IN DATA FILE'
      GOTO 990
  930 CONTINUE
      WRITE(1,*) ' TOO MANY SURFACE ELEMENTS (>50)'
      GOTO 990
  940 CONTINUE
      WRITE(1,*) ' SURFACE NUMBER NOT FOUND'
      GOTO 990
  950 CONTINUE
      WRITE(1,*) ' TOO MANY APPENDAGES (>10)'
      GOTO 990

  990 CONTINUE
      STOP
```

```
1410 FORMAT(A8,6I8)

1500 FORMAT(18X,'SPACECRAFT EXTERNAL SURFACE ELEMENTS',/,
    1' BODY     EXTERNAL NORMAL VECTOR           ELEMENT ',
    2'POSITION (M)               AREA',/,
    3' NUBR        X          Y          Z          X     ',
    4'          Y           Z           (M2)')

1510 FORMAT(I2,I3,3F9.5,4E10.4)

1600 FORMAT(24X,'SPACECRAFT SURFACE ELEMENTS',/,
    1' INT IDENT  EXT. NORMAL VECTOR          ELEMENT ',
    2'POSITION (M)              AREA',/,
    3' NBR NUMBR     X       Y       Z          X     ',
    4'         Y           Z          (M2)')

1610 FORMAT(I4,I6,3F7.4,3E10.4,E10.4)

     END
```

```
      SUBROUTINE REAINP(CHAT,NFIL,NUBR,AY)
C
C     THE SUBROUTINE REAINP READS THE INPUT  ELEMENTS  GIVEN
C     BY ITS NAME AND RETURNS WITH THE ELEMENTS IN AY.
C
C     INPUTS:
C       CHAT      NAME OF THE INPUT ELEMENTS.
C       NFIL      NUMBER OF THE FILE.
C       NUBR      NUMBER OF ELEMENTS THAT MUST BE READ.
C
C     OUTPUTS:
C       AY        ARRAY CONTAINING THE ELEMENTS.
C
C     AUTHOR:     VALDEMIR CARRARA,  MAY 87.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      CHARACTER *8 CHAT,CQUE

      DIMENSION AY(1)
      REWIND NFIL

  100 CONTINUE
      READ(NFIL,*,END=200) CQUE
      IF(CQUE.EQ.'ENDDATA ') GOTO 200
      IF(CQUE.NE.CHAT) GOTO 100
      BACKSPACE NFIL
      READ(NFIL,*) CQUE,(AY(I),I=1,NUBR)
      RETURN

  200 CONTINUE
      WRITE(1,*) CHAT,' DATA CARD NOT FOUND'
      STOP
      END
```

FILE AUROT.FTN

```
FTN77,J
$CDS ON


      SUBROUTINE AERODY(AEPR,UV,VN,RG,SPRT,TWTI,SC,AREA,FC,
     1                  TC)
C
C     THE SUBROUTINE AERODY  OBTAINS THE  AERODYNAMIC  FORCE
C     AND TORQUE  COEFFICIENTS FOR AN EXTERNAL SURFACE PLANE
C     ELEMENT. THE SUBROUTINE AERODY USES THE FREE MOLECULAR
C     FLOW THEORY TO COMPUTE THE ELEMENTARY FORCES AND  TOR-
C     QUES.
C
C     INPUTS:
C       AEPR   AERODYNAMIC PRESSURE:
C              HALF OF THE LOCAL  ATMOSPHERIC  DENSITY  TIMES
C              THE  SQUARE  OF  THE  SATELLITE  VELOCITY,  TO
C              CALCULATE THE FORCES OR THE UNIT TO  CALCULATE
C              THE COEFFICIENTS.
C       UV     UNIT VECTOR OF THE SATELLITE  VELOCITY IN  THE
C              BODY FRAME COORDINATES.
C       VN     UNIT VECTOR NORMAL TO THE ELEMENT.
C       RG     POSITION OF THE  ELEMENT  CENTRE  OF  PRESSURE
C              RELATIVE TO THE GRAVITY CENTRE OF  SPACECRAFT,
C              IN BODY FRAME COORDINATES, IN METERS.
C       SPRT   SPEED  RATIO   (MAGNITUDE   OF  THE  SATELLITE
C              VELOCITY DIVIDED BY THE MOST PROBABLE VELOCITY
C              OF THE MOLECULES).
C       TWTI   RATIO BETWEEN THE SURFACE ABSOLUTE TEMPERATURE
C              OF THE ELEMENT AND THE LOCAL TEMPERATURE.
C       SC     ARRAY THAT CONTAINS THE SURFACE CHARACTERISTCS
C              OF THE ELEMENT:
C              SC(1)  TANGENTIAL MOMENTUM COEFFICIENT.
C              SC(2)  NORMAL MOMENTUM EXCHANGE COEFFICIENT.
C       AREA   AREA OF THE ELEMENT IN METERS**2.
C
C     OUTPUTS:
C       FC     FORCE  COEFFICIENTS  OF  THE  SATELLITE IN THE
C              BODY FRAME.
C       TC     TORQUE COEFFICIENTS  OF  THE  SATELLITE IN THE
C              BODY FRAME.
C
C     SUBROUTINES CALLED IN THIS SUBPROGRAM:
C       DERF
C
C     AUTHOR:
C       VALDEMIR CARRARA    MAR/87
C
```

```
      IMPLICIT REAL*8 (A-H,O-Z)

      DIMENSION UV(3),VN(3),RG(3),SC(7),FC(3),TC(3)

      COMMON /CONSTA/ PI,PIT2,PID2,RAD,DEG
      DATA SQPI /1.7724538509D0/

      XDIR   = UV(1)
      YDIR   = UV(2)
      ZDIR   = UV(3)

      XNOR   = VN(1)
      YNOR   = VN(2)
      ZNOR   = VN(3)

      TWTS   = DSQRT(TWTI)
      SIGM   = SC(1)
      SIGP   = SC(2)

      CONE   = XNOR*XDIR + YNOR*YDIR + ZNOR*ZDIR

      IF(DABS(CONE).GT.1.D0) CONE   = DSIGN(1.D0,CONE)

      SINE   = DSQRT(1.D0 - CONE*CONE)

      IF(SINE.EQ.0.D0) GOTO 200
      XTOX   = (XDIR - XNOR*CONE)/SINE
      YTOX   = (YDIR - YNOR*CONE)/SINE
      ZTOX   = (ZDIR - ZNOR*CONE)/SINE

  200 CONTINUE
      ESCO   = SPRT*CONE
      ERF1   = 1.D0 + DERF(ESCO)
      ESC2   = ESCO*ESCO
      EXSE   = DEXP(-ESC2)
      APAS   = AEPR*AREA/SPRT

      PAER   = -(EXSE*((2.D0-SIGM)/SQPI*ESCO +
     1         .5D0*SIGP*TWTS) +
     2         ERF1*((2.D0-SIGP)*(.5D0+ESC2) +
     3         .5D0*SIGP*TWTS*SQPI*ESCO))*APAS/SPRT
      TAER   = -SIGM*SINE*(EXSE/SQPI + ESCO*ERF1)*APAS

      FC(1)  = PAER*XNOR + TAER*XTOX
      FC(2)  = PAER*YNOR + TAER*YTOX
      FC(3)  = PAER*ZNOR + TAER*ZTOX
      TC(1)  = FC(3)*RG(2) - FC(2)*RG(3)
      TC(2)  = FC(1)*RG(3) - FC(3)*RG(1)
      TC(3)  = FC(2)*RG(1) - FC(1)*RG(2)

      RETURN
      END
```

SPAR

```
      SUBROUTINE SOLPRE(RAPR,UV,VN,RG,SC,AREA,FC,TC)
C
C     THE SUBROUTINE  SOLPRE  OBTAINS  THE  SOLAR  RADIATION
C     FORCE AND TORQUE FOR A SURFACE ELEMENT OF THE SATELLI-
C     TE.
C
C     INPUTS:
C       RAPR  RADIATION PRESSURE AT THE LOCAL, IN N/M**2.
C       UV(3) UNIT VECTOR  OF THE SOLAR RADIATION DIRECTION,
C             IN THE BODY FRAME COORDINATES.
C       VN(3) UNIT VECTOR NORMAL TO THE SURFACE ELEMENT.
C       RG(3) POSITION  OF THE  ELEMENT  CENTRE OF  PRESSURE
C             RELATIVE  TO  THE  SPACECRAFT  GRAVITY CENTRE,
C             IN THE BODY FRAME COORDINATES, IN METERS.
C       SC(6) SURFACE CHARACTERISTICS:
C             SC(3)  SPECULAR REFLECTION COEFFICIENT.
C             SC(4)  DIFFUSE REFLECTION COEFFICIENT.
C             SC(5)  SURFACE ABSORPTION COEFFICIENT.
C             SC(6)  SURFACE EMISSIVETY OF THE  ELEMENT.
C             SC(7)  ABSOLUTE TEMPERATURE OF THE ELEMENT.
C       AREA  AREA OF THE ELEMENT IN M**2.
C
C     OUTPUTS:
C       FC    RADIATION FORCE ON THE ELEMENT, IN BODY  FRAME
C             COORDINATES, IN NEWTONS.
C       TC    RADIATION TORQUE ON THE  ELEMENT,  IN N*M,  IN
C             BODY FRAME COORDINATES.
C
C     AUTHOR:
C       VALDEMIR CARRARA    MAR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)

      DIMENSION UV(3),VN(3),RG(3),SC(7),FC(3),TC(3)

      COMMON /CONSTA/ PI,PIT2,PID2,RAD,DEG

      DATA STEC /1.891208D-19/

      XDIR   = UV(1)
      YDIR   = UV(2)
      ZDIR   = UV(3)

      XNOR   = VN(1)
      YNOR   = VN(2)
      ZNOR   = VN(3)

      CONE   = XNOR*XDIR + YNOR*YDIR + ZNOR*ZDIR

      IF(DABS(CONE).GT.1.D0) CONE   = DSIGN(1.D0,CONE)
```

SPAR

```
      RENI    = SC(6)
      TEMP    = SC(7)

      IF(CONE.GT.0.D0) GOTO 200
      EMMI    = TEMP*TEMP
      PSOL    = -2.D0*AREA*RENI*STEC*EMMI*EMMI/3.D0
      TSOL    = 0.D0
      GOTO 300

  200 CONTINUE
      SIES    = SC(3)
      SIDI    = SC(4)
      SIAB    = SC(5)
      EMMI    = TEMP*TEMP
      EMMI    = RENI*STEC*EMMI*EMMI
      CON2    = CONE*CONE

      IF(CON2.GT.1.D0) CON2 = 1.D0

      SINE    = DSQRT(1.D0 - CON2)

      IF(SINE.EQ.0.D0) GOTO 250
      XTOX    = (XDIR - XNOR*CONE)/SINE
      YTOX    = (YDIR - YNOR*CONE)/SINE
      ZTOX    = (ZDIR - ZNOR*CONE)/SINE

  250 CONTINUE

      PSOL    = -((2.D0/3.D0*SIDI +
     1           (SIAB+2.D0*SIES+SIDI)*CONE)*CONE*RAPR +
     2           2.D0/3.D0*EMMI)*AREA
      TSOL    = -(SIAB+SIDI)*CONE*SINE*RAPR*AREA

  300 CONTINUE
      FC(1)   = PSOL*XNOR + TSOL*XTOX
      FC(2)   = PSOL*YNOR + TSOL*YTOX
      FC(3)   = PSOL*ZNOR + TSOL*ZTOX
      TC(1)   = FC(3)*RG(2) - FC(2)*RG(3)
      TC(2)   = FC(1)*RG(3) - FC(3)*RG(1)
      TC(3)   = FC(2)*RG(1) - FC(1)*RG(2)

      RETURN
      END
```

```
      SUBROUTINE GEOCEN(GT,GC)
C
C     THE SUBROUTINE GEOCEN OBTAINS THE  GEOCENTRIC  COORDI-
C     NATES OF A POINT GIVEN BY ITS  TERRESTRIAL  GEOCENTRIC
C     COORDINATES.
C
C     INPUTS:
C       GV(3)    GEOCENTRIC COORDINATES IN METERS.
C
C     OUTPUTS:
C       GC(1)    LONGITUDE IN RADIANS.
C       GC(2)    GEOCENTRIC LATITUDE IN RADIANS.
C       GC(3)    GEOCENTRIC ALTITUDE IM METERS.
C
C     AUTHOR:    VALDEMIR CARRARA,  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION GT(3),GC(3)

      COMMON /CONSTA/ PI,PIT2,PID2,RAD,DEG
      COMMON /CEARTH/ RE,GM,FLAT,TETP

      GVXY  = GT(1)*GT(1) + GT(2)*GT(2)
      GXYS  = DSQRT(GVXY)
      GC(1) = DATAN2(GT(2)/GXYS,GT(1)/GXYS)
      GC(2) = DATAN2(GT(3),GXYS)
      GVZZ  = GT(3)*GT(3)
      GVM2  = GVXY + GVZZ
      FACT  = 1.D0 - FLAT
      FACT  = 1.D0/FACT/FACT - 1.D0
      GC(3) = (DSQRT(GVM2) - RE/DSQRT(1.D0+FACT*GVZZ/GVM2))

      RETURN
      END
```

```
      SUBROUTINE ROTMAT(ANGL,WV,RM)
C
C     THIS SUBROUTINE OBTAINS THE ROTATION MATRIX GIVEN  THE
C     VECTOR AND THE ANGLE OF ROTATION ABOUT THIS VECTOR.
C
C     INPUTS:
C       ANGL      ANGLE OF ROTATION IN RADIANS.
C       WV        UNIT VECTOR OF THE ROTATION DIRECTION.
C
C     OUTPUTS:
C       RM        ROTATION MATRIX.
C
C     AUTHOR:     VALDEMIR CARRARA,  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION WV(3),RM(3,3)

      COAN    = DCOS(ANGL)
      SIAN    = DSIN(ANGL)
      COM1    = 1.DO - COAN

      RM(1,1) = COM1*WV(1)*WV(1) + COAN
      RM(1,2) = COM1*WV(1)*WV(2) + SIAN*WV(3)
      RM(1,3) = COM1*WV(1)*WV(3) - SIAN*WV(2)
      RM(2,1) = COM1*WV(2)*WV(1) - SIAN*WV(3)
      RM(2,2) = COM1*WV(2)*WV(2) + COAN
      RM(2,3) = COM1*WV(2)*WV(3) + SIAN*WV(1)
      RM(3,1) = COM1*WV(3)*WV(1) + SIAN*WV(2)
      RM(3,2) = COM1*WV(3)*WV(2) - SIAN*WV(1)
      RM(3,3) = COM1*WV(3)*WV(3) + COAN

      RETURN
      END
```

```
      SUBROUTINE MATMUL(R1,R2,RS)
C
C     THE SUBROUTINE MATMUL  CALCULATES  THE PRODUCT  OF TWO
C     3X3 INPUT MATRIX, R1 AN R2.
C
C     OUTPUTS:
C       RS        = R1*R2
C
C     AUTHOR:    VALDEMIR CARRARA,  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION R1(3,3),R2(3,3),RS(3,3)

      DO 20 I=1,3
      DO 20 J=1,3
      RS(I,J) = R1(I,1)*R2(1,J) + R1(I,2)*R2(2,J) +
     1          R1(I,3)*R2(3,J)
   20 CONTINUE

      RETURN
      END
```

SPA

```
      SUBROUTINE VECROT(RM,VI,VO)
C
C     THE SUBROUTINE VECROT CALCULATES THE COORDINATES OF  A
C     VECTOR IN OTHER REFERENCE SYSTEM,  GIVEN THE  ROTATION
C     MATRIX BETWEEN THE FRAMES.
C
C     INPUTS:
C       RM         ROTATION MATRIX.
C       VI         VECTOR IN THE FIRST SYSTEM.
C
C     OUTPUTS:
C       VO         ROTATED VECTOR (VO = RM*VI).
C
C     AUTHOR:      VALDEMIR CARRARA, APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION RM(3,3),VI(3),VO(3)

      DO 20 I=1,3
      VO(I)   = RM(I,1)*VI(1) + RM(I,2)*VI(2) + RM(I,3)*VI(3)
   20 CONTINUE

      RETURN
      END
```

```
      SUBROUTINE STAVEC(EL,SV,RM)
C
C     THIS SUBROUTINE  OBTAINS THE  STATE  VECTOR (CARTESIAN
C     POSITION AND VELOCITY) OF A SATELLITE, GIVEN THE ORBI-
C     TAL KEPLERIAN ELEMENTS.
C
C     INPUTS:
C       EL(6)     KEPLERIAN ELEMENTS:
C         EL(1)   SEMI-MAJOR AXIS, IN METERS.
C         EL(2)   ECCENTRICITY
C         EL(3)   INCLINATION IN RADIANS.
C         EL(4)   RIGHT ASCENTION OF ASCENDING NODE IN RAD.
C         EL(5)   PERIGEE ARGUMENT IN RAD.
C         EL(6)   MEAN ANOMALY IN RAD.
C
C     OUTPUTS:
C       SV        POSITION (SV(1), SV(2) AND SV(3)) IN METERS
C                 AND  VELOCITY  (SV(4), SV(5) AND SV(6))  IN
C                 METERS PER SECOND OF THE SPACECRAFT  IN THE
C                 INERTIAL FRAME.
C       RM        ROTATION MATRIX  FROM THE INERTIAL FRAME TO
C                 THE ORBIT FRAME (X UPWARD, Y IN THE VELOCI-
C                 TY  DIRECTION  AND  Z  NORMAL  TO THE ORBIT
C                 PLANE).
C
C     SUBROUTINES CALLED IN THIS SUBPROGRAM:
C       KEPLER
C
C     AUTHOR:     VALDEMIR CARRARA    APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION EL(6),SV(6),RM(3,3)

      COMMON /CONSTA/ PI,PIT2,PID2,RAD,DEG
      COMMON /CEARTH/ RE,GM,FLAT,TETP

      COSI   =  DCOS(EL(3))
      SINI   =  DSIN(EL(3))
      CORA   =  DCOS(EL(4))
      SIRA   =  DSIN(EL(4))
      COPA   =  DCOS(EL(5))
      SIPA   =  DSIN(EL(5))

      A11    =  COPA*CORA - SIPA*SIRA*COSI
      A12    =  COPA*SIRA + SIPA*CORA*COSI
      A13    =  SIPA*SINI
      A21    = -SIPA*CORA - COPA*SIRA*COSI
      A22    = -SIPA*SIRA + COPA*CORA*COSI
      A23    =  COPA*SINI
```

SPAR

```
ECCE    =  EL(2)
ANOM    =  EL(6)

CALL KEPLER(ECCE,ANOM,ECAN)

COEA    =  DCOS(ECAN)
SIEA    =  DSIN(ECAN)

SECC    =  DSQRT(1.DO - ECCE*ECCE)
ECEA    =  1.DO - ECCE*COEA
VELO    =  DSQRT(GM/EL(1))/ECEA
CEME    =  COEA - ECCE

XORB    =  EL(1)*CEME
YORB    =  EL(1)*SECC*SIEA
XDOT    =  VELO*SECC*COEA
YDOT    =  VELO*SIEA

SV(1)   =  A11*XORB + A21*YORB
SV(2)   =  A12*XORB + A22*YORB
SV(3)   =  A13*XORB + A23*YORB
SV(4)   =  A21*XDOT - A11*YDOT
SV(5)   =  A22*XDOT - A12*YDOT
SV(6)   =  A23*XDOT - A13*YDOT

COTA    =  CEME/ECEA
SITA    =  SECC*SIEA/ECEA

RM(1,1)=  A11*COTA + A21*SITA
RM(1,2)=  A12*COTA + A22*SITA
RM(1,3)=  A13*COTA + A23*SITA
RM(2,1)=  A21*COTA - A11*SITA
RM(2,2)=  A22*COTA - A12*SITA
RM(2,3)=  A23*COTA - A13*SITA
RM(3,1)=  SINI*SIRA
RM(3,2)= -SINI*CORA
RM(3,3)=  COSI

RETURN
END
```

```
      SUBROUTINE ROTZXZ(EA,RS)
C
C     THE SUBROUTINE ROTZXZ CALCULATES  THE ROTATION  MATRIX
C     GIVEN THE EULER ANGLES OF A Z-X-Z ROTATION.
C
C     INPUTS:
C       EA        EULER ANGLES, IN RADIANS,  ABOUT  THE Z, X
C                 AND Z AXIS, RESPECTIVELY.
C
C     OUTPUTS:
C       RS        ROTATION MATRIX.
C
C     SUBROUTINES CALLED IN THIS SUBPROGRAM:
C       ROTMAX
C       ROTMAZ
C       MATMUL
C
C     AUTHOR:    VALDEMIR CARRARA,   APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION EA(3),RS(3,3),R1(3,3),R2(3,3)

      CALL ROTMAZ(EA(1),RS)
      CALL ROTMAX(EA(2),R1)
      CALL MATMUL(R1,RS,R2)
      CALL ROTMAZ(EA(3),R1)
      CALL MATMUL(R1,R2,RS)

      RETURN
      END
```

```
      SUBROUTINE ROTXYZ(EA,RS)
C
C     THE SUBROUTINE ROTXYZ CALCULATES  THE ROTATION  MATRIX
C     GIVEN THE EULER ANGLES OF A X-Y-Z ROTATION.
C
C     INPUTS:
C       EA         EULER ANGLES,  IN RADIANS,  ABOUT  THE X, Y
C                  AND Z AXIS, RESPECTIVELY.
C
C     OUTPUTS:
C       RS         ROTATION MATRIX.
C
C     SUBROUTINES CALLED IN THIS SUBPROGRAM:
C       ROTMAX
C       ROTMAY
C       ROTMAZ
C       MATMUL
C
C     AUTHOR:    VALDEMIR CARRARA,   APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION EA(3),RS(3,3),R1(3,3),R2(3,3)

      CALL ROTMAX(EA(1),RS)
      CALL ROTMAY(EA(2),R1)
      CALL MATMUL(R1,RS,R2)
      CALL ROTMAZ(EA(3),R1)
      CALL MATMUL(R1,R2,RS)

      RETURN
      END
```

SPAR

```
      SUBROUTINE ROTMAX(ANGL,RS)
C
C     THIS SUBROUTINE OBTAINS THE ROTATION MATRIX ABOUT  THE
C     X AXIS, GIVEN THE ANGLE OF ROTATION ABOUT THIS AXIS.
C
C     INPUTS:
C       ANGL      ANGLE OF ROTATION IN RADIANS.
C
C     OUTPUTS:
C       RS        ROTATION MATRIX.
C
C     AUTHOR:     VALDEMIR CARRARA,  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION RS(3,3)

      COAN     =  DCOS(ANGL)
      SIAN     =  DSIN(ANGL)

      RS(1,1) =  1.D0
      RS(1,2) =  0.D0
      RS(1,3) =  0.D0
      RS(2,1) =  0.D0
      RS(2,2) =  COAN
      RS(2,3) =  SIAN
      RS(3,1) =  0.D0
      RS(3,2) = -SIAN
      RS(3,3) =  COAN

      RETURN
      END
```

```
      SUBROUTINE ROTMAY(ANGL,RS)
C
C     THIS SUBROUTINE OBTAINS THE ROTATION MATRIX ABOUT  THE
C     Y AXIS, GIVEN THE ANGLE OF ROTATION ABOUT THIS AXIS.
C
C     INPUTS:
C       ANGL      ANGLE OF ROTATION IN RADIANS.
C
C     OUTPUTS:
C       RS        ROTATION MATRIX.
C
C     AUTHOR:     VALDEMIR CARRARA,  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION RS(3,3)

      COAN     =  DCOS(ANGL)
      SIAN     =  DSIN(ANGL)

      RS(1,1)  =  COAN
      RS(1,2)  =  0.D0
      RS(1,3)  = -SIAN
      RS(2,1)  =  0.D0
      RS(2,2)  =  1.D0
      RS(2,3)  =  0.D0
      RS(3,1)  =  SIAN
      RS(3,2)  =  0.D0
      RS(3,3)  =  COAN

      RETURN
      END
```

```
      SUBROUTINE ROTMAZ(ANGL,RS)
C
C     THIS SUBROUTINE OBTAINS THE ROTATION MATRIX ABOUT  THE
C     Z AXIS, GIVEN THE ANGLE OF ROTATION ABOUT THIS AXIS.
C
C     INPUTS:
C       ANGL     ANGLE OF ROTATION IN RADIANS.
C
C     OUTPUTS:
C       RS       ROTATION MATRIX.
C
C     AUTHOR:    VALDEMIR CARRARA,  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION RS(3,3)

      COAN     =  DCOS(ANGL)
      SIAN     =  DSIN(ANGL)

      RS(1,1) =  COAN
      RS(1,2) =  SIAN
      RS(1,3) =  0.D0
      RS(2,1) = -SIAN
      RS(2,2) =  COAN
      RS(2,3) =  0.D0
      RS(3,1) =  0.D0
      RS(3,2) =  0.D0
      RS(3,3) =  1.D0

      RETURN
      END
```

```
      SUBROUTINE UNIVEC(VI,VO,DMDL)
C
C     THE SUBROUTINE UNIVEC OBTAINS THE UNIT VECTOR AND  ITS
C     MAGNITUDE FROM THE INPUT VECTOR VI.
C
C     INPUTS:
C       VI          INPUT VECTOR.
C
C     OUTPUTS:
C       VO          UNIT VECTOR WITH THE SAME DIRECTION OF VI.
C       DMDL        MAGNITUDE OF VI.
C
C     AUTHOR:       VALDEMIR CARRARA,  APR/87
C
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION VI(3),VO(3)

      DMDL    = DSQRT(VI(1)*VI(1)+VI(2)*VI(2)+VI(3)*VI(3))
      IF(DMDL.EQ.0.D0) RETURN
      VO(1)   = VI(1)/DMDL
      VO(2)   = VI(2)/DMDL
      VO(3)   = VI(3)/DMDL

      RETURN
      END
```

```
      SUBROUTINE VECINV(RM,VI,VO)
C
C     THE SUBROUTINE VECINV CALCULATES THE COORDINATES OF  A
C     VECTOR  IN  THE  FIRST  REFERENCE  SYSTEM,  GIVEN  THE
C     MATRIX FROM THE  FIRST  TO THE  SECOND  FRAME  AND THE
C     VECTOR COORDINATES IN THE SECOND FRAME.
C
C     INPUTS:
C       RM         ROTATION MATRIX.
C       VI         VECTOR IN THE SECOND SYSTEM.
C
C     OUTPUTS:
C       VO         ROTATED VECTOR (VO = (RM**-1)*VI).
C
C     AUTHOR:      VALDEMIR CARRARA, APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION RM(3,3),VI(3),VO(3)

      DO 20 I=1,3
      VO(I)   = RM(1,I)*VI(1)+RM(2,I)*VI(2)+RM(3,I)*VI(3)
   20 CONTINUE

      RETURN
      END
```

```
      SUBROUTINE ROTSYS(IFRA,EL,RS)
C
C     THE SUBROUTINE ROTSYS OBTAINS THE ROTATION MATRIX FROM
C     THE INERTIAL FRAME (X=VERNAL EQUINOX) TO THE FRAME DE-
C     FINED BY IFRA.
C
C     INPUTS:
C
C       IFRA      ATTITUDE RELATED FRAME:
C                 1- INERTIAL FRAME (X=VERNAL POINT)
C                 2- X=ORBIT ASCENDING NODE, Z=NORTH POLE
C                 3- X=ORBIT ASCENDING NODE, Z=ORBIT NORMAL
C       EL(6)     KEPLERIAN ELEMENTS:
C         EL(1)   SEMI-MAJOR AXIS, IN METERS.
C         EL(2)   ECCENTRICITY
C         EL(3)   INCLINATION IN RADIANS.
C         EL(4)   RIGHT ASCENTION OF ASCENDING NODE IN RAD.
C         EL(5)   PERIGEE ARGUMENT IN RAD.
C         EL(6)   MEAN ANOMALY IN RAD.
C
C     OUTPUTS:
C       RS        ROTATION MATRIX  FROM THE INERTIAL FRAME TO
C                 THE DESIRED FRAME.
C
C     SUBROUTINES CALLED IN THIS SUBPROGRAM:
C       ROTMAX
C       ROTMAZ
C       MATMUL
C
C     AUTHOR:     VALDEMIR CARRARA    APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION EL(6),RS(3,3)
      DIMENSION V1(3),V2(3),V3(3),R1(3,3),R2(3,3)

      DATA V1 /1.D0,0.D0,0.D0/
      DATA V2 /0.D0,1.D0,0.D0/
      DATA V3 /0.D0,0.D0,1.D0/

      IF(IFRA.LT.0.OR.IFRA.GT.4) GOTO 999

      DO 20 I=1,3
      RS(1,I) = V1(I)
      RS(2,I) = V2(I)
      RS(3,I) = V3(I)
   20 CONTINUE
```

```
      IF(IFRA.EQ.1) GOTO 100
      CALL ROTMAZ(EL(4),RS)

      IF(IFRA.EQ.2) GOTO 100
      CALL ROTMAX(EL(3),R1)
      DO 30 I=1,3
      DO 30 J=1,3
      R2(I,J) = RS(I,J)
   30 CONTINUE
      CALL MATMUL(R1,R2,RS)

  100 CONTINUE
      RETURN

  999 CONTINUE
      WRITE(1,*) ' FRAME SELECTOR OUT OF RANGE (1-4) -> ',
     1           IFRA
      STOP
      END
```

```
      SUBROUTINE ATMVEL(SV,AV)
C
C     THIS SUBROUTINE  OBTAINS THE VELOCITY OF THE ATMOSPHE-
C     RE.
C
C     INPUTS:
C       SV          POSITION (SV(1), SV(2) AND SV(3)) IN METERS
C                   OF THE POINT IN THE INERTIAL FRAME.
C
C     OUTPUTS:
C       AV          VELOCITY OF  THE  ATMOSPHERE  IN METERS PER
C                   SECOND.
C
C     AUTHOR:       VALDEMIR CARRARA    APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION SV(6),AV(3)

      COMMON /CONSTA/ PI,PIT2,PID2,RAD,DEG
      COMMON /CEARTH/ RE,GM,FLAT,TETP

      AV(1)   = -SV(2)*TETP
      AV(2)   =  SV(1)*TETP
      AV(3)   =  0.D0

      RETURN
      END
```

```
      SUBROUTINE EARSHA(SA,SU,SHAD)
C
C     THE SUBROUTINE EARSHA VERIFIES IF THE SPACECRAFT IS OR
C     ISN'T IN THE EARTH SHADOW.
C
C     INPUTS:
C       SA(3)     SPACECRAFT COORDINATES IN THE INERTIAL SYS-
C                 TEM, IN METERS.
C       SU(3)     COORDINATES OF THE SUN IN THE INERTIAL FRA-
C                 ME, IN METERS.
C     OUTPUTS:
C       SHAD      0: SPACECRAFT IS IN THE EARTH SHADOW
C                 1: SPACECRAFT IS ILLUMINATED BY THE SUN
C                 BETWEEN 0 AND 1: SPACECRAFT IS IN THE EARTH
C                 PENUMBRA.
C
C     AUTHOR:     VALDEMIR CARRARA   APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)

      DIMENSION SA(6),SU(3)

      COMMON /CONSTA/ PI,PIT2,PID2,RAD,DEG
      COMMON /CEARTH/ RE,GM,FLAT,TETP

      DATA RSUN /0.6953D+09/

      DSUN    = DSQRT(SU(1)*SU(1)+SU(2)*SU(2)+SU(3)*SU(3))
      XSUN    = SU(1)/DSUN
      YSUN    = SU(2)/DSUN
      ZSUN    = SU(3)/DSUN
      RCOB    = SA(1)*XSUN + SA(2)*YSUN + SA(3)*ZSUN

      IF(RCOB.GE.0.DO) GOTO 200

      RADI    = RSUN/DSUN
      XSVS    = SA(2)*ZSUN - SA(3)*YSUN
      YSVS    = SA(3)*XSUN - SA(1)*ZSUN
      ZSVS    = SA(1)*YSUN - SA(2)*XSUN
      PSVS    = (DSQRT(XSVS*XSVS + YSVS*YSVS + ZSVS*ZSVS) -
     1          RE)/RCOB
```

```
      IF(ABS(PSVS).GE.RADI) GOTO 100

      UDIV    = PSVS/RADI
      SHAD    = (DACOS(UDIV) - UDIV*DSQRT(1.DO-UDIV*UDIV))/PI
      RETURN

  100 CONTINUE
      IF(PSVS.LT.O.DO) GOTO 200
      SHAD    = O.DO
      RETURN

  200 CONTINUE
      SHAD    = 1.DO

      RETURN
      END
```

```
      FUNCTION DERF(X)
C
C     THE DERF FUNCTION IS A DOUBLE PRECISION ERROR FUNCTION
C     OF AN ARGUMENT X. IT USES A RATIONAL APROXIMATION  FOR
C     THE FUNCTION, GIVEN BY M. ABRAMOWITZ IN HIS  'HANDBOOK
C     OF MATHEMATICAL FUNCTIONS', PAGE 299, EQUATION 7.1.25.
C
C     INPUTS:
C       X    ERROR FUNCTION ARGUMENT, IN RANGE -50<X<50.
C
C     OUTPUTS:
C       DERF DOUBLE PRECISION ERROR FUNCTION
C
C     AUTHOR:
C       VALDEMIR CARRARA   APRIL, 1987
C
      IMPLICIT REAL*8 (A-H,O-Z)

      DATA A1/ 0.254829592/, A2/-0.284496736/,
     1     A3/ 1.421413741/, A4/-1.453152027/,
     2     A5/ 1.061405429/, PE/ 0.327591100/

      T      = 1.DO/(1.DO + PE*DABS(X))
      DERF   = 1.DO -
     1         T*(A1+T*(A2+T*(A3+T*(A4+T*A5))))*DEXP(-X*X)
      DERF   = DSIGN(DERF,X)

      RETURN
      END
```

FILE ANATM.FTN

```
FTN77,J
$CDS ON

      SUBROUTINE ASDAMO(SA,SU,SF,RJUD,DAFR,GSTI,TE,AD,WMOL,
     1                  RHOD)
C
C     THE SUBROUTINE  ASDAMO  GIVES  THE  DENSITY, MOLECULAR
C     WEIGHT AND TEMPERATURE OF THE UPPER ATMOSPHERE,  USING
C     THE ANALITICAL STATIC VERSION (LAFONTAINE -HUGHES) AND
C     THE DYNAMIC ATMOSPHERIC MODEL (JACCHIA 1977).
C
C     INPUTS:
C        SA(1)     RIGHT ASCENTION OF THE POINT, IN RADIANS.
C        SA(2)     DECLINATION (GEOCENTRIC  LATITUDE)  OF  THE
C                  POINT, IN RADIANS (-PI TO PI).
C        SA(3)     GEOCENTRIC ALTITUDE IN METERS, BETWEEN  THE
C                  RANGE 90,000-2,000,000.
C        SU(1)     RIGHT ASCENTION OF THE SUN AT THE DATE,  IN
C                  RADIANS (0 TO 2*PI).
C        SU(2)     SUN DECLINATION IN RADIANS (-PI TO PI).
C        SF(1)     DAILY SOLAR FLUX AT  10.7 CM,  ADJUSTED FOR
C                  THE DISTANCE BETWEEN THE EARTH AND THE  SUN
C                  AT THE DATE, IN 1E-22 W/M/M/HZ.
C        SF(2)     AVERAGED DAILY FLUX  AS DEFINED BY JACCHIA,
C                  IN 1E-22 W/M/M/HZ, ADJUSTED FOR THE  EARTH-
C                  SUN DISTANCE.
C        SF(3)     3-HOURLY PLANETARY GEOMAGNETIC INDEX KP, AT
C                  THE TIME DAFR - TAU, WHERE TAU IS GIVEN  BY
C                  JACCHIA'S 1977 MODEL.
C        RJUD      MODIFIED JULIAN DATE (JULIAN DATE-2400000).
C        DAFR      TIME (UT) OF THE DAY, IN SECONDS.
C        GSTI      GREENWICH SIDERAL TIME, IN RADIANS, AT  THE
C                  TIME DAFR OF THE DATE RJUD (0 TO 2*PI).
C
C     OUTPUTS:
C        TE(1)     MEAN EXOSPHERIC TEMPERATURE ABOVE THE POINT
C                  AS DEFINED BY EQUATION 20 IN THE  JACCHIA'S
C                  1977 MODEL, IN KELVIN.
C        TE(2)     LOCAL  TEMPERATURE  AROUND  THE  POINT,  IN
C                  KELVIN
C        AD(1)     LOGARITHM BASE 10 OF THE HE NUMBER-DENSITY.
C        AD(2)     LOGARITHM BASE 10 OF THE O2 NUMBER-DENSITY.
C        AD(3)     LOGARITHM BASE 10 OF THE N2 NUMBER-DENSITY.
C        AD(4)     LOGARITHM BASE 10 OF THE AR NUMBER-DENSITY.
C        AD(5)     LOGARITHM BASE 10 OF THE  O NUMBER-DENSITY.
C        AD(6)     LOGARITHM BASE 10 OF THE  H NUMBER-DENSITY.
C        WMOL      MEAN MOLECULAR WEIGHT OF THE ATMOSPHERE  AT
C                  THE POINT, IN KG/KGMOL.
```

```
C         RHOD       MEAN MASS DENSITY OF THE ATMOSPHERE AT  THE
C                    POINT, IN KG/M/M/M.
C       OBS:
C         HE         HELIUM
C         O2         MOLECULAR OXYGEN
C         N2         MOLECULAR NITROGEN
C         AR         ARGON
C         O          ATOMIC OXYGEN
C         H          ATOMIC HYDROGEN
C
C       SUBROUTINES CALLED IN THIS SUB-PROGRAM:
C         ASMADE
C         DIVARA
C         GEOACA
C         SEALAT
C         SEMIAN
C
C       REFERENCES:
C         [1]        LAFONTAINE, J.; HUGHES, P. AN ANALYTIC VER-
C                    SION OF  JACCHIA'S 1977  MODEL  ATMOSPHERE.
C                    "CELESTIAL MECHANICS" 29(3-26) 1983.
C         [2]        JACCHIA, L. G. "THERMOSPHERIC  TEMPERATURE,
C                    DENSITY AND COMPOSITION: NEW MODELS."  CAM-
C                    BRIDGE, MA, SAO 1977. (SAO  SPECIAL  REPORT
C                    375).
C
C       AUTHOR:      VALDEMIR CARRARA  APR/87
C
        IMPLICIT REAL*8 (A-H,O-Z)

        DIMENSION SA(3),SU(2),SF(3),TE(2),AD(6)
        DIMENSION AL(6),WM(6)

        COMMON /STADE/ AC(6),TH(6)

        DATA AVOG /6.02217D+26/
        DATA WM   /4.0026,31.9988,28.0134,39.948,15.9994,
     1             1.00797/

        YEFR   = (RJUD-.332825D05+DAFR/.86400D05)/.3652422D03
        TYFR   = YEFR - IDINT(YEFR)
        GEAC   = SF(3)
        RLAT   = SA(2)
        RLON   = SA(1) - GSTI
        HEIG   = SA(3)
        ALTU   = HEIG/1.D03
        SUDC   = SU(2)
```

```
      CALL ASMADE(HEIG,SF,TE,AL,WMOL,RHOD)

      TEXO   = TE(1)

      CALL DIVARA(TEXO,SA,SU,WMOL,AL)

      DO 100 I = 1, 6
      AD(I)  = AL(I)
  100 CONTINUE

      TQUT   = TH(6)

      CALL GEOACA(TQUT,GEAC,RLAT,RLON,ALTU,AL)

      DO 200 I = 1, 6
      AD(I)  = AD(I) + AL(I) - AC(I)
  200 CONTINUE

      CALL SEALAT(TYFR,SUDC,RLAT,ALTU,AL)

      DO 300 I = 1, 6
      AD(I)  = AD(I) + AL(I)
  300 CONTINUE

      CALL SEMIAN(TYFR,ALTU,ALCO)

      DO 400 I = 1, 6
      AD(I)  = AD(I) + ALCO
  400 CONTINUE

      WEIG   = 0.D0
      ANUT   = 0.D0

      DO 500 I = 1, 6
      ANAC   = 10.D0**AD(I)
      ANUT   = ANUT + ANAC
      WEIG   = WEIG + WM(I)*ANAC
  500 CONTINUE

      WMOL   = WEIG/ANUT
      RHOD   = WEIG/AVOG

      RETURN
      END
```

SPAR

```
      SUBROUTINE ASMADE(ALTU,SF,TE,AL,WMOL,RHOD)
C
C     THE SUBROUTINE CALCULATES THE ATMOSPHERIC DENSITY  FOR
C     HEIGHTS FROM 100 TO 2000 KM, USING THE ANALYTIC STATIC
C     MODEL OF LAFONTAINE-HUGHES.
C
C     INPUTS:
C       ALTU       ALTITUDE OF THE POINT IN METERS.
C       SF(1)      DAILY OBSERVED  SOLAR  FLUX AT 10.7 CM,  IN
C                  1E-22 W/M/M/HZ.
C       SF(2)      AVERAGED DAILY FLUX, AS DEFINED BY JACCHIA,
C                  IN 1E-22 W/M/M/HZ.
C
C     OUTPUTS:
C       TE(1)      MEAN EXOSPHERIC TEMPERATURE ABOVE THE POINT
C                  AS DEFINED BY EQUATION 20 IN THE  JACCHIA'S
C                  1977 MODEL, IN KELVIN.
C       TE(2)      LOCAL  TEMPERATURE  AROUND  THE  POINT,  IN
C                  KELVIN
C       AL(1)      LOGARITHM BASE 10 OF THE HE NUMBER-DENSITY.
C       AL(2)      LOGARITHM BASE 10 OF THE O2 NUMBER-DENSITY.
C       AL(3)      LOGARITHM BASE 10 OF THE N2 NUMBER-DENSITY.
C       AL(4)      LOGARITHM BASE 10 OF THE AR NUMBER-DENSITY.
C       AL(5)      LOGARITHM BASE 10 OF THE  O NUMBER-DENSITY.
C       AL(6)      LOGARITHM BASE 10 OF THE  H NUMBER-DENSITY.
C       WMOL       MEAN MOLECULAR WEIGHT OF THE ATMOSPHERE  AT
C                  THE POINT, IN KG/KGMOL.
C       RHOD       MEAN MASS DENSITY OF THE ATMOSPHERE AT  THE
C                  POINT, IN KG/M/M/M.
C
C     OBS:
C       HE         HELIUM
C       O2         MOLECULAR OXYGEN
C       N2         MOLECULAR NITROGEN
C       AR         ARGON
C       O          ATOMIC OXYGEN
C       H          ATOMIC HYDROGEN
C
C     SUBROUTINES CALLED IN THIS SUB-PROGRAM:
C       AMOWEI
C       TEMLO
C
C     REFERENCES:
C       [1]        LAFONTAINE, J.; HUGHES, P. AN ANALYTIC VER-
C                  SION OF  JACCHIA'S 1977  MODEL  ATMOSPHERE.
C                  "CELESTIAL MECHANICS" 29(3-26) 1983.
C       [2]        JACCHIA, L. G. "THERMOSPHERIC  TEMPERATURE,
C                  DENSITY AND COMPOSITION: NEW MODELS."  CAM-
C                  BRIDGE, MA, SAO 1977. (SAO  SPECIAL  REPORT
C                  375).
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C
C     AUTHOR:    VALDEMIR CARRARA  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)

      DIMENSION SF(3),TE(2),AL(6)
      DIMENSION WM(6),CP(7)

      DATA AVOG /6.02217D+26/
      DATA PI   /3.14159265359D0/

      DATA WM   /4.0026,31.9988,28.0134,39.948,15.9994,
     1           1.00797/
      DATA TO   /188.D0/
      DATA ZX   /125.D0/
      DATA ZO   /90.0D0/
      DATA BE   /5.5D-5/

      FLUX    = SF(1)
      FBAR    = SF(2)
      THAF    = 5.48D0*(FBAR**.8D0) + 101.8D0*(FLUX**.4D0)
      HEIG    = ALTU/1.D3

      CALL AMOWEI(THAF,HEIG,AL,WMOL,RHOD)

      POTE    = 0.0045D0*(THAF - TO)
      ARGU    = POTE/DSQRT(1.D0 + POTE*POTE)
      TX      = TO + 110.5D0*DATANH(ARGU)
      GX      = 1.9D0*(TX - TO)/(ZX - ZO)

      CP(1)   = 2.D0*(TX - TO)/PI
      CP(2)   = GX/CP(1)
      CP(3)   = 1.7D0*CP(2)
      CP(4)   = 2.D0*(THAF - TX)/PI
      CP(5)   = GX/CP(4)
      CP(6)   = BE*CP(5)
      CP(7)   = TX

      TE(1)   = THAF
      TE(2)   = TEMLO(HEIG,CP)

      RETURN
      END
```

```
      SUBROUTINE DIVARA(TEXO,SA,SU,WMOL,AL)
C
C     THE SUBROUTINE  CALCULATES THE  DIURNAL VARIATIONS  IN
C     THE ATMOSPHERE DENSITY, AS PROPOSED BY JACCHIA,  USING
C     THE ANALYTIC STATIC MODEL BY LAFONTAINE-HUGHES.
C
C     INPUTS:
C       TEXO       MEAN EXOSPHERIC TEMPERATURE, IN KELVIN.
C       SA(1)      RIGHT ASCENTION OF THE POINT, IN RADIANS.
C       SA(2)      DECLINATION (GEOCENTRIC  LATITUDE)  OF  THE
C                  POINT, IN RADIANS (-PI TO PI).
C       SA(3)      GEOCENTRIC ALTITUDE IN METERS, BETWEEN  THE
C                  RANGE 90,000-2,000,000.
C       SU(1)      RIGHT ASCENTION OF THE SUN AT THE DATE,  IN
C                  RADIANS (0 TO 2*PI).
C       SU(2)      SUN DECLINATION IN RADIANS (-PI TO PI).
C       WMOL       MEAN MOLECULAR WEIGHT AT THE LOCAL  REGION,
C                  IN KG/KGMOL.
C
C     OUTPUTS:
C       AL(1)      LOGARITHM BASE 10 OF THE HE NUMBER-DENSITY.
C       AL(2)      LOGARITHM BASE 10 OF THE O2 NUMBER-DENSITY.
C       AL(3)      LOGARITHM BASE 10 OF THE N2 NUMBER-DENSITY.
C       AL(4)      LOGARITHM BASE 10 OF THE AR NUMBER-DENSITY.
C       AL(5)      LOGARITHM BASE 10 OF THE  O NUMBER-DENSITY.
C       AL(6)      LOGARITHM BASE 10 OF THE  H NUMBER-DENSITY.
C       WMOL       MEAN MOLECULAR WEIGHT OF THE ATMOSPHERE  AT
C                  THE POINT, IN KG/KGMOL.
C       RHOD       MEAN MASS DENSITY OF THE ATMOSPHERE AT  THE
C                  POINT, IN KG/M/M/M.
C
C     OBS:
C       HE         HELIUM
C       O2         MOLECULAR OXYGEN
C       N2         MOLECULAR NITROGEN
C       AR         ARGON
C       O          ATOMIC OXYGEN
C       H          ATOMIC HYDROGEN
C
C     COMMON OUTPUTS:
C       COMMON /STADE/ AC(6),TH(6)
C                  AC      SAME AS  AL,  BUT  USING THE  PSEUDO
C                          EXOSPHERIC   TEMPERATURE   FOR   THE
C                          HYDROGEN.
C                  TH(1)   EXOSPHERIC TEMPERATURE FOR HE, IN K.
C                  TH(2)   EXOSPHERIC TEMPERATURE FOR O2, IN K.
C                  TH(3)   EXOSPHERIC TEMPERATURE FOR N2, IN K.
C                  TH(4)   EXOSPHERIC TEMPERATURE FOR AR, IN K.
C                  TH(5)   EXOSPHERIC TEMPERATURE FOR  O, IN K.
C                  TH(6)   EXOSPHERIC TEMPERATURE FOR  H, IN K.
C
```

```
C      SUBROUTINES CALLED IN THIS SUB-PROGRAM:
C        AMOWEI
C
C      REFERENCES:
C        [1]        LAFONTAINE, J.; HUGHES, P. AN ANALYTIC VER-
C                   SION OF  JACCHIA'S 1977  MODEL  ATMOSPHERE.
C                   "CELESTIAL MECHANICS" 29(3-26) 1983.
C        [2]        JACCHIA, L. G. "THERMOSPHERIC  TEMPERATURE,
C                   DENSITY AND COMPOSITION: NEW MODELS."  CAM-
C                   BRIDGE, MA, SAO 1977. (SAO  SPECIAL  REPORT
C                   375).
C
C      AUTHOR:      VALDEMIR CARRARA  APR/87
C
       IMPLICIT REAL*8 (A-H,O-Z)

       DIMENSION SA(3),SU(2),AL(6)
       DIMENSION AN(6),WM(6),CP(7)

       COMMON /STADE/ AC(6),TH(6)

       DATA AVOG /6.02217D+26/
       DATA PI   /3.14159265359D0/
       DATA RAD  /1.7453292778D-2/

       DATA WM   /4.0026,31.9988,28.0134,39.948,15.9994,
     1            1.00797/

       RLAT    = SA(2)
       DELT    = SU(2)
       SOAN    = SA(1) - SU(1)
       ALTU    = SA(3)/1.D3
       ARGU    = RLAT*RLAT/1.5707963D0
       COAR    = DCOS(ARGU)
       COLA    = DCOS(RLAT)
       E1      = 2.D0 + COAR*COAR
       TEAU    = 1.D0 + 0.3666069D0*DELT*DSIN(RLAT)

       DO 100 I = 1, 5
       BISH    = RAD*(27.D0*(WMOL/WM(I) - 1.D0) - 35.D0)
       ARGU    = SOAN + BISH
       FHAG    = 0.08D0*DCOS(3.D0*ARGU - 1.3089969D0) +
     1           DABS(DCOS(0.5D0*ARGU))**E1
       TH(I)   = (0.24D0*COLA*(FHAG - 0.5D0) + TEAU)*TEXO
   100 CONTINUE

       ARGU    = SOAN - 1.0471976D0
       FHAG    = 0.08D0*DCOS(3.D0*ARGU - 1.3089969D0) +
     1           DABS(DCOS(0.5D0*ARGU))**E1
       TH(6)   = TEXO*(TEAU + 0.24*COLA*(FHAG - 0.5D0))
```

SPAR

```
      DO 200 I = 1, 6
      TEMP   = TH(I)
      CALL AMOWEI(TEMP,ALTU,AN,WEIG,RHOD)
      AL(I)  = AN(I)
  200 CONTINUE

      DO 300 I = 1, 6
      AC(I)  = AN(I)
  300 CONTINUE

      RETURN
      END
```

```
      FUNCTION TEMLO(ALTU,C)
C
C     THE SUBROUTINE TEMLO EVALUATES THE TEMPERATURE AT  THE
C     LOCAL REGION.
C
C     INPUTS:
C       ALTU       ALTITUDE OF THE POINT, IN KM (90 TO 2000).
C       C          ARRAY THAT CONTAINS THE PARAMETERS USED  IN
C                  THE EVALUATION OF EQUATIONS 3 AND 4, AS  GI-
C                  VEN BY JACCHIA.
C
C     OUTPUTS:
C       TEMLO      LOCAL TEMPERATURE AS  DEFINED  IN EQUATIONS
C                  3 AND 4, IN KELVIN.
C
C     REFERENCES:
C       [1]        JACCHIA, L. G. "THERMOSPHERIC  TEMPERATURE,
C                  DENSITY AND COMPOSITION: NEW MODELS."  CAM-
C                  BRIDGE, MA, SAO 1977. (SAO  SPECIAL  REPORT
C                  375).
C
C     AUTHOR:      VALDEMIR CARRARA  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)

      DIMENSION C(7)

      DATA ZX    /125.DO/
      DATA ZO    /90.ODO/
      DATA TO    /188.DO/

      HIGX    = ALTU - ZX
      HIGO    = ALTU - ZO
      TEMLO   = TO

      IF(HIGX.GT.O.DO) GOTO 100

      IF(HIGO.EQ.O.DO) RETURN
      AUXI    = HIGX/HIGO
      TEMLO   = C(7) +
     1          C(1)*DATAN(C(2)*HIGX + C(3)*HIGX*AUXI*AUXI)
      RETURN

  100 CONTINUE
      TEMLO   = C(7) +
     1          C(4)*DATAN(C(5)*HIGX + C(6)*HIGX*HIGX*HIGX)

      RETURN
      END
```

```
      SUBROUTINE AMOWEI(TEXO,ALTU,AN,WMOL,RHOD)
C
C     THIS SUBROUTINE  CALCULATES  MEAN  MOLECULAR WEIGHT OF
C     THE   ATMOSPHERE  IN  THE  LOCAL   REGION,  USING  THE
C     LAFONTAINE-HUGHES  VERSION  FOR  THE  JACCHIA'S   1977
C     MODEL.
C
C     INPUTS:
C       TEXO      MEAN EXOSPHERIC TEMPERATURE, IN KELVIN.
C       ALTU      GEOMETRICAL  HEIGHT   WHERE  THE  MOLECULAR
C                 WEIGHT WILL BE CALCULATED, IN KM (90-2000).
C
C     OUTPUTS:
C       AN(1)     LOGARITHM BASE 10 OF THE HE NUMBER-DENSITY.
C       AN(2)     LOGARITHM BASE 10 OF THE O2 NUMBER-DENSITY.
C       AN(3)     LOGARITHM BASE 10 OF THE N2 NUMBER-DENSITY.
C       AN(4)     LOGARITHM BASE 10 OF THE AR NUMBER-DENSITY.
C       AN(5)     LOGARITHM BASE 10 OF THE  O NUMBER-DENSITY.
C       AN(6)     LOGARITHM BASE 10 OF THE  H NUMBER-DENSITY.
C       WMOL      MEAN MOLECULAR WEIGHT OF THE ATMOSPHERE  AT
C                 THE POINT, IN KG/KGMOL.
C       RHOD      MEAN MASS DENSITY OF THE ATMOSPHERE AT  THE
C                 POINT, IN KG/M/M/M.
C
C     OBS:
C       HE        HELIUM
C       O2        MOLECULAR OXYGEN
C       N2        MOLECULAR NITROGEN
C       AR        ARGON
C       O         ATOMIC OXYGEN
C       H         ATOMIC HYDROGEN
C
C     REFERENCES:
C       [1]       LAFONTAINE, J.; HUGHES, P. AN ANALYTIC VER-
C                 SION OF  JACCHIA'S 1977  MODEL  ATMOSPHERE.
C                 "CELESTIAL MECHANICS" 29(3-26) 1983.
C       [2]       JACCHIA, L. G. "THERMOSPHERIC  TEMPERATURE,
C                 DENSITY AND COMPOSITION: NEW MODELS."  CAM-
C                 BRIDGE, MA, SAO 1977. (SAO  SPECIAL  REPORT
C                 375).
C
C     AUTHOR:     VALDEMIR CARRARA  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)

      DIMENSION AN(6)
      DIMENSION CC(6),QI(6),AP(6),WM(6)
      DIMENSION CE(9),AA(9),BE(9),BN(6),CN(6)

      DATA PI   /3.14159265359D0/
      DATA CONV /2.302585092994D0/
      DATA AVOG /6.02217D+26/
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SPAR

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      DATA CC   /28.575551D0,-0.472715D0,-0.118328D0,
     1           0.054405D0,0.009942D0,-0.005744D0/
      DATA QI   /0.78110D0,0.20955D0,0.009343D0,.5242D-5,
     1           0.D0,0.D0/
      DATA AP   /0.D0,0.D0,0.D0,-0.38D0,-0.25D0,0.D0/
      DATA WM   /28.0134,31.9988,39.948,4.0026,1.00797,
     1           15.9994/
      DATA RA   /6356.766D0/
      DATA GA   /9.806650D0/
      DATA CTGP /8.314320D0/
      DATA ZX   /125.0D0    /
      DATA ZO   /90.0D0     /
      DATA ZH   /100.0D0    /
      DATA TO   /188.0D0    /
      DATA RHOI /3.43D-06   /
      DATA EMEI /28.960D0   /
      DATA EPSI /1.D-06     /

      AKXI    = 2.D0*(RA + ZX)/(ZX - ZO)
      VH      = AKXI*(ZH - ZO)/(RA + ZH) - 1.D0
      WO      = (1.D0 - VH)/(1.D0 + VH)
      W1      = WO + 1.D0

      CE(1)   = CC(1) + WO*(CC(2) + WO*(CC(3) + WO*CC(4)))
      CE(2)   = W1*(CC(2) + WO*(2.D0*CC(3) + 3.D0*WO*CC(4)))
      CE(3)   = W1*W1*(CC(3) + 3.D0*WO*CC(4))
      CE(4)   = W1*W1*W1*CC(4)
      CE(5)   = 0.D0
      CE(6)   = 0.D0
      CE(7)   = 0.D0
      CE(8)   = 0.D0
      CE(9)   = 0.D0

      ARGU    = 0.0045D0*(TEXO - TO)
      AUXI    = ARGU/DSQRT(1.D0 + ARGU*ARGU)
      TX      = TO + 110.5D0*DATANH(AUXI)
      TAUO    = (TX + TO)/(TX - TO)
      TAU1    = 2.D0*TO*TX/(TO - TX)
      GDEX    = 1.9D0*(TX - TO)/(ZX - ZO)
      GDXE    = 0.475D0*TO*(RA + ZX)/TX/(RA + ZO)

      AA(5)   = 0.06205282D0*DLOG(TEXO + 213.9884D0) -
     1          0.6286968D0
      AA(6)   = 0.06555110D0*DLOG(TEXO - 329.6454D0) -
     1          0.1520990D0
      AA(1)   = AA(5) - GDXE - TAUO
      AA(2)   = AA(6) - GDXE + 1.5D0
      AA(3)   = GDXE - 2.D0*AA(5)
      AA(4)   = GDXE - 2.D0*AA(6) - 0.5D0
      AA(7)   = 0.D0
      AA(8)   = 0.D0
      AA(9)   = 0.D0
```

```
      Z        = ZH
      IF(ALTU.LT.ZH) Z      = ALTU

      VE       = AKXI*(Z - ZO)/(RA + Z) - 1.DO
      TAUC     = AA(1) + VE*(AA(2) + VE*(AA(3) + VE*(AA(4) +
     1           VE*(AA(5) + VE*AA(6)))))
      TCHA     = TAU1/TAUC
      GAVE     = GA*RA*RA/AKXI/(RA + ZO)

      DO 220 I = 1, 9
      BE(I)    = 0.DO

      DO 200 J = 1, I
      BE(I)    = BE(I) + CE(J)*AA(I+1-J)
  200 CONTINUE
  220 CONTINUE

      BEAU     = 0.DO
      EMCH     = 0.DO
      VHEI     = 1.DO
      VEEI     = 1.DO

      DO 250 I = 1, 9
      VEEI     = VEEI*VE
      BEAU     = BEAU + BE(I)*(VEEI + 2.DO*(DBLE(I) -
     1           2.DO*DBLE(INT(I/2))) - 1.DO)/DBLE(I)
      EMCH     = EMCH + CE(I)*VHEI
      VHEI     = VEEI
  250 CONTINUE

      BETA     = EMCH/TCHA
      ARGU     = DEXP(-GAVE*BEAU/CTGP/TAU1)
      RHOD     = BETA*ARGU*TO*RHOI/EMEI
      AUXI     = AVOG*RHOD
      DENU     = AUXI/EMCH
      ARGU     = AUXI/EMEI

      BN(1)    = QI(1)*ARGU
      BN(3)    = QI(3)*ARGU
      BN(4)    = QI(4)*ARGU
      CN(2)    = DENU*(EMCH*(QI(2) + 1.DO)/EMEI - 1.DO)
      CN(6)    = 2.DO*DENU*(1.DO - EMCH/EMEI)
      AUXI     = DLOG(CN(2))/CONV -
     1           0.07DO*(1.DO + DTANH(0.18DO*(Z - 111.DO)))
      BN(2)    = 10.DO**AUXI
      AUXI     = DLOG(CN(6))/CONV -
     1           0.24DO*DEXP(-.009DO*(Z-97.7DO)*(Z-97.7DO))
      BN(6)    = 10.DO**AUXI
      BN(5)    = 1.DO

      IF(ALTU.LE.ZH) GOTO 800
```

```
      Z        = ZX
      IF(ALTU.LT.ZX) Z       = ALTU

      VE       = AKXI*(Z - ZO)/(RA + Z) - 1.DO
      TCHA     = AA(1) + VE*(AA(2) + VE*(AA(3) + VE*(AA(4) +
     1           VE*(AA(5) + VE*AA(6)))))
      THAU     = AA(1) + VH*(AA(2) + VH*(AA(3) + VH*(AA(4) +
     1           VH*(AA(5) + VH*AA(6)))))
      THAU     = TAU1/THAU
      TCHA     = TAU1/TCHA
      USAR     = THAU/TCHA
      BN(2)    = CN(2)
      AUXI     = 0.DO
      VEEI     = VE
      VHEI     = VH

      DO 380 I  = 1, 6
      AUXI     = AUXI + AA(I)*(VEEI - VHEI)/DBLE(I)
      VEEI     = VEEI*VE
      VHEI     = VHEI*VH
  380 CONTINUE

      DO 400 I = 1, 4
      ARGU     = -AUXI*WM(I)*GAVE/CTGP/TAU1
      USAR     = USAR**(1.DO + AP(I))
      BN(I)    = BN(I)*USAR*DEXP(ARGU)
  400 CONTINUE

      ARGU     = -AUXI*WM(6)*GAVE/CTGP/TAU1

      CN(6)    = CN(6)*THAU/TCHA*DEXP(ARGU)
      CN(2)    = BN(2)
      AUXI     = DLOG(CN(2))/CONV -
     1           0.07DO*(1.DO + DTANH(0.18DO*(Z - 111.DO)))
      BN(2)    = 10.DO**AUXI
      AUXI     = DLOG(CN(6))/CONV -
     1           0.24DO*DEXP(-.009DO*(Z-97.7DO)*(Z-97.7DO))
      BN(6)    = 10.DO**AUXI

      IF(ALTU.LE.ZX) GOTO 800

      DCAP     = DEXP(8.042617DO)*TEXO**(-0.4197668DO) +
     1           22.58421DO -
     2           0.05719352DO*TEXO*DEXP(-TEXO/1187.417DO)
      GAMF     = (TEXO - TX)/GDEX/(RA + ZX)
      ALFA     = GAMF*DCAP/(GAMF*DCAP - 1.DO)
      ASUT     = DCAP/ALFA/(TX - TEXO)
      BSUT     = -2.DO*ASUT*TEXO - DCAP
      CSUT     = TEXO*(TEXO*ASUT + DCAP)
```

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```
      ARGU   = ((ALFA/EPSI*(TX-TEXO) +
     1         1.DO)/(1.DO-ALFA))**(1.DO/DCAP)
      XINF   = DLOG(ARGU)
      ZINF   = (RA*XINF + ZX)/(1.DO - XINF)
      HAGA   = ALTU

      IF(HAGA.GE.ZINF) HAGA   = ZINF

      XOFZ   = (HAGA - ZX)/(RA + HAGA)
      AUXI   = DEXP(-DCAP*XOFZ)
      ARGU   = ALFA*(TX - TEXO)*AUXI
      TCHA   = ARGU/(AUXI  + ALFA - 1.DO) + TEXO
      GAMA   = GA*RA*RA/CTGP/(RA + ZX)/CSUT
      BN(2)  = CN(2)

      ARGU   = (ASUT*TX + BSUT)*TX + CSUT
      ABBA   = ((ASUT*TCHA + BSUT)*TCHA + CSUT)/ARGU
      DTDO   = TCHA - TEXO
      DTD1   = TEXO - TX
      DTD2   = ALFA/(1.DO - ALFA)
      AAAA   = DTD1*DTD2/DTDO + 1.DO/(1.DO - ALFA)

      DO 600 I = 1, 4
      GAAU   = GAMA*WM(I)
      AUXI   = BN(I)*(TX/TCHA)**(1.DO + AP(I) + GAAU)
      BN(I)  = AUXI*(AAAA**(GAAU*BSUT/2.DO/DCAP))*
     1         (ABBA**(GAAU/2.DO))
  600 CONTINUE

      CN(2)  = BN(2)
      AUXI   = DLOG(CN(2))/CONV -
     1         0.07DO*(1.DO + DTANH(0.18DO*(HAGA - 111.DO)))
      BN(2)  = 10.DO**AUXI
      AUXI   = CN(6)*AAAA**(GAMA*WM(6)*BSUT/2.DO/DCAP)
      AUXI   = AUXI*ABBA**(GAMA*WM(6)/2.DO)
      CN(6)  = AUXI*(TX/TCHA)**(1.DO + AP(6) + GAMA*WM(6))
      AUXI   = DLOG(CN(6))/CONV -  0.24DO*
     1         DEXP(-.009DO*(HAGA - 97.7DO)*(HAGA - 97.7DO))
      BN(6)  = 10.DO**AUXI

      HDEN   = 10.DO**(TEXO**(-.25DO)*28.9DO + 5.94DO)
      X500   = (500.DO - ZX)/(RA + 500.DO)

      AUXI   = DEXP(-X500*DCAP)
      T500   = ALFA*(TX - TEXO)*AUXI/(AUXI+ALFA-1.DO) + TEXO
      AUXI   = (TCHA*ASUT + BSUT)*TCHA + CSUT
      AUXI   = AUXI/((ASUT*T500 + BSUT)*T500 + CSUT)
      ARGU   = GAMA*WM(5)*BSUT/2.DO*(XOFZ - X500)
      AUXI   = HDEN*AUXI**(GAMA*WM(5)/2.DO)*DEXP(ARGU)
      BN(5)  = AUXI*(T500/TCHA)**(1.DO + AP(5) + GAMA*WM(5))
```

```
      IF(HAGA.EQ.ALTU) GOTO 750
      X1      = 1.D0/(1.D0 + ZINF/RA)
      X2      = 1.D0/(1.D0 + ALTU/RA)
      COEF    = GA*RA/CTGP/TEXO*(X2 - X1)
      BN(2)   = CN(2)
      BN(6)   = CN(6)

      DO 700 I = 1, 6
      BN(I)   = BN(I)*DEXP(COEF*WM(I))
  700 CONTINUE

      AUXI    = DLOG(BN(2))/CONV -
     1          0.07D0*(1.D0 + DTANH(0.18D0*(ALTU - 111.D0)))
      BN(2)   = 10.D0**AUXI
      AUXI    = DLOG(BN(6))/CONV -  0.24D0*
     1          DEXP(-.009D0*(ALTU - 97.7D0)*(ALTU - 97.7D0))
      BN(6)   = 10.D0**AUXI

  750 CONTINUE

      DO 760 I = 1, 6
      IF(BN(I).LT.1.D-30) BN(I)  = 1.D-30
  760 CONTINUE

  800 CONTINUE
      WMOL    = 0.D0
      ARGU    = 0.D0

      DO 850 I = 1, 6
      AUXI    = BN(I)
      ARGU    = ARGU + AUXI
      WMOL    = WMOL + AUXI*WM(I)
  850 CONTINUE

      RHOD    = WMOL/AVOG
      WMOL    = WMOL/ARGU

      AN(1)   = DLOG(BN(4))/CONV
      AN(2)   = DLOG(BN(2))/CONV
      AN(3)   = DLOG(BN(1))/CONV
      AN(4)   = DLOG(BN(3))/CONV
      AN(5)   = DLOG(BN(6))/CONV
      AN(6)   = DLOG(BN(5))/CONV

      RETURN
      END
```

```
      SUBROUTINE GEOACA(TQUT,GEAC,RLAT,RLON,ALTU,DN)
C
C     THE  SUBROUTINE  GEOACA  OBTAINS  THE VARIATION OF THE
C     ATMOSPHERE  NUMBER-DENSITY,  DUE  TO  THE  GEOMAGNETIC
C     ACTIVITY, USING THE ANALYTIC STATIC MODEL.
C
C     INPUTS:
C       TQUT       EXOSPHERIC  TEMPERATURE  FOR  THE  HYDROGEN
C                  ABOVE THE POINT, IN KELVIN.
C       GEAC       THE PLANETARY THREE-HOUR INDEX, KP, IN  THE
C                  RANGE 0. TO 9.0
C       RLAT       DECLINATION (GEOCENTRIC  LATITUDE)  OF  THE
C                  POINT, IN RADIANS (-PI TO PI).
C       RLON       LOCAL LONGITUDE, IN RADIANS (-PI TO PI).
C       ALTU       GEOCENTRIC  ALTITUDE  IN  KM,  IN THE RANGE
C                  90. TO 2000..
C
C     OUTPUTS:
C       DN         ARRAY WITH THE COMMON LOGARITHM  (BASE 10),
C                  OF THE VARIATION IN THE  NUMBER DENSITY  OF
C                  THE HE (HELIUM), O2 (MOLECULAR OXYGEN),  N2
C                  (MOLECULAR NITROGEN), AR (ARGON), O (ATOMIC
C                  OXYGEN) AND H (ATOMIC HYDROGEN),  RESPECTI-
C                  VELY, DUE TO THE GEOMAGNETIC ACTIVITY.
C
C     SUBROUTINES CALLED IN THIS SUB-PROGRAM:
C       AMOWEI
C
C     REFERENCES:
C       [1]        LAFONTAINE, J.; HUGHES, P. AN ANALYTIC VER-
C                  SION OF  JACCHIA'S 1977  MODEL  ATMOSPHERE.
C                  "CELESTIAL MECHANICS" 29(3-26) 1983.
C       [2]        JACCHIA, L. G. "THERMOSPHERIC  TEMPERATURE,
C                  DENSITY AND COMPOSITION: NEW MODELS."  CAM-
C                  BRIDGE, MA, SAO 1977. (SAO  SPECIAL  REPORT
C                  375).
C
C     AUTHOR:      VALDEMIR CARRARA  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)

      DIMENSION DN(6)
      DIMENSION GM(6)

      DATA GM   /-6.30D-05,1.03D-05,0.D0,3.07D-05,-4.85D-05,
     1          0.D0/
```

```
      AUXI    = 57.5D0*GEAC*(1.D0 + 0.027D0*DEXP(0.4D0*GEAC))
      SILA    = DSIN(RLAT)
      SENO    = 0.9792*SILA +
     1          0.2028*DCOS(RLAT)*DCOS(RLON - 5.0789081D0)
      SEN2    = SENO*SENO
      COL2    = 1.D0 - SEN2
      DELT    = AUXI*SEN2*SEN2
      TEMP    = TQUT + DELT

      CALL AMOWEI(TEMP,ALTU,DN,WMOL,RHOD)

      DELT    = 0.01D0*DELT
      DEZH    = 5000.D0*DLOG(DSQRT(1.D0 + DELT*DELT) + DELT)
      DELE    = 5.2D-04*AUXI*COL2*COL2

      DO 100 I = 1, 6
      DN(I)   = DN(I) + GM(I)*DEZH + DELE
  100 CONTINUE

      RETURN
      END
```

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```
      SUBROUTINE SEALAT(TYFR,SUDC,RLAT,ALTU,AL)
C
C     THE SUBROUTINE SEALAT  OBTAINS  THE VARIATIONS  ON THE
C     NUMBER DENSITY OF THE ATMOSPHERE, DUE TO THE SEAZONAL-
C     LATITUDINAL EFFECT.
C
C     INPUTS:
C       TYFR     FRACTION OF THE TROPIC YEAR, IN  THE  RANGE
C                0. TO 1., STARTING ON JAN. 1ST.
C       SUDC     SUN DECLINATION IN RADIANS (-PI TO PI).
C       RLAT     DECLINATION (GEOCENTRIC  LATITUDE)  OF  THE
C                POINT, IN RADIANS (-PI TO PI).
C       ALTU     GEOCENTRIC ALTITUDE  IN KM,  IN  THE  RANGE
C                90. TO 2000..
C
C     OUTPUTS:
C       AL       ARRAY CONTAINING  THE  SEAZONAL-LATITUDINAL
C                VARIATIONS FOR THE HE (HELIUM), O2 (MOLECU-
C                LAR OXYGEN), N2  (MOLECULAR  NITROGEN),  AR
C                (ARGON), O (ATOMIC OXYGEN)  AND  H  (ATOMIC
C                HYDROGEN) NUMBER DENSITY, RESPECTIVELY.
C
C
C     REFERENCES:
C       [1]      JACCHIA, L. G. "THERMOSPHERIC  TEMPERATURE,
C                DENSITY AND COMPOSITION: NEW MODELS."  CAM-
C                BRIDGE, MA, SAO 1977. (SAO  SPECIAL  REPORT
C                375).
C
C     AUTHOR:    VALDEMIR CARRARA  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION AL(6)
      DIMENSION CR(6)

      DATA PITW /6.28318530718D0/
      DATA CR   /-0.79D0,0.D0,0.D0,0.D0,-.16D0,0.D0/

      SILA   = DSIN(RLAT)
      DSLT   = SUDC*SILA/0.40915736545D0
      DELZ   = ALTU - 91.D0
      ESSE   = 0.014D0*DELZ*DEXP(-0.0013D0*DELZ*DELZ)
      PCAP   = DSIN(PITW*TYFR + 1.72D0)
      DSLM   = DSIGN(SILA*SILA*ESSE*PCAP,RLAT)

      DO 100 I = 1, 6
      AL(I)  = DSLT*CR(I) + DSLM
  100 CONTINUE

      RETURN
      END
```

```
      SUBROUTINE SEMIAN(TYFR,ALTU,ALCO)
C
C     THE SUBROUTINE SEMIAN GIVES THE CORRECTION FACTOR ALCO
C     FOR   THE  ATMOSPHERE   NUMBER  DENSITY,  DUE  TO  THE
C     SEMIANNUAL EFFECT.
C
C     INPUTS:
C       TYFR       FRACTION OF THE TROPIC  YEAR,  IN THE RANGE
C                  0. TO 1., STARTING ON JAN. 1ST.
C       ALTU       GEOCENTRIC ALTITUDE  IN KM,  IN  THE  RANGE
C                  90. TO 2000..
C
C     OUTPUTS:
C       ALCO       THE SEMIANNUAL VARIATION OF THE  ATMOSPHERE
C                  NUMBER DENSITY.
C
C     REFERENCES:
C       [1]        JACCHIA, L. G. "THERMOSPHERIC  TEMPERATURE,
C                  DENSITY AND COMPOSITION: NEW MODELS."  CAM-
C                  BRIDGE, MA, SAO 1977. (SAO  SPECIAL  REPORT
C                  375).
C
C     AUTHOR:      VALDEMIR CARRARA  APR/87
C
      IMPLICIT REAL*8 (A-H,O-Z)

      DATA PITW /6.28318530718D0/

      AUXI    = 0.04D0*ALTU*ALTU/1.D+04 + 0.05D0
      FOFT    = AUXI*DEXP(-0.25D-02*ALTU)
      AUXI    = (0.5D0+0.5D0*DSIN(PITW*TYFR+6.04D0))**1.65D0
      TAUC    = 0.0954D0*(AUXI - 0.5D0) + TYFR
      AUXI    = DSIN(2.D0*PITW*TAUC + 4.26D0)*(1.D0 +
     1          0.467D0*DSIN(PITW*TAUC + 4.14D0))
      GOFT    = AUXI*0.382D0 + 0.0284D0
      ALCO    = FOFT*GOFT

      RETURN
      END
```