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ANODE: An Analytic Orbit Determination System

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FOR THE COMMANDER

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This note has described the theory and structure of the first versions of the realtime and interactive analytic orbit estimation program, ANODE. The appendices detail the theory as implemented, the command structure for using the program and examples of its functioning.

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ANODE: AN ANALYTIC ORBIT DETERMINATION SYSTEM

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1. INTRODUCTION

The Millstone Hill radar has been active since February, 1975, as a contributing sensor to the deep space satellite detection and tracking network of the North American Air Defense Command. The primary mission of the radar has been the detection and tracking of deep space satellites. (Satellites whose orbital periods are greater than 0.25 day have been arbitrarily classified as in the deep space regime.)

The computer system at the Millstone Hill radar was upgraded in August, 1977, with the acquisition of a Harris 7/220 system. The new computer is a virtual memory multitasking system capable of supporting up to 768 K bytes of user program simultaneously.

A software system design was made for the radar system with the new computer (Fig. 1). One of the components of the system is an on-line real time analytic orbit determination program. The purpose of the program is threefold:

1. It is intended to act as a real-time monitor on the tracking performance of the radar.
2. It is designed to function as a rapid orbit estimator available interactively to analyst.

3. It is a preprocessor for an accurate but computationally expensive numerical orbit estimation program (TMPEST*).

2. OUTLINE OF NOTE

ANODE is the analytic orbit determination program that has been developed at Millstone and is functioning successfully on the Harris computer. This note describes the theory, structure, and functioning of ANODE as an orbit propagation and estimation program. Special attention has been paid to computer implementation and efficiency, as it operates in the real time environment of a tracking radar.

High altitude satellites, which are of concern to the Millstone radar, are perturbed by geopotential, luni-solar gravitation and atmospheric drag. This technical note will be restricted to a version of ANODE with geopotential perturbations only. The other perturbations and their inclusion in ANODE will be dealt with in other technical notes.

3. ORBITAL THEORY

The orbits of concern at the Millstone Hill radar are of the "deep space" type only, arbitrarily defined as those with mean motions less than four revolutions/day. The two large classes of such orbits are the half-synchronous and the synchronous. The former are typically in high inclination orbits with a spread in mean motion of between 1.8 and 2.5 revs/day. The latter are generally in low inclination orbits with mean motions between 0.9 and 1.2 revs/day.

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*TMPEST is an acronym for the Millstone Precision orbit Estimation program.

3.1 Choice of Elements

A substantial body of theory has been developed over the years for the evolution of orbits of artificial satellites using a variety of techniques. The most commonly used technique has been the method of averages [Ref. 1]. Formulations using the method of averages differ in their choice of orbital elements. We decided to adopt the so-called Keplerian elements as the basis for the development of the software. These orbital elements consist of

I = the inclination of the orbit to the equator.

Ω or RAN = the right ascension of the ascending node of the orbit.

e = the eccentricity of the orbit

ω or AP = the argument of perigee of the orbit.

M = the mean anomaly of the satellite in the orbit

a = the semi-major axis of the orbit

and T = epoch time at which these elements are defined.

A subsidiary orbital element that is not independent but is used extensively is

n = the mean motion of the satellite in its orbit.

3.2 The Method of Averages

The method of averages proceeds to develop a theory by eliminating the fastest periodic variable in the system of differential equations. Let

$$\frac{dz}{dt} = f(\underset{\sim}{z}, \vec{F})$$

where z is an element from the set $\underset{\sim}{z}$ and $\vec{F}$ is the perturbing force. Typically, the mean anomaly M is the fastest variable in the system of equations, with a period τ_{sat}, the orbital period of the satellite. An averaged rate of change of the element z is derived as

$$<\frac{dz}{dt}> = \frac{1}{\tau_{sat}} \int_{o}^{\tau_{sat}} f(\underset{\sim}{z}, \vec{F})dt$$

Thus the fast variable has been averaged out of the system of equations. To render the theory complete, the short-periodic variations are also computed as

$$\Delta z_{sp} = \int^{\tau} [f(\underset{\sim}{z}, \vec{F}) - <\frac{dz}{dt}>]dt.$$

The resulting singly-averaged dynamical system for the orbit exhibits a periodic dependence on ω, the argument of perigee. Hence, conventional orbital theory proceeded to average over the period of the argument of perigee, τ_{ω}, thus resulting in a secular or doubly-averaged theory

$$<<\frac{dz}{dt}>> = \frac{1}{\tau_{\omega}} \int_{o}^{\tau_{\omega}} <\frac{dz}{dt}>dt$$

Periodic terms from this step of averaging are called the long periodics and are given by

$$\Delta z_{LP} = \int^{\tau} [<\frac{dz}{dt}> - <<\frac{dz}{dt}>>]dt$$

Thus, if one uses the doubly-averaged results, a complete theory would consist of the doubly averaged or secular terms, the long periodics, and the short periodics.

Incidentally, multi-variable expansion techniques for quasi-periodic systems applied to orbital theory yield similar results though the formal development proceeds differently.

3.3 Choice of Theory

Several different formulations are available in the literature for an orbital theory in the Keplerian elements. The formulation by Liu [Ref. 2] was adopted for ANODE for the following reasons:

1. it is a complete theory to second order in the zonal harmonic of the geopotential with terms due to J_{20}, J_{20}^2, J_{30}, and J_{40};
2. both the singly averaged and the doubly averaged theories are given;

and 3. the expressions are given explicitly for the rates of change of the Keplerian elements.

3.4 Features of Implementation of Theory

The theory adopted is described in Ref. 2; neither the derivations nor the results will be repeated here. Several points, however, are worthy of note:

1. Depending on the elements and the method used, a theory may have associated singularity problems. These will be discussed in the next section.
2. Any theory that is developed by "hand-algebra" tends to be inefficient in terms of computer implementation. Particularly, advantage is rarely taken of commonality of expressions to reduce the computations involved.

Every effort was made in the implementation of the theory in ANODE to identify common expressions and precompute them before computing any of the secular or periodic corrections to the elements. While the effort was probably incomplete, it still resulted in a significant saving of computer time. The most computationally compact form of the equations can be achieved only by a rederivation of the theory using computer algebra.

3.5 Other Orbital Perturbations

Liu's theory is restricted to the effects of the first few terms in the zonal harmonics of the geopotential. However, in high altitude orbits, the perturbations due to the luni-solar gravitation are significant, particularly so in near-synchronous orbits where the gravitational perturbations of the moon can be a tenth to a half as large as that of the principal oblateness term (J_{20}) of the earth. An interesting technique called "intermediate" averaging was developed during the course of this work to capture luni-solar perturbations in the theory. The theoretical basis of this technique is given in another note by the authors [Ref. 3].

Finally, satellites in high eccentricity orbits around the earth are subject to atmospheric drag as their perigee heights decrease. An old suggestion of King-Hele was adopted to account for drag effects. Satellites in high eccentricity orbits are in a significant atmospheric drag regime (defined as <500 km altitude) for a very short interval of time (5 to 15 minutes), relative to the orbital period. Thus, it is feasible to represent the drag effect as an impulse applied at the perigee position of the orbit.

As mentioned in Section 2, this technical note will concentrate on the implementation of Liu's theory with geopotential zonal harmonic perturbations only. Other perturbations and their inclusion in ANODE will be deferred to future technical notes.

3.6 Choice of Constants

Major users within the DoD community have adopted the WGS-72 model of geopotential constants [Ref. 4] as the standard for all orbital computations. The same set is used for ANODE also. However, Ref. 4 does not list any adopted values of the ratios of the masses of the sun and the moon to that of the earth. Hence, these constants are taken from the list of recommended constants of the International Astronomical Union [Ref. 5].

4. ANALYTICAL STRUCTURE OF ANODE

ANODE is an orbit estimation program. Thus, it has to read orbital elements and metric data, has to compute pointing and residuals at observation times and has to estimate corrections to the orbital elements to fit the data. This section is devoted to an analytical description of the structure of the program. It also addresses the problem of singularities.

4.1 Analytical Description

Figure 2 is an outline of the structure of ANODE.

4.1.1 Data

The input data to the orbit processor consists of a set of orbital elements and a sequence of observational data points. The metric data may be from any sensor whose coordinates are known. The data consist of observation times associated with values for one or more of the metric dimensions of azimuth, elevation, range, and range rate.

4.1.2 Orbit Propagation and Differentials

The orbit estimation is carried out in terms of the mean Keplerian elements. Mean elements are calculated by subtracting the periodic corrections from the osculating elements. The definition of the mean elements is inextricably tied to the theory that is being used.

Let the mean elements at time t_0 be $\underset{\sim}{z}_0$. Then

$$\dot{\underset{\sim}{z}}_0 = \text{secular or averaged rates of change of the mean elements.}$$

Let the times of observation data be $t_1, t_2 \ldots t_M$. Then at time t_k

$$\underset{\sim}{z}_k = \underset{\sim}{z}_0 + (t_k - t_0)\dot{\underset{\sim}{z}}_0 , \; k = 1, \ldots M.$$

The osculating elements at t_k can be calculated by

$$\underset{\sim}{z}_{osc,k} = \underset{\sim}{z}_k + (\delta \underset{\sim}{z})_p$$

where $(\delta \underset{\sim}{z})_p$ = periodic corrections calculated at the orbital position at t_k. Further, the differentials of the elements at t_k with respect to the elements at epoch t_0 are

$$\left[\frac{\partial \underset{\sim}{z}_k}{\partial \underset{\sim}{z}_0}\right] = [I] + (t_k - t_0)\left[\frac{\partial \dot{\underset{\sim}{z}}_0}{\partial \underset{\sim}{z}_0}\right]$$

where the [. . .] denote a 6 x 6 matrix, [I] is the unit matrix and the partial derivatives on the right hand side are taken with respect to each element in turn. The expressions for the partials of the doubly averaged elements are given in Appendix 1.

The secular rates $\dot{z}_0$ and the periodic corrections, $(\delta \underset{\sim}{z})_p$, long and short, are taken directly from Ref. 2.

4.1.3 Residuals and Pointing Differentials

The next step is the calculation of the residuals. The computed pointing at time t_k is given by

$$\underset{\sim}{C}_k = \underset{\sim}{C}(\underset{\sim}{z}_{osc,k}, \underset{\sim}{S})$$

where $\underset{\sim}{C}_k$ is the pointing in azimuth, elevation, range, and range rate,

$\underset{\sim}{z}_{osc,k}$ is the set of osculating elements t_k,

$\underset{\sim}{S}$ is a site vector in appropriate coordinates,

and C represents the well-known functional relationship, given in Appendix 2.

Given $\underset{\sim}{P}_k$, the observed pointing from the site, the residuals are

$$\underset{\sim}{Y}_k = \underset{\sim}{P}_k - \underset{\sim}{C}_k \text{ at } k = 1, 2 \ldots, M$$

A complete vector of residuals is thus built up. This vector has a maximum size of 4M x 1 (say K x 1).

The differentials of the residuals with respect to the mean elements at epoch t_0 are then computed

$$\left[\frac{\partial \underset{\sim}{Y}_k}{\partial \underset{\sim}{z}_0}\right] = -\left[\frac{\partial \underset{\sim}{C}_k}{\partial \underset{\sim}{z}_0}\right]$$

Note that $\underset{\sim}{P}_k$ are actual data and hence $\frac{\partial \underset{\sim}{P}_k}{\partial \underset{\sim}{z}_0} = 0$.

Further,

$$\left[\frac{\partial \underset{\sim}{C}_k}{\partial \underset{\sim}{z}_0}\right] = \left[\frac{\partial \underset{\sim}{C}_k}{\partial \underset{\sim}{z}_{osc,k}}\right]\left[\frac{\partial \underset{\sim}{z}_{osc,k}}{\partial \underset{\sim}{z}_k}\right]\left[\frac{\partial \underset{\sim}{z}_k}{\partial \underset{\sim}{z}_0}\right]$$

where $\underset{\sim}{z}_{osc}$ denotes osculating elements. But $[\partial \underset{\sim}{z}_{osc,k}/\partial \underset{\sim}{z}_k]$ are functions of the periodic corrections only. Hence this matrix can, for simplicity, be set equal to the unit matrix. This approximation is allowed only in the differential calculation; and its only negative effect would be to increase the number of iterations required to reach a solution. The approximation will not affect the results. The positive effect of the approximation lies in the saving of the inordinate amount of computer time that would be needed for the calculation of the differentials of the periodic corrections. Hence,

$$\left[\frac{\partial \underset{\sim}{Y}_k}{\partial \underset{\sim}{z}_0}\right] = -\left[\frac{\partial \underset{\sim}{C}_k}{\partial \underset{\sim}{z}_0}\right]$$

$$= -\left[\frac{\partial \underset{\sim}{C}_k}{\partial \underset{\sim}{z}_k}\right]\left[\frac{\partial \underset{\sim}{z}_k}{\partial \underset{\sim}{z}_0}\right] = -[T]$$

where the right hand side can be computed as a function of the osculating or the mean elements under the same caveat as stated above. The resulting matrix of the derivatives of the residuals with respect to the epoch elements has a size of K x 6.

4.1.4 Corrections to the Elements

A set of corrections to the orbital elements at epoch t_o can now be computed using a minimum variance technique. The steps below are taken from Ref. 6. Let

$$\underset{\sim}{Y} = \frac{\partial \underset{\sim}{Y}}{\partial \underset{\sim}{z}_0} \Delta \underset{\sim}{z} + \underset{\sim}{N}$$

$$= -[T]\Delta \underset{\sim}{z}_0 + \underset{\sim}{N}$$

[T] has been calculated in Section 4.1.3. N is a noise vector computed from the weights (or error magnitudes) of the observations read from the input data.

Then the minimum variance estimate for the corrections $\Delta \underset{\sim}{z}_0$ is given by

$$\Delta \underset{\sim}{z}_0 = [W]\underset{\sim}{Y}$$

where

$$[W] = [T^T R^{-1} T]^{-1} T^T R^{-1}$$

$$[T^T] = \text{transpose of } [T]$$

$$[R] = \text{expected value of } \underset{\sim}{N}$$

$$= [N]\ [N]^T$$

$$\underset{\sim}{Y} = \underset{\sim}{P} - \underset{\sim}{C} = \text{residual vector}$$

and

$$[\ldots]^{-1} = \text{the matrix inverse.}$$

Under normal assumptions about the distribution function of the errors, the minimum variance estimate is also the weighted maximum likelihood estimate. The covariance error matrix of the estimate $\Delta \underset{\sim}{z}_0$ is

$$[S] = [T^T R^{-1} T]^{-1}$$

The new estimate of the epoch elements is given by

$$\underset{\sim}{z}_0 = \underset{\sim}{z}_0 + \Delta \underset{\sim}{z}_0$$

4.1.5 Iteration and Convergence

The estimate of the epoch elements can be iteratively improved by going through the above steps repeatedly (as shown in Fig. 2). At each iteration, the estimate of the mean elements of epoch from the previous iteration is used for all calculations.

Convergence can be assessed in at least two ways. An analytically pleasing technique is to calculate the sum of the squares of the weighted residuals, and look at the reduction in its value from iteration to iteration. For purposes of ANODE, however, a simpler alternative was chosen. The sizes of the corrections $\Delta \underset{\sim}{z}_0$ are monitored and when the corrections are sufficiently small, convergence is assumed.

4.1.6 Cautions

Various cautionary steps have to be taken during the orbit estimation process.

1. Multiplicative constants (sigma multipliers) for the weights of the observations have to be used so that all observations are initially accepted. These sigma multipliers have to be reduced in a logical fashion as the iterations proceed; and convergence has to be linked to those values too.
2. Software logic has to be provided for eliminating observations that have large errors.
3. The size of the corrections applied at any iteration has to be bounded. It must be remembered that a non-linear problem is being solved by iterative linear approximation. Hence, large corrections may drive the solution away from the linear region.
4. Nonconvergence has to be detected.

ANODE observes all these cautions. A detailed description is provided in the description of program implementation.

4.2 The Problem of Singularities

The specific choice of orbital elements and the theory used lead to three possible singularities in the equations.

4.2.1 Zero Eccentricity

As the eccentricity of the orbit tends to zero, the short periodic corrections in the mean anomaly and the argument of perigee become large. This is due to the fact that in near-circular orbits the position of the perigee is poorly defined. As long as the eccentricity does not become zero (within the limits of computer precision), however, the near-singularity does not cause any problems. For, the short-periodic correction in the mean anomaly is nearly equal in magnitude and opposite in sign to that in the argument of perigee. Thus the position of the satellite in orbit, as measured by $(\omega + M)$ is not affected. And the correction $\Delta(\omega + M)$ can be used to monitor convergence. Hence, in practice, this analytical singularity is of little consequence.

4.2.2 Zero Inclination

As the inclination of the orbit tends to zero, the line of nodes becomes poorly defined, and for small changes in inclination, large changes occur in Ω, the right ascension of the ascending node and ω, the argument of perigee. Again, the change in Ω is nearly equal and opposite to that in ω. Thus, in low inclination orbits, the sum $(\Omega + \omega)$ changes slowly and can be monitored to assess convergence. The position of the satellite is also not affected by these large variations, as long as the inclination does not reach zero within the precision of the computer.

Occasionally, during orbit estimation, the change in inclination during an iteration will cause it to become negative. This can be allowed for by taking the following steps

1. reset the sign on the inclination to be positive;
2. add 180° to the value of Ω, the right ascension of the ascending node; and

3. subtract 180° from the value of ω, the argument of perigee.

There is another solution to the zero inclination problem. The plane of reference can be changed to a polar plane, containing the polar axis and, say, the axis to the first point of Aries. Such a rotation of the reference system can be quite painlessly and consistently implemented within the confines of the theory used in ANODE. However, this option has not been necessary.

If both the inclination and the eccentricity are very small, as is the case in geostationary orbits, the values monitored are $(\Omega + \omega + M)$ and $\Delta(\Omega + \omega + M)$ for the position of the satellite and convergence respectively.

4.2.3 "Critical" Inclination

Finally, there is an analytical singularity at the "critical" inclination in the doubly averaged equations. A glance at the doubly averaged equations in Ref. 2 suffices to show a singularity at an inclination of 63.43°. At this value, the rate of change of the argument of perigee to first order goes to zero. And, in conventional doubly averaged theories, the second averaging is over the period of rotation of the argument of perigee. Thus, in the neighborhood of the "critical" inclination, the step of the second averaging is no longer valid. Fortunately, the solution is obvious: as the perigee does not move rapidly, the second averaging step is no longer needed. The singly averaged equations along with the short-periodic terms can be used as the complete theory. The singularity is thus eliminated.

Hence in ANODE, the singly averaged theory is used for all inclinations between 52° and 75°. Appendix 3 tabulates the expressions for $[\partial \tilde{z}_k / \partial \tilde{z}_0]$ in the singly averaged theory.

5. COMPUTER STRUCTURE OF ANODE

5.1 Implementation of ANODE

ANODE has been designed to function both as an interactive program, driven by command inputs as supplied by the operator, and also as a real-time processor in the SATTRK software system on the Harris S220. In the real-time mode, all necessary command input parameters are extracted from the Master Object File (MOF) entry for the desired satellite.

A command input design philosophy was chosen in the interactive mode because it provides the analyst with flexible control of the parameters controlling the fit and any future modification to include new features to the program can be easily implemented. Any desired action is carried out by entering a command name followed by the appropriate parameters and all inputs can be entered in free format. After decoding the command and the parameter input, a branch is made to a section in the main routine which is designed to handle that particular command. In the case of a relatively simple procedure, such as displaying the elements, the main routine contains all the necessary code to carry out that command. However, if the command involves a more complex procedure, or if the real-time program needs the same capability (e.g., extracting and storing an element set from the Master Object File), a branch is made to a subroutine designed to handle it. So the only major difference between the real-time and interactive versions lies in the front-end command decoding routine. A listing of all the current ANODE interactive commands and parameters is given in Appendix 4.

All real variables and constants in the program are stored as double precision (48 bit, 11 decimal digits) words on the Harris and all floating point operations and intrinsic functions (sin, cos, etc.) are carried out using the full precision available. Specific efficiency considerations are detailed in a subsequent section, but these considerations extend both to minimizing the total size of the program and reducing execution time. Any special assembly language routines that are used to increase execution speed have a standard Fortran IV counterpart which insures portability from one computer to another, leaving only obvious differences, such as word size and I/O incompatibilities, in transferring the program to other machines.

5.2 Data Bases

ANODE accesses two major data bases of the SATTRK System, namely the Master Object File (MOF) and the Metric Data Base (MDB) of the particular satellite (see Fig. 1).

The MOF is a random file in which the current information on every satellite is stored (see Appendix 5 for a short description of the MOF). The orbital elements contained in the MOF entry for the given satellite are read in (via the ELSET command, Appendix 4) and stored in ELEM array in /ELSFIT/ common and are used as the initial elements during the fit. When a fit has successfully converged, the new orbital elements can be inserted in the MOF using the SEND command. The elements are then reformatted into the standard EX-EY card-image format and an orbit fit output card (EO) is generated. All this information is then sent to the System Supervisor

(SUPVSR) processor via a standard inter-processor communication protocol and the SUPVSR does the actual updating of the MOF entry.

The desired metric observational data for a satellite are accessed using the OBSIN command. A dynamic logical file number assignment is made and the records read sequentially from the beginning of the file in the metric data base. When an observation meets the specified input criteria, the measured pointing, time, site and estimated error (weight) of that particular observation are decoded and stored. All this information is kept in a common block, called /OBSAL/, and for any observation K, contains

SITE (K) ≡ 2 character site code

TIME (K) ≡ time of the observation

VALUE (J,K) ≡ measured values of azimuth (J=1), elevation (J=2), range (J=3), range rate (J=4)

SIGMA (J,K) ≡ estimated accuracies of the associated measured values

IOB (J,K) ≡ a flag associated with each measured value indicating whether that particular value was provided in that observation (i.e., IOB (4,K) = 0 indicates that range rate information was not available in observation k)

After the entire file is scanned, or the maximum number of observations (presently 100) have been stored, the variable NUMOBS in /OBSFIL/ common, is set to the total number of observations that have been read in.

5.3 Calculation of Differential Corrections

The routine, called FIT, which calculates the differential corrections that are applied to the orbital elements, is outlined in this section and a block diagram is given in Fig. 2. The necessary control inputs that are passed to this routine are:

1. The maximum number of iterations to perform.
2. A flag indicating whether the initial orbital elements (I) or the elements calculated in the previous iterations (N) are to be used at the start of this current cycle.
3. A flag to indicate that the iterations should proceed in an "automatic" mode, i.e., whether the sigma multipliers (multiplicative factors of the observational errors) should be reduced if the iteration has converged at that level. Once the sigma multipliers have reached their final minimum values and correction convergence has been attained, control is returned to the main program in this mode.

At the beginning of the first iteration, an average time of the observations is calculated and the initial orbital elements are propagated to that time. This is done to minimize the effects of uneven distribution of the observations over the time span.

5.3.1 Definitions and Notation

During the iteration cycle, various matrices and arrays are computed and used. Whenever a particular subscript is used, it will refer to a specific type of variable in order to minimize confusion. The subscripts j and j1 index the orbital elements and their secular rates of change, respectively, in the following order j (or j1) = 1 ≡ inclination

= 2 ≡ right ascension of ascending node

= 3 ≡ eccentricity

= 4 ≡ argument or perigee

= 5 ≡ mean anomaly

= 6 ≡ semi-major axis

The subscript i indexes the types of pointing values (either observed or computed), where

i = 1 ≡ azimuth

= 2 ≡ elevation

= 3 ≡ range

= 4 ≡ range rate.

A metric observation including all the measured observables, time, site and weights of the respective measurements, will be indexed by the subscript m; m can take values between 1 and MTOT where MTOT ≡ total number of observations.

Each of the accepted data points is indexed by the subscript n; n may have a value between 1 and NTOT, where NTOT ≡ total number of accepted data points.

The arrays and matrices that are used are:

POINT (i) ≡ array containing computed pointing vector of updated orbital elements

VALUE (i,m) ≡ array containing observed pointing data values.

[NOTE: A distinction between metric observations and data point should be made. A data point is a single value of any observable at some time, t. A metric observation is the collection of the values of all the observables measured at that time, t.]

SIGMA (i,m) ≡ array containing the weight of the corresponding VALUE (i,m) data point

SMULT (i) ≡ multiplicative factors of the corresponding input SIGMA data point accuracy. The computed weight of a data point in a given iteration cycle is taken as SMULT (i) * SIGMA (i,m)

SREDCE (i) ≡ the reduction factors of the corresponding SMULT values in the auto fit mode. Once an iteration converges at the present SMULT level, the SMULT values will be reduced by SMULT (i) * SREDCE (i) for the next iteration.

SMULMN (i) ≡ desired final values of the SMULT factors. Once the iteration process converges at these values of SMULT, the process is considered to have converged to the final solution in the auto-mode.

DY (n) ≡ array containing the differences between the measured and calculated data points (i.e., the residuals)

R (n) ≡ the inverse of the expected value of the noise associated with the data point used in the calculation of the DY (n) element. (The section dealing with programming efficiencies will detail why the inverse was stored directly.)

ZDELTA (j) ≡ array containing the computed differential corrections to be applied to the epoch elements.

DZO (j1,j) ≡ the matrix of the differentials of the secular rates of change of the orbital elements with respect to the epoch elements, i.e., $\partial \dot{\underset{\sim}{z}}_o / \partial \underset{\sim}{z}_o$

DPDZ (j,i) ≡ the matrix of the differentials of the calculated pointing with respect to the updated orbital elements ($\partial P/\partial Z$).

T(j,n) ≡ the matrix of the differentials of the observational data points with respect to the epoch elements ($\partial P/\partial Z_o$).

[NOTE: The T matrix in the analytic derivation is really an NTOT x 6 matrix, however, it is stored as a 6 x NTOT matrix internally (T^T analytically) for efficiency reasons as discussed in the next section.]

5.3.2 Storage Considerations and Efficiencies

The major steps taken to minimize both the storage requirements and the execution time of the program are outlined in this section. First, if we assume that all the measurements are independent of one another, then the expected value of the noise matrix becomes

$$R(m,n) = R(m,n)\delta_{mn} = R(n), \text{ where } \delta_{mn} = 1 \text{ if } m = n, \text{ zero otherwise.}$$

The inverse is simply

$$R^{-1}(n) = 1/R(n)$$

which is stored directly.

By far the largest single contributors to the size of the program are the T and W matrices. From the analytic formulation (Sec. 4.1.4), we see that for 100 observations consisting of azimuth, elevation, range and range rate (with 2 24-bit words representing a floating point word on the Harris S220):

$$T(400,6) = 2400 \text{ elements}$$
$$= 4800 \text{ words}$$
$$W(6,400) = 4800 \text{ words}$$

for a total of 9.6 K words just for these two matrices. Furthermore, in our virtual machine paging environment, if we keep T as a 400 x 6 matrix, it requires access to at least 5 physical pages (of 1024 words each) for each data point and thus making demand page faults much more probable and overall run time slower.

However, if we store the transpose of T (T(6,400) rather than T directly, we realize a two-fold benefit. First, for any data point we will need only one page of physical memory be currently resident, significantly cutting down the working context of this part of the program. And if we look at the computation of the W matrix

$$W = ST^T R^{-1}$$

Let

$$X(i,j) = \sum_{n=1}^{400} T^T(i,n) R^{-1}(n,j)$$

But the R^{-1} matrix is a diagonal matrix, and hence

$$X(i,j) = \sum_{n=1}^{400} T^T(i,n) R^{-1}(n,j)\,\delta_{nj}$$

$$= T^T(i,j) R^{-1}(j,j)$$

Now

$$W(i,j) = \sum_{n=1}^{6} S(i,n) X(n,j)$$

$$= \sum_{n=1}^{6} S(i,n) T^T(n,j) R^{-1}(j,j)$$

$$= R^{-1}(j,j) \sum_{n=1}^{6} S(i,n) T^T(n,j)$$

Once a j^{th} column of W is calculated, the corresponding j^{th} column of T^T is no longer needed. Since we have stored T^T directly, we can equivalence the first element of the T matrix (T(1,1)) with the first element of the second column of W if calculations are carried out column-wise with respect to W. The total storage requirements of W ant T then become the storage needed for T and only one row of W, for a total of 4812 words as compared to the original estimation of 9600 words.

In the calculation of the secular rates of change of the orbital elements and their differentials, an effort was made to cast the equations in as compact a form as possible, while grouping sub-terms together that are functionally dependent on the same orbital element and saving the results in temporary variables. This is a considerable saving, for the sub-groupings are often redundant in many of the differential computations.

Since operations involving matrices and arrays are generally expensive because of the calculations of the relative displacements of the address of the array elements, one general purpose (MATMUL) and two special purpose (FITML1,FITML2) subroutines were coded in assembly language for increased speed. MATMUL, a general routine which multiplies two matrices together and stores the result in a third matrix, is a factor of 3 faster than a standard Fortran matrix multiplication subroutine. The two specialized routines calculate the S and W matrices, respectively. By using these routines, a 30% savings in the computer time per iteration was realized.

5.3.3 The Iteration Process

The iteration cycle can be broken down into five major steps, namely, the calculation of

1. secular rates and their differentials with respect to the current elements.
2. matrix of the differentials of the pointing with respect to the current elements and the differences between the measured and computed pointing (i.e., the residuals).
3. covariance error matrix.
4. minimum variance estimation matrix.
5. corrections to the elements.

The details of the calculations in each step will be outlined next.

Step 1

The calculation of the secular rates of change ($\dot{Z}_o$) and the differentials of these rates with respect to the elements is done first. The current elements are maintained in array, ELENEW, where the array elements correspond to

(1) = epoch of the element set

(2) = inclination

(3) = right ascension of ascending node

(4) = eccentricity

(5) = argument of perigee

(6) = mean anomaly

(7) = semi-major axis

A call is made to a subroutine, RATES, to do all the necessary computations. The secular rates are stored in array elements ELENEW (8-13) and the differentials are returned in the matrix DZO.

Both the secular rates and differentials are derived from either the singly or doubly averaged formulae depending on the value of the inclination. If the inclination lies between 52^{o} and 75^{o}, singly-averaged formulae will be used, otherwise the doubly-averaged equations will be employed.

Step 2

In order to calculate the matrix, T, of the differentials of the pointing with respect to the current elements, the elements need to be updated to the time of observation, the pointing from the site in question needs to be computed (POINT(i)) and the differentials of the computed pointing with respect to the updated elements (DPDZ) also need to be calculated.

A call is made to subroutine, ORBNEW, for these calculations. The input arguments are the current elements, ELENEW, and the update time (the time of the observation). After updating the elements by their secular rates of change, the periodic variations are calculated and applied to the elements by a call to the subroutine VARIAT. All the necessary rotation and translation transforms are done next to go from the position in the orbital coordinate system to pointing from the given site. The position of the site is in earth-centered rotational coordinates (SITPOS array) and earth-centered rotational to topocentric coordinate transform matrix (ECRTOP) for the current site are contained in the /CSITE/ common block. If the current site is not the observation site, a call to routine ECITOP is made to recompute these values for the site of the observation before the call to ORBNEW is made.

After returning from ORBNEW, the residuals, DY, are calculated for each of the data points of the observation

$$DY(n) = VALUE(I,m) - POINT(I)$$

The data point will be rejected if

$$|DY(n)| > SMULT(i) * SIGMA(i,m)$$

If the observation is accepted, then the inverse of the noise vector element is stored directly in R for that residual

$$R(n) = (SMULT(i) * SIGMA(i,m))^{-2}$$

and finally the differential matrix row of the T matrix of that residual, n, of observation type i

$$T(j,n) = DPDZ(j,i) + \sum_{j1=1}^{6} DPDZ(j1,i) * DZO(J1,j) * DT$$

where DT = time difference between the time of the observation and the epoch of the current elements.

Step 3

Once the T and R matrices have been computed, it is a simple matter to compute the covariance error matrix, S. Let

$$S1 = T^T R^{-1} T$$

Since we have stored R^{-1} directly as R and the T matrix is really T^T of the analytic derivation

$$S1(k,l) = \sum_{n=1}^{NTOT} T(k,n)R(n)T(l,n)$$

where $k = 1,6$

$l = 1,6$

A call is made next to subroutine SYMINV which computes the inverse of S1, if it exists, which is the covariance error matrix, S.

It should be pointed out that it is not always possible to invert the matrix S1 accurately, within the computational accuracy of the computer and thus, the iteration may not converge. The singular matrix problem is usually the result of insufficient or poorly spaced data and is most apparent in the case of a single track on a synchronous satellite.

Step 4

After the covariance error matrix, S, has been computed, the minimum variance estimation matrix, W, is calculated next. Analytically

$$W = ST^T R^{-1}$$

and we have shown in the section on efficiencies that this can be expressed as:

$$W(j,n) = R(j) \sum_{k=1}^{6} S(j,k)T(k,n)$$

Step 5

All that is left is the calculation of the corrections to the elements, ZDELTA, which is

$$ZDELTA(j) = \sum_{n=1}^{NTOT} W(j,n) * DY(n)$$

Once the ZDELTA's have been computed, a check is made whether any of the corrections exceed the maximum allowable changes (CHNMAX) which have been specified by the analyst. If any of the corrections exceed their bound, a scale factor is computed such that

$$SCALE = CHNMAX(J)/ZDELTA(J)$$

where J represents the element correction exceeding its bound by the greatest factor. Then the actual corrections applied to the elements are all scaled by the same factor, and the new elements become

$$ELENEW(K+1) = ELENEW(K+1) + ZDELTA(K) * SCALE$$

If the new value of inclination, ELENEW(1), is negative, then the following replacements are made.

ELENEW(2) = -ELENEW(2) (FLIP inclination)

ELENEW(3) = ELENEW(3) + 180.0 (correct RAN)

ELENEW(5) = ELENEW(5) - 180.0 (correct AP)

5.3.4 Iteration Control

The first aspect of iteration control is the assurance that the present iteration has not rejected too many of the input data points. The check is made after all the observations have been processed in Step 2 of the cycle. During this step, a running count is taken of the number of data point types (az, el, range and range rate) that have been accepted, NUMACC(I), and rejected, NUMREJ(I).

In the automatic mode of iteration control, if any of the data types, i, have

$$\frac{\text{NUMACC(i)}}{\text{NUMACC(i) + NUMREJ(I)}} < \begin{matrix} .5 \\ .25 \end{matrix}$$

(if this is the first iteration .5, .25 with the present sigma multipliers if not)

then all the sigma multipliers will be raised by dividing by its corresponding reduction factor

SMULT(i) = SMULT(i)/SREDCE(i)

Then this step of the cycle will be repeated with these new values.

If the non-automatic mode has been selected by the analyst, then the check is made only on the total number of points accepted and rejected and not on the individual types; so that if

$$\frac{TOTACC}{TOTACC + TOTREJ} < .5$$

where

$$TOTACC = \sum_{i=1}^{4} NUMACC(i)$$

$$TOTREJ = \sum_{i=1}^{4} NUMREJ(i)$$

then the sigma multipliers will be raised and the step repeated.

After the corrections have been computed and been applied to the orbital elements, subject to the constraints detailed in Step 5, the iteration cycle will be repeated with the corrected elements and the same sigma multipliers if the non-automatic mode was specified. In this mode, the iteration cycle will be repeated until the maximum number of cycles, NITER, has been completed.

However, in the auto-fit mode, after the corrections have been applied, a check is made whether or not the corrections have converged at the present level of sigma multiplicative values. Convergence is assumed only if all the following requirements are met

1. in all cases

ZDELTA(J) $\leq$ ZCNVGE(J)

J = 1 (inc.), 3 (eccentricity), and 6 (semi-major axis)

ZDELTA = computed unscaled correction

ZCNVGE = specified convergence value

2. for an eccentric (ecc > .01), inclined (incl > 1^{o}) orbit orbit

ZDELTA(J) $\leq$ ZCNVGE(J)

where J = 2 (RAN), 4 (W), 5 (M).

3. for a low eccentricity (e < .01), inclined (incl > 1^{o}) orbit

ZDELTA(4) + ZDELTA(5) $\leq$ max (ZCNVGE(4), ZCNVGE(5))

and

ZDELTA(2) $\leq$ ZCNVGE(2)

4. for a low eccentricity (e < .01), low inclination orbit

ZDELTA(2) + ZDELTA(4) + ZDELTA(5) $\leq$ max (ZCNVGE(J)

where J = 2, 4, 5.

If any of these criteria are not met, the iteration will be repeated with the corrected elements and current sigma multipliers (assuming that the maximum number of iterations has not been reached). On the other hand, if all these conditions are satisfied, the sigma multipliers will be reduced, if they are not at their specified minimum values, by

$$SMULT(i) = \max [SMULT(i) * SREDCE(i), SMULN(i)]$$

where k = 1,4

and the iteration cycle will be repeated now with these new values.

Once the final desired values of SMULT have been achieved (SMULMN), and the convergence criteria of the orbital element corrections have also converged at a level of .001 times the specified ZCNVGE criteria, final convergence is assumed. Control is then returned to the main calling program.

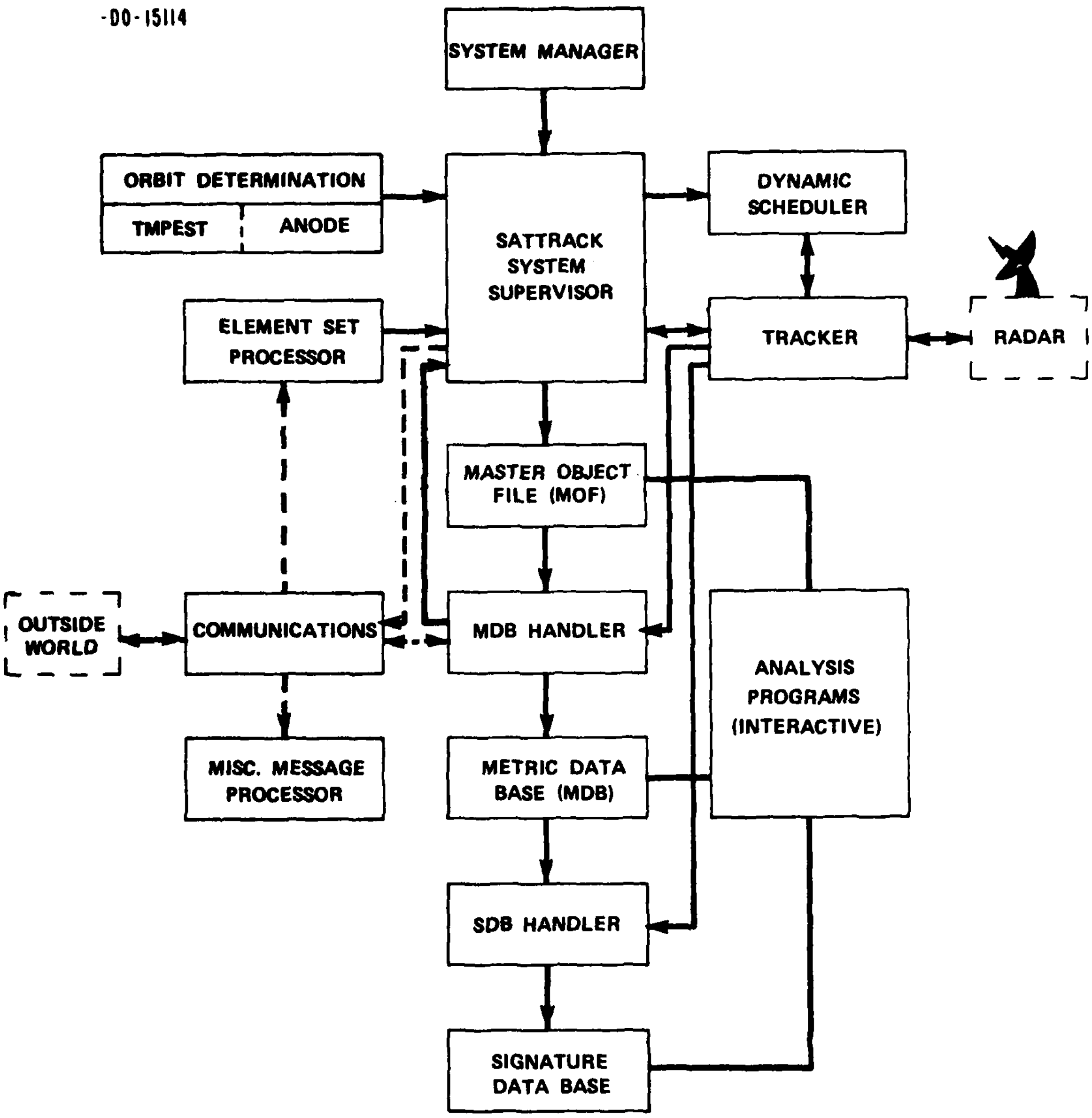

Fig. 1. SATTRACK software system.

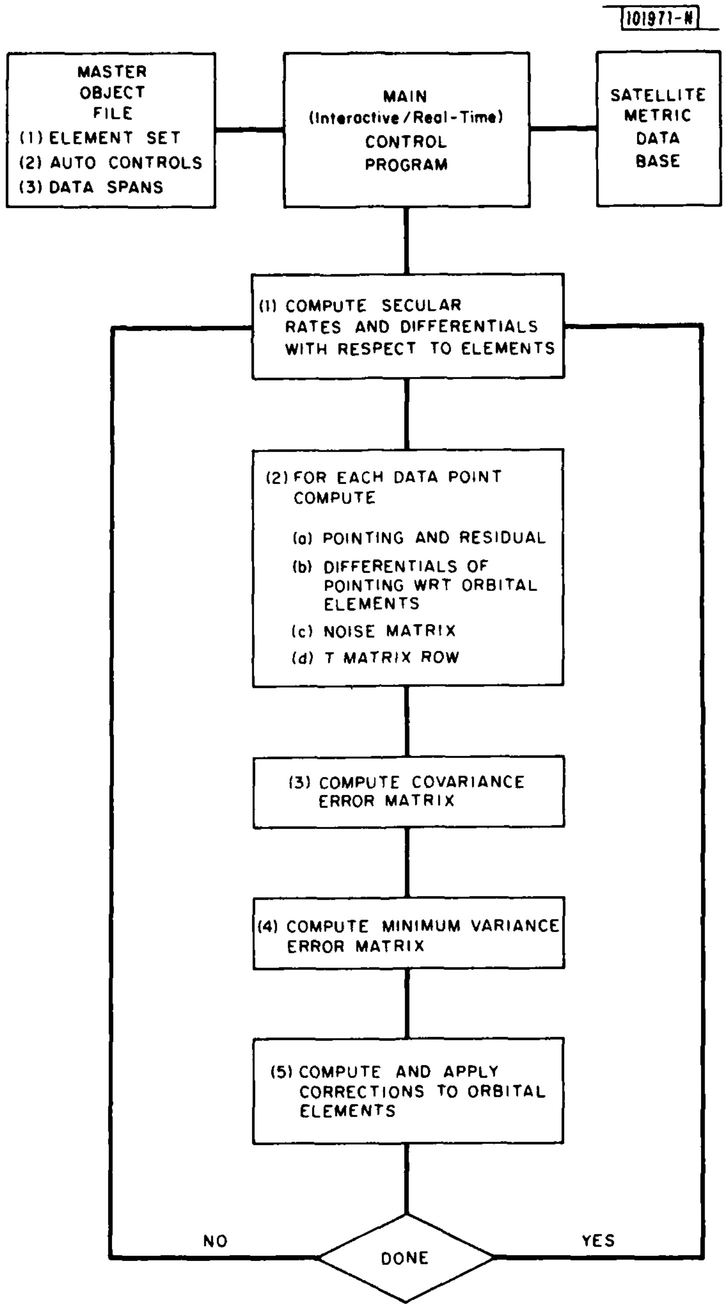

Fig. 2. Outline of the structure of ANODE.

SUMMARY

This note has described the theory and structure of the first versions of the realtime and interactive analytic orbit estimation program, ANODE. The appendices detail the theory as implemented, the command structure for using the program and examples of its functioning.

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APPENDIX 1

SECULAR RATES AND DIFFERENTIALS DUE TO THE EARTH'S GEOPOTENTIAL

The secular rates of change of the orbital elements of a satellite ($\dot{Z}$) and the differentials of the rates with respect to the initial orbital elements ($\partial\dot{Z}/\partial Z_o$) are given in this appendix. The doubly averaged rates and differentials ($<<\dot{Z}>>$ and $\partial<<\dot{Z}>>/\partial Z_o$) are given first and the singly averaged rates are next expressed as

$$<\dot{Z}> = <<\dot{Z}>> + <\dot{Z}'(\omega)>$$

where the $<\dot{Z}'(\omega)>$ terms are those explicitly dependent on the argument of perigee (ω) of the satellite orbit which disappear in the second averaging which is carried out over the argument of perigee. Thus the rates and differentials for the singly averaged case need only the further calculation of the $<\dot{Z}'(\omega)>$ and $\partial<\dot{Z}'(\omega)>/\partial Z_o$ terms.

First define the constants

$$CJ2 \equiv \frac{3}{2} n \, J_2 \, \left(\frac{R_e}{p}\right)^2$$

$$CJ22 \equiv CJ2 \, J_2 \, \left(\frac{R_e}{p}\right)^2$$

$$CJ3 \equiv \frac{3}{8} n \, J_3 \, \left(\frac{R_e}{p}\right)^3$$

$$CJ4 \equiv \frac{15}{16} \; n \; J_4 \; \left(\frac{R_e}{p}\right)^4$$

1. The doubly averaged rates and differentials are given next.

A. $\langle\langle \dot{M} \rangle\rangle$ and differentials.

Let

$$C1M = 1 - \frac{3}{2} \sin^2 I$$

$$C2M = 2 - 5 \sin^2 I + \frac{13}{4} \sin^4 I$$

$$C3M = 1 - \sin^2 I - \frac{5}{8} \sin^4 I$$

$$C4M = \frac{8}{5} (C1M)^2$$

$$C5M = 3 - \frac{15}{2} \sin^2 I + \frac{47}{8} \sin^4 I$$

$$C6M = \frac{3}{2} - 5 \sin^2 I + \frac{117}{16} \sin^4 I$$

$$C7M = \frac{1}{8} \left(1 + 5 \sin^2 I - \frac{101}{8} \sin^4 I\right)$$

$$C8M = 8 - 40 \sin^2 I + 35 \sin^4 I$$

and

$$TERM1 = CJ2 \; \varepsilon^{1/2} \; (C1M)$$

$$TERM2 = \frac{5}{8} CJ22 \; \varepsilon^{1/2} \; (C2M + e^2 \; C3M + \varepsilon^{1/2} \; C4M)$$

$$TERM3 = \frac{3}{4} CJ22 \; \varepsilon^{-1/2} \; (C5M + e^2 \; C6M - e^4 \; C7M)$$

$$TERM4 = -\frac{3}{8} CJ4 \; e^2 \; \varepsilon^{1/2} \; (C8M)$$

Then

$$<<\dot{M}>> = n + TERM1 + TERM2 + TERM3 + TERM4$$

$$\frac{\partial<<\dot{M}>>}{\partial I} = \sin I \cos I \ \varepsilon^{1/2}$$

$$\{-3CJ2$$

$$+ \frac{5}{8} CJ22 \ [- (10 + 2 e^2)$$

$$+ (13 - \frac{5}{e} e^2) \sin^2 I$$

$$- \frac{48}{5} (C1M) \ \varepsilon^{1/2}]$$

$$+ \frac{3}{4} CJ22 \ \varepsilon^{-1/2} \ [- (15 + 10 e^2 + \frac{5}{4} e^4)$$

$$+ (\frac{47}{2} + \frac{117}{4} e^2 + \frac{101}{16} e^4) \sin^2 I]$$

$$- \frac{3}{2} CJ4 \ e^2 (-20 + 35 \sin^2 I)\}$$

Now let

$$TEM = - (\frac{4}{p}) (\frac{TERM1}{2} + TERM2 + TERM3 + TERM4)$$

Then

$$\frac{\partial \langle\langle \dot{M} \rangle\rangle}{\partial e} = - 2\ e\ a\ (TEM)$$

$$- e\ \varepsilon^{1/2}\ \{CJ2\ (C1M)$$

$$+ \frac{5}{8}\ CJ22\ [C2M + (3\ e^2 - 2)\ C3M + (2\varepsilon)\ C4M]$$

$$- \frac{3}{4}\ CJ22\ \varepsilon^{-1/2} [C5M + (2 - e^2)\ C6M - (4\ e^2 - 3\ e^4)\ C7M]$$

$$+ \frac{3}{8}\ CJ4\ (2 - 3\ e^2)\ C8M\}$$

and

$$\frac{\partial \langle\langle \dot{M} \rangle\rangle}{\partial a} = - \frac{3}{2a} \langle\langle \dot{M} \rangle\rangle$$

$$+ (TEM)\ \varepsilon$$

B. $\langle\langle\dot{\Omega}\rangle\rangle$ and differentials.

Let

$$C1R = \frac{9}{4} - \frac{5}{2} \sin^2 I$$

$$C2R = \frac{3}{2} - \frac{9}{4} \sin^2 I$$

$$C3R = \frac{1}{4} + \frac{5}{16} \sin^2 I$$

$$C4R = 4 - 7 \sin^2 I$$

and

$$TERM1 = - CJ22 \; [C1R + \varepsilon^{1/2} \; C2R + e^2 \; C3R]$$

$$TERM2 = CJ4 \; (1 + \frac{3}{2} e^2) \; C4R$$

Then

$$\langle\langle\dot{\Omega}\rangle\rangle = \cos I \; [- CJ2 + TERM1 + TERM2]$$

Now

$$\frac{\partial\langle\langle\dot{\Omega}\rangle\rangle}{\partial I} = - \sin I \; [- CJ2 + TERM1 + TERM2]$$

$$+ \cos^2 I \sin I \; \{CJ22 \; (5 + \frac{9}{2} \varepsilon^{-1/2} - \frac{5}{8} e^2)$$

$$- CJ4 \; (14 + \frac{45}{2} e^2)\}$$

Letting

$$TEM = - (\frac{4}{p}) \; (- \frac{CJ2}{2} + TERM1 + TERM2) \cos I$$

Then

$$\frac{\partial\langle\langle\dot{\Omega}\rangle\rangle}{\partial e} = - 2ea \; (TEM)$$

$$+ CJ22 \; e \cos I \; (\varepsilon^{-1/2} \; C2R - 2C3R)$$

$$+ 3CJ4 \; e \cos I \; (C4R)$$

and

$$\frac{\partial <<\dot{\Omega}>>}{\partial a} = - \frac{3}{2a} <<\dot{\Omega}>> + (TEM)\ \varepsilon$$

C. $<<\dot{\omega}>>$ and differentials.

Let

$$C1\omega = 4 - 5 \sin^2 I$$

$$C2\omega = 12 - \frac{103}{4} \sin^2 I + \frac{215}{16} \sin^4 I$$

$$C3\omega = \frac{7}{4} - \frac{9}{8} \sin^2 I - \frac{45}{32} \sin^4 I$$

$$C4\omega = 1 - \frac{3}{2} \sin^2 I$$

$$C5\omega = 16 - 62 \sin^2 I + 49 \sin^4 I$$

$$C6\omega = \frac{3}{4} (24 - 84 \sin^2 I + 63 \sin^4 I)$$

and

$$TERM1 = \frac{1}{2} CJ2\ (C1\omega)$$

$$TERM2 = \frac{1}{2} CJ22\ [C2\omega + e^2\ C3\omega + \frac{3}{2} \varepsilon^{1/2}\ (C4\omega)\ (C1\omega)]$$

$$TERM3 = - \frac{1}{2} CJ4\ (C5\omega + e^2\ C6\omega)$$

Then

$$<<\dot{\omega}>> = TERM1 + TERM2 + TERM3$$

and

$$\frac{\partial\langle\langle\dot{\omega}\rangle\rangle}{\partial I} = \sin I \cos I \{-5CJ2$$

$$+ CJ22 [- \frac{103}{4} - \frac{9}{8} e^2$$

$$- \frac{3}{4} \varepsilon^{1/2} (3C1\omega + 10C4\omega)$$

$$+(\frac{215}{8} - \frac{45}{16} e^2) \sin^2 I]$$

$$- CJ4 [- 62 - 63 e^2 + (98 + \frac{189}{2} e^2) \sin^2 I]\}$$

Next, let

$$TEM = - (\frac{4}{p}) (\frac{TERM1}{2} + TERM2 + TERM3)$$

Then

$$\frac{\partial\langle\langle\dot{\omega}\rangle\rangle}{\partial e} = - 2\, ea(TEM)$$

$$+ CJ22(e)[C3\omega - \frac{3}{4} (C4\omega) (C1\omega) \varepsilon^{-1/2}]$$

$$- CJ4 (e) C6\omega$$

and

$$\frac{\partial\langle\langle\dot{\omega}\rangle\rangle}{\partial a} = - \frac{3}{2a} \langle\langle\dot{\omega}\rangle\rangle + (TEM) \varepsilon$$

and

$$\langle\langle\dot{I}\rangle\rangle = 0$$

$$\langle\langle\dot{e}\rangle\rangle = 0$$

$$\langle\langle\dot{a}\rangle\rangle = 0$$

2. The singly averaged rates and differentials are given next. First define

$$C1 = 14 - 15 \sin^2 I$$

$$C2 = 6 - 7 \sin^2 I$$

$$C3 = 4 - 5 \sin^2 I$$

A. $\langle \dot{M} \rangle$ and differentials

Let

$$C9M = \frac{1}{16} \sin^2 I \ (C1)$$

$$C10M = \sin^2 I \left(\frac{35}{4} - \frac{123}{8} \sin^2 I\right)$$

$$C11M = \sin^2 I \left(8 - \frac{33}{4} \sin^2 I\right)$$

$$C12M = \sin I \ (C3)$$

$$C13M = \sin^2 I \ (C2)$$

and

$$TERM1 = CJ22 \ (C9M) \ \left(1 - \frac{5}{2} e^2\right) \varepsilon^{1/2}$$

$$TEM1 = \frac{1}{4} CJ22 \ e^2 \ \varepsilon^{-1/2}$$

$$TERM2 = TEM1 \ (C10M + C11M \ e^2)$$

$$TERM3 = TEM1 \ \left(\frac{27}{128} e^2 \sin^4 I\right)$$

$$TERM4 = -CJ3 \ (C12M) (1 - 4 \ e^2) \ \varepsilon^{1/2} \ (1/e)$$

$$TERM5 = CJ4 \ (C13M) \ (1/2 - 5/4 \ e^2) \ \varepsilon^{1/2}$$

So

$$\frac{\partial \langle \dot{M} \rangle}{\partial \omega} = - [TERM1 + TERM2 + TERM3 \ (4 \cos 2\omega)$$

$$+ TERM5] \ 2 \sin 2\omega$$

$$+ (TERM4) \cos \omega$$

Now define

$$\dot{M}' = (TERM1 + TERM2 + TERM5) \cos 2\omega$$

$$+ (TERM3) \cos 4\omega$$

$$+ (TERM4) \sin \omega$$

and the secular rate becomes

$$<\dot{M}> = <<\dot{M}>> + \dot{M}'$$

Now if we define

$$TEM1 = -\frac{4}{p} [TERM1 + TERM2 + TERM5) \cos 2\omega$$

$$+ \frac{3}{4} (TERM4) \cos 4\omega$$

$$+ TERM5 \sin \omega]$$

Then

$$\frac{\partial <\dot{M}>}{\partial a} = \frac{\partial <<\dot{M}>>}{\partial a}$$

$$+ (TEM1) \varepsilon - \frac{3}{2a} (\dot{M}')$$

$$\frac{\partial <\dot{M}>}{\partial e} = \frac{\partial <<\dot{M}>>}{\partial e}$$

$$- 2\, ea\, (TEM\ 1)$$

$$- CJ22\ (C9M)\ e\ \varepsilon^{-1/2} (6 - \frac{15}{2} e^2) \cos 2\omega$$

$$+ (TERM2) \cos 2\omega \ (\frac{e}{\varepsilon} + \frac{2}{e})$$

$$+ CJ22\ e^3\ \varepsilon^{-1/2} [\frac{1}{2} C11M \cos 2\omega + \frac{27}{256} \sin^4 I \cos 4\omega]$$

$$+ CJ3\ (C12M) \sin \omega\ \varepsilon^{-1/2}$$

$$[8 - 8\,e^2 + (1 - 4\,e^2)\,(\frac{1}{e^2})\,]$$

$$-\ CJ4\ (C13M)\ \cos 2\omega\ e\ \varepsilon^{-1/2}\ (3 - \frac{15}{4}\,e^2)$$

$$\frac{\partial\langle\dot{M}\rangle}{\partial I} = \frac{\partial\langle\langle\dot{M}\rangle\rangle}{\partial I}$$

$$+\ CJ22\ (\frac{1}{8} - \frac{5}{16}\,e^2)\ \varepsilon^{1/2}\ \cos 2\omega$$

$$(\sin I \cos I)\ (7/4 - 15/4\ \sin^2 I)$$

$$+\ \frac{1}{2}\ CJ22\ \varepsilon^{-1/2}\ e^2\ (\sin I \cos I)$$

$$\{[\frac{35}{4} - \frac{123}{4}\sin^2 I + (7 - \frac{33}{2}\sin^2 I)\ e^2]\ \cos 2\omega$$

$$+\ \frac{27}{64}\,e^2\ \sin^2 I\ \cos 4\omega\}$$

$$-\ CJ3\ (1 - 4e^2)\ (\frac{1}{e})\ \varepsilon^{1/2}\ \sin\omega\ \cos I$$

$$(4 - 15\ \sin^2 I)$$

$$+\ CJ4\ (1 - \frac{5}{2}\,e^2)\ \varepsilon^{1/2}\ \cos 2\,\omega$$

$$(\sin I \cos I)\ (3 - 7\ \sin^2 I)$$

B. Next the right ascension rate and differentials will be given

Let

$$C5R = \cos I \left(- \frac{7}{8} + \frac{15}{8} \sin^2 I\right)$$

$$C6R = \left(\frac{\cos I}{\sin I}\right) (15 \sin^2 I - 4)$$

$$C7R = - \cos I (3 - 7 \sin^2 I)$$

Now

$$TERM1 = [CJ22 (C5R) + CJ4 (C7R)] e^2$$

$$TERM2 = - CJ3 (C6R) e$$

Then

$$\frac{\partial \langle \dot{\Omega} \rangle}{\partial \omega} = - 2 (TERM1) \sin \omega + (TERM2) \cos \omega$$

and

$$\dot{\Omega}' = (TERM1) \cos 2\omega + (TERM2) \sin \omega$$

So

$$\langle \dot{\Omega} \rangle = \langle\langle \dot{\Omega} \rangle\rangle + \dot{\Omega}'$$

Let

$$TEM1 = - \frac{4}{p} \left[(TERM1) \cos 2\omega + \frac{3}{4} (TERM2) \sin \omega\right]$$

Then

$$\frac{\partial \langle \dot{\Omega} \rangle}{\partial a} = \frac{\partial \langle\langle \dot{\Omega} \rangle\rangle}{\partial a}$$

$$- \frac{3}{2a} \dot{\Omega}' + (TEM1) \varepsilon$$

$$\frac{\partial\langle\dot{\Omega}\rangle}{\partial e} = \frac{\partial\langle\langle\dot{\Omega}\rangle\rangle}{\partial e}$$

$$- 2ea\ (TEM1)$$

$$- CJ3\ (C6R) \sin\omega$$

$$+ [CJ4\ (C7R) + CJ22\ (C5R)]\ 2e \cos 2\omega$$

$$\frac{\partial\langle\dot{\Omega}\rangle}{\partial I} = \frac{\partial\langle\langle\dot{\Omega}\rangle\rangle}{\partial I}$$

$$+ CJ22\ e^2 \cos 2\omega \cos I \left(\frac{1}{8}\right) [37 - 45 \sin^2 I]$$

$$- CJ3\ e \sin\omega \left(\frac{4}{\sin^2 I} + 15 - 30 \sin^2 I\right)$$

$$+ CJ4\ e^2 \cos 2\omega \sin I\ (17 - 21 \sin^2 I)$$

C. Now the argument of perigee and differentials will be presented. Let

$$C7\omega = \frac{1}{16} (C1) \sin^2 I$$

$$C8\omega = \frac{7}{8} - \frac{158}{32} \sin^2 I + \frac{135}{32} \sin^4 I$$

$$C9\omega = \sin I \ (26 - 30 \sin^2 I)$$

$$C10\omega = \sin^2 I \ (C2)$$

$$C11\omega = - 6 + 35 \sin^2 I - \frac{63}{2} \sin^4 I$$

and

$$TERM1 = CJ22 \ (C7\omega + C8\omega \ e^2)$$

$$TERM2 = CJ3 \ [C3 \ (\frac{\sin I}{e} - e \frac{\cos^2 I}{\sin I}) + c9\omega \ e]$$

$$TERM3 = - \frac{1}{2} CJ4 \ (C10\omega + (C11\omega) \ e^2)$$

So

$$\frac{\partial \langle \dot{\omega} \rangle}{\partial \omega} = - 2 \ (TERM1 + TERM3) \sin 2\omega + TERM2 \cos \omega$$

Now

$$\dot{\omega}' = (\text{TERM1} + \text{TERM3}) \cos 2\omega$$

$$+ (\text{TERM2}) \sin \omega$$

So

$$<\dot{\omega}> = <<\dot{\omega}>> + \dot{\omega}'$$

Let

$$\text{TEM1} = -\frac{4}{p} [(\text{TERM1} + \text{TERM3}) \cos 2\omega + \frac{3}{4} (\text{TERM2}) \sin \omega]$$

Then

$$\frac{\partial<\dot{\omega}>}{\partial a} = \frac{\partial<<\dot{\omega}>>}{\partial a}$$

$$- \frac{3}{2a} \dot{\omega}' + (\text{TEM1}) \varepsilon$$

$$\frac{\partial<\dot{\omega}>}{\partial e} = \frac{\partial<<\dot{\omega}>>}{\partial e}$$

$$- 2 e a (\text{TEM1})$$

$$+ 2 \text{ CJ22 } e (\text{C8}\omega) \cos 2\omega$$

$$+ \text{CJ3} \sin \omega [- \text{C3} (\frac{\sin I}{e^2} + \frac{\cos^2 I}{\sin I}) + \text{C9}\omega]$$

$$- \text{CJ4} (\text{C11}\omega) e \cos 2\omega$$

$$\frac{\partial<\dot{\omega}>}{\partial I} = \frac{\partial<<\dot{\omega}>>}{\partial I}$$

$$+ \frac{1}{4} \text{CJ22} (\sin I \cos I) \cos 2\omega$$

$$[- 7 + 15 \sin^2 I + (\frac{79}{2} + \frac{135}{2} \sin^2 I) e^2]$$

$$+ CJ3 \sin I \sin \omega$$

$$\{- 10 \left(\frac{\sin^2 I}{e} - e \cos^2 I\right)$$

$$+ C3 \left[\frac{1}{2} + e \left(2 + \frac{\cos^2 I}{\sin^2 I}\right)\right]$$

$$+ e (26 - 90 \sin^2 I)\}$$

$$- CJ4 (\sin I \cos I) \cos 2 \omega$$

$$[6 - 14 \sin^2 I + (35 - 63 \sin^2 I) e^2]$$

D. The rate of change of eccentricity and differentials are given next. Let

$$C1e = \sin^2 I \quad (C1)$$

$$C2e = \sin I \quad (C3)$$

$$C3e = \sin^2 I \quad (C2)$$

and

$$TERM1 = - \frac{1}{16} CJ22 (C1e) e \varepsilon$$

$$TERM2 = - CJ3 (C2e) \varepsilon$$

$$TERM3 = - \frac{1}{2} CJ4 (C3e) e \varepsilon$$

So

$$\frac{\partial \langle \dot{e} \rangle}{\partial \omega} = 2 (TERM1 + TERM3) \cos 2\omega$$

$$- (TERM2) \sin \omega$$

and

$$\langle \dot{e} \rangle = (\text{TERM1} + \text{TERM3}) \sin 2\omega$$

$$+ (\text{TERM2}) \cos \omega$$

Letting

$$\text{TEM1} = -\frac{4}{p} \left[(\text{TERM1} + \text{TERM3}) \sin 2\omega + \frac{3}{4} (\text{TERM2}) \cos \omega \right]$$

Thus

$$\frac{\partial \langle \dot{e} \rangle}{\partial a} = -\frac{3}{2a} \langle \dot{e} \rangle + (\text{TEM1})\ \varepsilon$$

$$\frac{\partial \langle \dot{e} \rangle}{\partial e} = -2\ e\ \varepsilon\ (\text{TEM1})$$

$$- \text{CJ22}\ (\text{C1e}) \sin 2\omega \left(\frac{1}{16}\right) (1 - 3 e^2)$$

$$+ 2\text{CJ3}\ (\text{C2e})\ e \cos \omega$$

$$- \text{CJ4}\ (\text{C3e}) \sin 2\omega \left(\frac{1}{2} - \frac{3}{2} e^2\right)$$

$$\frac{\partial \langle \dot{e} \rangle}{\partial I} = - \text{CJ22}\ (\sin I \cos I)\ e\ \varepsilon$$

$$\left(\frac{7}{4} - \frac{15}{4} \sin^2 I\right) \sin 2\omega$$

$$- \text{CJ3}\ (\cos I)\ \varepsilon\ (4 - 15 \sin^2 I) \cos \omega$$

$$- \text{CJ4}\ (\sin I \cos I)\ e\ \varepsilon$$

$$(6 - 14 \sin^2 I) \sin 2\omega$$

E. and lastly, the inclination rate and differentials.

Let

$$TERM1 = \frac{1}{32} CJ22 \sin 2I \ (C1) \ e^2$$

$$TERM2 = CJ3 \cos I \ (C3) \ e$$

$$TERM3 = \frac{1}{4} CJ4 \sin 2I \ (C2) \ e^2$$

So that

$$\frac{\partial \langle \dot{I} \rangle}{\partial \omega} = 2(TERM1 + TERM3) \cos 2\omega$$

$$- (TERM2) \sin \omega$$

and

$$\langle \dot{I} \rangle = (TERM1 + TERM3) \sin 2\omega$$

$$+ (TERM2) \cos \omega$$

Let

$$TEM1 = \frac{4}{p} [(TERM1 + TERM3) \sin 2\omega + \frac{3}{4} (TERM2) \cos \omega]$$

then

$$\frac{\partial \langle \dot{I} \rangle}{\partial e} = - \frac{3}{2a} \langle \dot{I} \rangle + (TEM1) \ \varepsilon$$

$$\frac{\partial \langle \dot{I} \rangle}{\partial e} = - 2 \ e \ a \ (TEM1)$$

$$+ \frac{2}{e} [(TERM1 + TERM3) \sin 2\omega + \frac{1}{2} (TERM2) \cos \omega]$$

$$\frac{\partial\langle\dot{I}\rangle}{\partial I} = \frac{1}{32}\,CJ22\ e^2 \sin 2\omega$$

$$(28 - 146 \sin^2 I + 120 \sin^4 I)$$

$$- CJ3\ e \cos \omega\ (C1) \sin I$$

$$+ CJ4\ e^2 \sin 2\omega\ (3 - \frac{33}{2} \sin^2 I + 14 \sin^2 I)$$

APPENDIX 2

PERIODIC PERTURBATIONS DUE TO THE GEOPOTENTIAL

This appendix presents both the short and long periodic variations to the orbital elements due to the earth's geopotential. As mentioned previously, the short periodics come from the first averaging of the equations over the mean anomaly while the long periodics come from the second averaging over the period of the argument of perigee of the satellite orbit.

1. The short periodic terms due to the single averaging are given first. Define

$$C1 \equiv (1 - \frac{3}{2}\sin^2 I)\ [(1 - \frac{e^2}{4})\sin\nu + \frac{e}{2}\sin 2\nu + \frac{e^2}{12}\sin 3\nu]$$

$$C2 \equiv \nu - M + e\sin\nu$$

$$C3 \equiv \frac{e}{2}\sin(2\omega + \nu) + \frac{1}{2}\sin(2\omega + 3\nu)$$

$$C4 \equiv \frac{9}{16}\,CJ2\,\sin^2 I\,\sin 2\omega$$

$$C5 \equiv \sin^2 I\ [-\frac{1}{4}\sin(2\omega + \nu) - \frac{1}{16}e^2\sin(2\omega - \nu)$$
$$+\frac{7}{12}\sin(2\omega + 3\nu) + \frac{3}{8}e\sin(2\omega + 4\nu)$$
$$+\frac{1}{16}e^2\sin(2\omega + 5\nu)].$$

$$CJ2 = J_2\,(Re/p)^2$$

Then the short periodic terms are

$$\Delta I_s = \frac{3}{8} CJ2 \sin 2I \, [e \cos (2\omega + \nu) + \cos (2\omega + 2\nu) + \frac{e}{3} \cos (2\omega + 3\nu)]$$

$$\Delta \Omega_s = -\frac{3}{2} CJ2 \cos I \, (C2 - C3)$$

$$\Delta e_s = \frac{1}{2} CJ2 \left(1 - \frac{3}{2} \sin^2 I\right)$$

$$[\frac{1}{e} (1 + \frac{3}{2} e^2 - \varepsilon^{3/2}) + (3 + \frac{3}{4} e^2) \cos \nu + \frac{3}{2} e \cos 2\nu + \frac{1}{4} e^2 \cos 3\nu)]$$

$$+ \frac{3}{8} CJ2 \sin^2 I$$

$$[(1 + \frac{11}{4} e^2) \cos (2 \quad + \quad) + \frac{1}{4} e^2 \cos (2\omega - \nu)$$

$$+ 5e \cos (2\omega + 2\nu) + (\frac{7}{3} + \frac{17}{12} e^2) \cos (2\omega + 3\nu)$$

$$+ \frac{3}{2} e \cos (2\omega + 4\nu) + \frac{1}{4} e^2 \cos (2\omega + 5\nu)$$

$$+ \frac{3}{2} e \cos 2\omega]$$

$$\Delta \omega_s = \frac{3}{4} CJ2 \left(4 - 5 \sin^2 I\right) C\,2$$

$$+ \frac{3}{2} CJ2 \left(\frac{1}{e}\right) C1$$

$$-\frac{3}{2} \text{ CJ2 } \{C3 - (\frac{1}{e}) \text{ C5}$$

$$- \sin^2 I \; [\frac{15}{16} e \sin (2\omega + \nu) + \frac{5}{4} \sin (2\omega + 2\nu)$$

$$+ \frac{19}{48} e \sin (2\omega + 3\nu)]\}$$

$$-C_4$$

$$\Delta M_s = -\frac{3}{2} (\frac{1}{e}) \text{ CJ2 } \varepsilon^{1/2} \{C1 + C5$$

$$-\sin^2 I \; [\frac{5}{16} e^2 \sin (2\omega + \nu) + \frac{1}{48} e^2 \sin (2\omega + 3\nu)]\}$$

$$+ \text{ C4 } \varepsilon^{1/2}$$

$$\Delta a_s = J_2 (\frac{R_e^2}{a}) \{(\frac{1 + 3 \cos \nu^3}{\varepsilon})[(1 - \frac{3}{2} \sin^2 I) + \frac{3}{2} \sin^2 I \cos (2\omega + 2\nu)]$$

$$- (1 - \frac{3}{2} \sin^2 I) \; \varepsilon^{-3/2}\}$$

2. The long periodics due to the second averaging over the argument of perigee are given in this section.

Letting

$$\text{CJ3DJ2} = (\frac{J_3}{J_2})(\frac{R_3}{p})$$

$$CJ4DJ2 = \left(\frac{J_4}{J_2}\right)\left(\frac{R_e}{p}\right)^2$$

$$G = 1 / (4 - 5 \sin^2 I)$$

$$D1 = G \sin^2 I \; (14 - 15 \sin^2 I)$$

$$D2 = G \sin^2 I \; (6 - 7 \sin^2 I)$$

$$D3 = 1 - G \; (13 - 15 \sin^2 I) \; e^2$$

a. The inclination long periodic correction becomes

$$\Delta I_{1p} = \{-\frac{1}{32} \, CJ2 \; (14 - 15 \sin^2 I)$$

$$-\frac{5}{32} \, CJ4DJ2 \; (6 - 7 \sin^2 I\} \; G \sin 2I \; e^2 \cos 2\omega$$

$$+\frac{1}{2} \, CJ3DJ2 \cos I \; e \sin \omega$$

b. The right ascension of ascending mode

$$\Delta\Omega_{1p} = \{-\frac{5}{16} \, CJ2 \; (\frac{14}{5} - 6 \sin^2 I + D1)$$

$$-\frac{25}{16} \, CJ4DJ2 (\frac{6}{5} - \frac{14}{5} \sin^2 I + D2)\} \; G \; e^2 \cos I \sin 2\omega$$

$$-\frac{1}{2} \, CJ3DJ2 \; e \cos \omega \; (\frac{\cos I}{\sin I})$$

c. The eccentricity

$$\Delta e_{1p} = \{\frac{1}{16} CJ2\ D1$$

$$+\frac{5}{16} CJ4DJ2\ D2\}\ \varepsilon\ e \cos 2\omega$$

$$-\frac{1}{2} CJ3DJ2\ \varepsilon \sin I \sin \omega$$

d. The argument of perigee

$$\Delta\omega_{1p} = -\frac{1}{32} CJ2 \sin 2\omega$$

$$\{2D1D3 - (28 - 158 \sin^2 I + 135 \sin^4 I)\ G\ e^2\}$$

$$-\frac{1}{2} CJ3DJ2 \cos \omega\ (\sin^2 I - e^2 \cos^2 I)/(e \sin I)$$

$$-\frac{5}{32} CJ4DJ2 \sin 2\omega$$

$$\{2\ D2\ D3 - (12 - 70 \sin^2 I + 63 \sin^4 I)\ G\ e^2\}$$

e. The mean anomaly

$$\Delta M_{1p} = \{\frac{1}{16} CJ2\ D1$$

$$+\frac{5}{16} CJ4Dj2\ D2\}\ \varepsilon^{3/2} \sin 2\omega$$

$$+\frac{1}{32}\ CJ2\ G\ \sin^2 I\ \sin 2\omega\ \varepsilon^{-1/2}$$

$$[(70 - 123 \sin^2 I)\ e^2 + (56 - 66 \sin^2 I)\ e^4]$$

$$+\frac{27}{1024}\ CJ2\ G\ \sin^4 I\ e^4\ \sin 4\omega\ \varepsilon^{-1/2}$$

$$+\frac{1}{2}\ CJ3DJ2\ \sin I\ \varepsilon^{3/2}\ \cos\omega\ (\frac{1}{e})$$

f. And the semi major axis

$$\Delta a_{1p} = 0$$

APPENDIX 3

DIFFERENTIALS OF POINTING WITH RESPECT TO ELEMENTS

This section presents the differentials of the calculated pointing values of azimuth, elevation, range and range rate from a site with respect to the orbital elements of a satellite.

First the unit vector and differential of the geocentric range in the orbital coordinate frame is

$$\vec{ur}_o = \begin{bmatrix} \cos\gamma \\ \sin\gamma \\ 0 \end{bmatrix} \quad \vec{ut}_o = \begin{bmatrix} -\sin\gamma \\ \cos\gamma \\ 0 \end{bmatrix}$$

The transform matrices and differentials from the orbital coordinate frame to the earth-centered interial (ECI) frame are

$$f(\Omega) = \begin{bmatrix} \cos\Omega & -\sin\Omega & 0 \\ \sin\Omega & \cos\Omega & 0 \\ 0 & 0 & 1 \end{bmatrix}; \quad f'(\Omega) = \begin{bmatrix} -\sin\Omega & -\cos\Omega & 0 \\ \cos\Omega & -\sin\Omega & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$g(I) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos I & -\sin I \\ 0 & \sin I & \cos I \end{bmatrix}; \quad g'(I) = \begin{bmatrix} 0 & 0 & 0 \\ 0 & -\sin I & -\cos I \\ 0 & \cos I & -\sin I \end{bmatrix}$$

$$h(\omega) = \begin{bmatrix} \cos\omega & -\sin\omega & 0 \\ \sin\omega & \cos\omega & 0 \\ 0 & 0 & 1 \end{bmatrix}; \quad h'(\omega) = \begin{bmatrix} -\sin\omega & -\cos\omega & 0 \\ \cos\omega & -\sin\omega & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

The ECI unit vectors of the geocentric range in the radial and transverse direction are then

$$\vec{u}_r = [f\ g\ h]\ \vec{u}\ r_o$$

$$\vec{u}_t = [f\ g\ h]\ \vec{u}\ t_o$$

The magnitude of the geocentric range vector, r, is

$$r = a(1-e \cos E)$$

and

$$\vec{r} = r\ \vec{u}_r.$$

The differentials of $\vec{r}$ *with respect to the orbital* elements can then be expressed as

$$\frac{\partial \vec{r}}{\partial I} = r[f\ g'\ h]\ u\ \vec{r}_o$$

$$\frac{\partial \vec{r}}{\partial r} = r\ [f'\ g\ h]\ \vec{u}\ r_o$$

$$\frac{\partial \vec{r}}{\partial e} = \frac{a^2}{r} (e - \cos E)\ \vec{ur}$$

$$+ r\ DNU\ \vec{ut}$$

$$\frac{\partial \vec{r}}{\partial \omega} = r\ [f\ g\ h']\ \vec{ur}_o$$

$$\frac{\partial \vec{r}}{\partial M} = \frac{a^2}{r}\ e \sin E\ \vec{ur}$$

$$+ r\ \varepsilon^{1/2}\ (1 - e \cos E)^{-2}\ \vec{ut}$$

$$\frac{\partial \vec{r}}{\partial a} = \frac{r}{a}\ \vec{ur}$$

where DNU is the differential of the true anomaly with respect to the eccentricity

$$DNU = \sin E\ (1-e \cos + \varepsilon)/[\varepsilon^{1/2}\ (1-e \cos E)^2]$$

Now the differential of the slant range, ρ, with respect to the elements is

$$\frac{\partial \rho}{\partial I} = -\frac{1}{\rho}\ [\frac{\partial \vec{r}}{\partial I} \cdot \vec{RSITE}]$$

$$\frac{\partial \rho}{\partial \Omega} \quad \frac{1}{\rho}\ [\frac{\partial \vec{r}}{\partial \Omega} \cdot \vec{RSITE}]$$

$$\frac{\partial \rho}{\partial e} = \frac{a^2}{\rho} (e - \cos E) - \frac{1}{\rho} [\frac{\partial \vec{r}}{\partial e} \cdot \vec{RSITE}]$$

$$\frac{\partial \rho}{\partial \omega} \quad \frac{1}{\rho} \quad \frac{\partial \vec{r}}{\partial \omega} \cdot \vec{RSITE}]$$

$$\frac{\partial \rho}{\partial M} = \frac{a^2}{\rho} e \sin E - \frac{1}{\rho} [\frac{\partial \vec{r}}{\partial M} \cdot \vec{RSITE}]$$

$$\frac{\partial \rho}{\partial a} = \frac{r^2}{\rho a} - \frac{1}{\rho} \frac{\partial \vec{r}}{\partial a} \cdot \vec{RSITE}]$$

where the "." operation indicates the scalar dot product of the two vectors

$\vec{RSITE}$ ≡ ECI vector to the site

Now if we define the vectors

$\vec{uv}$ ≡ unit vector of the site vertical in the Geodetic coordinate frame

$\vec{un}$ ≡ unit vector of the site to North in the Geodetic coordinate frame.

Then the differentials of elevation (EL) with respect to an orbital element Z_i becomes:

$$\frac{\partial\ EL}{\partial\ Z_i} = - \frac{1}{\rho\ \cos\ EL} [\frac{\partial \vec{r}}{\partial Z_I} \cdot \vec{uv} - \frac{\partial \rho}{\partial Z_i}\ \sin\ EL]$$

and the differentials of azimuth (AZ) with respect to an element Z_i becomes

$$\frac{\partial\ AZ}{\partial\ Z_i} = - \frac{1}{\rho\ \cos\ EL\ \sin\ AZ} [\frac{\partial \vec{r}}{\partial Z_i} \cdot \vec{un}$$

$$- \quad \frac{\partial \rho}{\partial Z_i} \cos\ EL\ \cos\ AZ + \rho\ \sin\ EL\ \cos\ AZ\ \frac{\partial EL}{\partial Z_i}]$$

In order to calculate the differentials of the slant range rate $(\dot{\rho})$ we must first compute the differentials of the ECI velocity vector $(\dot{\vec{r}})$ of the satellite with respect to the orbital elements. If we define a vector $\vec{\alpha}$ as

$$\vec{\alpha} = e\ \sin\ \gamma\ \vec{ur}_o + \frac{p}{r}\ \vec{ut}_o$$

where $p = a(1 - e^2)$.

Then

$$\frac{\partial\ \dot{\vec{r}}}{\partial\ I} = \sqrt{\frac{\mu}{p}}\ [f\ g'\ h]\ \vec{\alpha}$$

$$\frac{\partial \dot{\vec{r}}}{\partial \Omega} = \sqrt{\frac{\mu}{p}}\ [f'\ g\ h]\ \vec{\alpha}$$

$$\frac{\partial \dot{\vec{r}}}{\partial e} = \{[\sin \gamma\ (DNU) - \frac{a}{r}]\ e \sqrt{\frac{\mu}{p}}$$

$$+ \frac{1}{r^2} \sqrt{\mu p}\ a \cos \gamma\}\ \vec{ut}_o$$

$$\{[\cos \gamma - DNU + \frac{ae^2}{p} \cos \gamma] \sqrt{\frac{\mu}{p}}\}\ \vec{ur}_o$$

$$\frac{\partial \dot{\vec{r}}}{\partial \omega} = \sqrt{\frac{\mu}{p}}\ [f\ g\ h']\ \vec{\alpha}$$

$$\frac{\partial \dot{\vec{r}}}{\partial M} = - a^2\ \varepsilon^{1/2} \sqrt{\frac{\mu}{p}}\ \vec{ur}_o$$

$$\frac{\partial \dot{\vec{r}}}{\partial a} = - \frac{1}{2} / \sqrt{\frac{\mu}{p}}\ \varepsilon\ \{\frac{e \sin \gamma}{p}\ \vec{ur}_o + \frac{1}{r}\ \vec{ut}_o\}$$

So the differential of the slant range rate with respect to an orbital element Z_i can be then expressed as

$$\frac{\partial \dot{\rho}}{\partial Z_i} = \frac{1}{\rho} \{\frac{\partial \dot{\vec{r}}}{\partial Z_i} \cdot \vec{\rho} + \dot{\vec{p}} \cdot \frac{\partial \vec{r}}{\partial Z_i} - \dot{\rho}\ \frac{\partial \rho}{\partial Z_i}\}$$

where

$$\vec{\rho} = \vec{r} - \vec{RSITE}$$

$$\dot{\vec{\rho}} = \dot{\vec{r}} - \dot{\vec{RSITE}}$$

APPENDIX 4

ANODE
ANALYTIC ORBIT DETERMINATION
COMMAND LIST

DATA BASE INITIALIZATION COMMANDS

OBSIN: IDNO DAY1 DAY2

PURPOSE: TO READ IN OBSERVATIONS OF THE GIVEN SATELLITE FROM ITS METRIC DATA BASE FILE (9SASS*M:XXXXX FILES ON HARRIS S220)

PARAMETERS:

IDNO: SATELLITE OBJECT NUMBER

DAY1: STARTING DAY NUMBER OF DESIRED OBSERVATIONS

DAY2: ENDING DAY NUMBER OF DESIRED OBSERVATIONS

(NOTE: IF DAY2 IS NOT SPECIFIED, ALL OBSERVATIONS FROM DAY1 ON WILL BE READ IN. IF NEITHER DAY1 NOR DAY2 IS SPECIFIED, ALL OBSERVATIONS IN THE MOB FILE OF IDNO WILL BE READ IN)

NUM: NUMOBS

PURPOSE: TO MANUALLY SET THE NUMBER OF OBSERVATIONS TO BE USED IN THE ORBIT FIT

PARAMETERS:

NUMOBS: THE NUMBER OF OBSERVATIONS TO USE IN THE FIT, WHICH MUST LESS THAN OR EQUAL TO THE NUMBER OF OBSERVATIONS READ IN. IFF NUMOBS = 0, ALL THE OBSERVATIONS READ IN ARE ELIMINATED.

ELSET: IDNO

PURPOSE: TO READ IN THE ORBITAL ELEMENT SET OF THE SPECIFIED SATELLITE FOR USE AS THE INITIAL EL SET.

PARAMETERS:

IDNO: SATELLITE OBJECT NUMBER OF DESIRED ELEMENT SET.

ORBIT FIT ITERATION CONTROL COMMANDS

FIT: NITER < ELSET < AUTO > >

PURPOSE: TO SPECIFY THE NUMBER OF ITERATIONS TO PERFORM, THE ELEMENT SET TO BE USED AS INITIAL CONDITIONS AT THE START OF THE PRESENT FITTING CYCLE, AND THE TYPE OFITERATION CONTROL DESIRED.

PARAMETERS:

NITER: THE NUMBER OF ITERATIONS TO CARRY OUT, OR IF THE AUTO OPTION IS SELECTED, THE MAXIMUM LIMIT OF ITERATIONS TO PERFORM.

ELSET: IF SPECIFIED, SHOULD BE EITHER 'INIT' TO USE THE INITIAL ELEMENT SET, OR 'NEW' TO USE THE ELEMENT SET GENERATED FROM THE LAST ITERATION. (DEFAULTS: IF NO ITERATIONS HAVE BEEN PERFORMED, 'INIT', OTHERWISE 'NEW')

'AUTO': IF SPECIFIED, THE ORBIT FIT ITERATIONS WILL PROCEED IN AN AUTOMATIC FASHION, I.E. THE SIGMA WEIGHTING MULTIPLIERS WILL BE REDUCED BY SPECIFIED FACTORS WHEN INTERMEDIATE CONVERGENCE CRITERIAE ARE REACHED AND THE ITERATION PROCESS WILL TERMINATE IF FINAL CONVERGENCE CRITERIA ARE MET OR IF THE NUMBER OF ITERATIONS EXCEED NITER SPECIFIED. (SEE 'SIGMA' AND 'CONVERGE' COMMANDS FOR CONVERGENCE AND REDUCTION SPECIFICATION).

SIGMA: ITYPE VAL1 VAL2 VAL3 VAL4

PURPOSE: TO SPECIFY THE OBSERVATIONAL WEIGHTING (SIGMA) MULTIPLIERS TO USE DURING THE ITERATIONS AND, IF THE AUTO OPTION WAS SET IN THE 'FIT' COMMAND, THE MULTIPLIER REDUCTION FACTORS AND THE FINAL SIGMA MULTIPLIERS DESIRED.

PARAMETERS:

ITYPE: TYPE OF SIGMA VALUE BEING SET, NAMELY

'CUR' : TO SET THE CURRENT SIGMA MULTIPLIERS

'RED' : TO SET THE REDUCTION FACTORS OF THE CURRENT SIGMA MULTIPLIERS ONCE CONVERGENCE HAS BEEN REACHED. AT THAT POINT, THE CURRENT SIGMA MULTIPLIERS FOR THE NEXT ITERATION WILL BE THE CURRENT MULTIPLIERS TIMES THE CORRESPONDING REDUCTION FACTOR.

'FIN' : TO SET THE FINAL SIGMA MULTIPLIERS DESIRED.

VAL1: ITYPE AZIMUTH VALUE

VAL2: ITYPE ELEVATION VALUE

VAL3: ITYPE RANGE VALUE

VAL4: ITYPE RANGE RATE VALUE

NOTE: WHEN AN EL SET IS READ IN, THE INITIAL VALUES ARE SET TO:

SIGMA CUR 10 10 100 100 (AZ,EL,RANGE,RANGE RATE WEIGHTS MULTIPLIED BY 10,10,100,100 RESPECTIVELY)

SIGMA RED .25 .25 .25 .25 .25 (REDUCE CURRENT SIGMA MULTIPLIERS BY .25 EACH, IF CONVERGED

SIGMA FIN 1 1 3 3 (DESIRED FINAL SIGMA MULTIPLIERS)

CONVERGE: INCL RAN ECC W M A

PURPOSE: TO SPECIFY THE CONVERGENCE CRITERIA IN AUTO FIT MODE. THESE VALUES ARE FOR INTERMEDIATE CONVERGENCE, I.E. SIGMA MULTIPLIERS ARE NOT AT THE FINAL LEVEL. WHEN THE SIGMA MULTIPLIERS ARE AT THEIR FINAL LEVELS, CONVERGENCE IS REACHED AT .001 TIMES THESE RESPECTIVE VALUES.

PARAMETERS: IN ORDER TO CONSIDER THE ITERATION TO HAVE CONVERGED WITH THE PRESENT FIT CONTROL PARAMETERS, THE CORRECTIONS TO THE CURRENT ORBITAL ELEMENTS MUST ALL BE LESS THAN THE FOLLOWING:

INCL: INCLINATION CORRECTION (DEG)
RAN: RIGHT ASCENSION OF ASCENDING NODE (DEG)
ECC: ECCENTRICITY
W: ARGUMENT OF PERIGEE (DEG)
M: MEAN ANOMALY (DEG)
A: SEMI MAJOR AXIS (KM)
(DEFAULT: .L, L., .001, 1., 1., .1 RESPECTIVELY)

BOUNDS: INCL RAN ECC W M A

PURPOSE: TO SPECIFY THE MAXIMUM CORRECTIONS THAT CAN BE APPLIED TO THE CURRENT ORBITAL ELEMENTS, IF ANY OF THE CORRECTIONS ARE GREATER THAN THOSE SPECIFIED, ALL THE CORRECTIONS WILL BE SCALED BY THE SAME FACTOR SUCH THAT NO CORRECTION IS GREATER THAN ITS BOUND. IF A BOUND EQUALS ZERO, THE CORRECTION IS UNBOUNDED.

PARAMETERS:

INCL: INCLINATION BOUND (DEG)
RAN: RIGHT ASCENSION OF ASCENDING NODE BOUND (DEG)
ECC: ECCENTRICITY BOUND
W: ARGUMENT OF PERIGEE BOUND (DEG)
M: MEAN ANOMALY BOUND (DEG)
A: SEMI MAJOR AXIS BOUND (KM)

(DEFAULTS: .1, 0, .001, 0, 0, 2. RESPECTIVELY)

PERIODICS: ISET

PURPOSE: TO MANUALLY SPECIFY WHETHER PERIODIC VARIATIONAL CORRECTIONS SHOULD BE APPLIED TO THE ORBITAL ELEMENTS WHEN POINTING COMPUATIONS ARE MADE.

PARAMETERS:

ISET: IF ISET=1, PERIODIC CORRECTIONS WILL BE APPLIED,
=0, NO PERIODIC CORRECTIONS WILL BE APPLIED.

(DEFAULTS: PERIODIC CORRECTIONS ARE ALWAYS APPLIED, EXCEPT WHEN THE INITIAL ORBITAL ELEMENTS HAVE INCL BETWEEN 63.3 AND 63.6 DEG., OR THE ECCENTRICITY IS LESS THAN .00005)

INPUT/OUTPUT COMMANDS

DISPLAY: INFO < IDNO >

PURPOSE: TO DISPLAY SPECIFIED INFORMATION AT AN INTERATIVE TERMINAL.

PARAMETERS:

INFO: CAN ANY OF THE FOLLOWING

- 'O': TO DISPLAY THE OBSERVATIONS
- 'E': TO DISPLAY THE CURRENT AND INITIAL ORBITAL ELEMENTS
- 'M': TO DISPLAY THE MOF FILE ENTRY OF IDNO (DEFAULT IDNO IS IDNO OF ELSET COMMAND)
- 'R': TO DISPLAY THE RESIDUALS OF THE OBSERVATIONS AS CALCULATED DURING THE LAST ITERATION.

PRINT: INFO1 < INFO2 < .... INFON > >

PURPOSE: TO SPECIFY DESIRED OUTPUT INFORMATION DURING EACH ITERATION. EACH PRINT COMMAND CLEARS ANY OPTIONS ALREADY SPECIFIED.

PARAMETERS:

INFO: CAN BE ANY OF THE FOLLOWING IN ANY COMBINATION

- 'R': TO PRINT THE RESIDUALS
- 'E': TO PRINT THE ELEMENTS (CURRENT AND INITIAL)
- 'C': TO PRINT THE CORRECTIONS APPLIED
- 'M': TO PRINT CONVARIANCE ERROR MATRIX, ITS INVERSE, AND THE PRODUCT OF THE TWO
- 'T': TO PRINT THE CPU TIME OF THE ITERATION

ALSO, TO PRINT THE OBSERVATIONS (ONLY ONCE, NO OTHER OPTIONS AND DOES NOT CLEAR ANY OTHER PARAMETERS)

- 'O': TO PRINT THE OBSERVATIONS AND WEIGHTS

(DEFAULT: NO PRINT OUTPUT)

SPOOL

PURPOSE: TO SPOOL THE OUTPUT GENERATED THUS FAR (FROM ANY PRINT COMMANDS ISSUED) TO THE LINE PRINTER. THE PRINT FILE IS ALSO PURGED BY THIS COMMAND AND A NEW ONE GENERATED.

GENERATE: DAY1 < DAY2 < DELTA > >

PURPOSE: TO GENERATE MEAN AND OSCULATED ELEMENT SETS FROM THE CURRENT ELEMENTS, EPOCHED ON THE SPECIFIED DAYS. THE ELEMENTS ARE OUTPUT TO THE PRINT FILE.

PARAMETERS:

- DAY1: STARTING DAY NUMBER
- DAY2: ENDING DAY NUMBER
- DELTA: INCREMENT TIME (DAYS) TO GENERATE ELEMENTS BETWEEN DAY1 AND DAY2. (DEFAULT=1)

REWIND

PURPOSE: TO REWIND ANY PRINTER OUTPUT ALREADY GENERATED

PARAMETERS: NONE

INPUT/OUTPUT COMMANDS

DISPLAY: INFO < IDNO >

PURPOSE: TO DISPLAY SPECIFIED INFORMATION AT AN INTERATIVE TERMINAL.

PARAMETERS:

INFO: CAN ANY OF THE FOLLOWING

- 'O': TO DISPLAY THE OBSERVATIONS
- 'E': TO DISPLAY THE CURRENT AND INITIAL ORBITAL ELEMENTS
- 'M': TO DISPLAY THE MOF FILE ENTRY OF IDNO (DEFAULT IDNO IS IDNO OF ELSET COMMAND)
- 'R': TO DISPLAY THE RESIDUALS OF THE OBSERVATIONS AS CALCULATED DURING THE LAST ITERATION.

PRINT: INFO1 < INFO2 <.... INFON> >

PURPOSE: TO SPECIFY DESIRED OUTPUT INFORMATION DURING EACH ITERATION. EACH PRINT COMMAND CLEARS ANY OPTIONS ALREADY SPECIFIED.

PARAMETERS:

INFO: CAN BE ANY OF THE FOLLOWING IN ANY COMBINATION

- 'R': TO PRINT THE RESIDUALS
- 'E': TO PRINT THE ELEMENTS (CURRENT AND INITIAL)
- 'C': TO PRINT THE CORRECTIONS APPLIED
- 'M': TO PRINT CONVARIANCE ERROR MATRIX, ITS INVERSE, AND THE PRODUCT OF THE TWO
- 'T': TO PRINT THE CPU TIME OF THE ITERATION

ALSO, TO PRINT THE OBSERVATIONS (ONLY ONCE, NO OTHER OPTIONS AND DOES NOT CLEAR ANY OTHER PARAMETERS)

- '0' TO PRINT THE OBSERVATIONS AND WEIGHTS

(DEFAULT: NO PRINT OUTPUT)

SPOOL

PURPOSE: TO SPOOL THE OUTPUT GENERATED THUS FAR (FROM ANY PRINT COMMANDS ISSUED) TO THE LINE PRINTER. THE PRINT FILE IS ALSO PURGED BY THIS COMMAND AND A NEW ONE GENERATED.

GENERATE: DAY1 < DAY2 < DELTA > >

PURPOSE: TO GENERATE MEAN AND OSCULATED ELEMENT SETS FROM THE CURRENT ELEMENTS, EPOCHED ON THE SPECIFIED DAYS. THE ELEMENTS ARE OUTPUT TO THE PRINT FILE.

PARAMETERS:

- DAY1: STARTING DAY NUMBER
- DAY2: ENDING DAY NUMBER
- DELTA: INCREMENT TIME (DAYS) TO GENERATE ELEMENTS BETWEEN DAY1 AND DAY2. (DEFAULT= 1)

REWIND

PURPOSE: TO REWING ANY PRINTER OUTPUT ALREADY GENERATED

PARAMETERS: NONE

MISCELLANEOUS COMMANDS

LABEL: (FOLLOWED BY THE NEXT INPUT LINE)
PURPOSE: TO SET A GENERAL PURPOSE LABEL TO BE USED AS HEADING IN ANY OUTPUT GENERATED.
PARAMETERS: NONE
NOTE: THE NEXT LINE INPUT WILL BE USED AS THE 80 CHARACTER LABEL

SEND: < DAY < IDNO > >
PURPOSE: TO SEND THE FITTED ELEMENT SET TO THE SUPVSR IN ORDER TO UPDATE THE MOF FILE ENTRY ON IDNO.
PARAMETERS:
DAY: DESIRED EL SET EPOCH TIME. (DEFAULT= DAY NUMBER OF LAST TRACK)
IDNO = SATELLITE NUMBER OF EL SET. (DEFAULT= IDNO OF ELSET COMMAND)

INOUT: IDSCCI IDSCCO
PURPOSE: TO REDIRECT COMMAND CONTROL INPUT AND OUTPUT
PARAMETERS:
IDSCCI= COMMAND CONTROL INPUT DATA SET. IF IDSCCI= 'CRT', SPECIAL TEC TERMINAL I/O WILL BE USED
IDSCCO= COMMAND CONTROL OUTPUT DATA SET

SITE : NAME LAT LONG <ALT>
PURPOSE: TO ADD A SENSOR TO LIST OF DEFINED SENSORES IN CSITE COMMON
PARAMETERS:
NAME = TWO CHARACTER SITE IDENTIFIER (EG. MH)
LAT = SITE LATITUDE (DEG. NORTH)
LONG = SITE LONGITUDE (DEG. EAST)
<ALT> = SITE ALTITUDE (METERS)

FINIS
PURPOSE: TO EXIT THE PROGRAM
PARAMETERS: NONE

APPENDIX 5

EXAMPLES OF THE USE OF ANODE

Some examples of the ANODE program are presented in this section. The orbit fits were run on the Harris S220 and three different cases are given, namely:

1. A low inclination, low eccentricity synchronous satellite (COMSTAR 1, SDC number 8838).
2. A high inclination, high eccentricity rocket body (Molniya 1-23 rocket body, SDC number 9411).
3. A high inclination, low eccentricity Global Position Satellite (GPS-4, SDC number 11141).

In the examples, three iterations are shown: the initial iteration, an intermediate iteration, and the final converged solution. In each of these iterations, the following information is presented:

1. For each observation, the time (day, hour, minute, second, relative to 1980), a 2-character site name, and the measured values of azimuth, elevation, range and range rate.
2. The residual differences between each of the measured and predicted values using the current element set.
3. The RMS value of the residuals for each data type.

4. The current and initial element sets.

5. The number of values accepted and rejected for each data type.

6. The current values of the sigma multipliers for each data type.

7. The computed corrections to the orbital elements (unscaled).

8. The CPU time of the iteration.

The site names and locations are:

ID	LATITUDE (Deg. N)	LONGITUDE (Deg. E)	ALTITUDE (Meters)	TYPE	NAME
MH	42.6174	288.5089	123.1	Radar	Millstone Hill Radar
MJ	-43.9873	170.4638	1067.5	Optical	Mt. John, New Zealand
ST	33.8177	253.3407	1506.9	Optical	Stallion, Geodds Experimental Test Site
AM	20.7085	203.7418	3059.8	Optical	Amos, Hawaii
ED	34.9630	242.0855	777.7	Optical	Edwards Air Force Base

IDNO= 8838 ITERATION NUMBER 1

L 8838 1976 134 042A USA PL AC COMSTAR 1-D1//WAS 83592 80103

OBSERVATIONS AND RESIDUALS:
DAY START: 144 END: 149 NUMBER: 30

DAY	HH	MM	SS	SITE	AZ (DEG)		EL (DEG)		RNG (KM)		RDOT (M/SEC)	
149	1	26	9	MH	245.871	-0.086	15.524	-0.117	40002.15	9.01	0.456	0.701
149	1	25	27	MH	245.879	-0.078	15.517	-0.124	40001.95	8.80	0.456	0.702
149	1	24	45	MH	245.872	-0.085	15.518	-0.123	40001.80	8.64	0.461	0.708
149	1	23	52	MH	245.881	-0.076	15.519	-0.122	40002.01	8.84	0.465	0.713
149	1	23	10	MH	245.864	-0.093	15.534	-0.107	40002.01	8.82	0.466	0.715
146	8	10	12	AM	123.379	0.076	49.860	-0.104	0.00	0.00	0.000	0.000
146	8	10	0	AM	123.379	0.075	49.860	-0.105	0.00	0.00	0.000	0.000
146	8	9	48	AM	123.378	0.075	49.859	-0.105	0.00	0.00	0.000	0.000
146	8	9	24	AM	123.378	0.075	49.859	-0.106	0.00	0.00	0.000	0.000
146	8	9	12	AM	123.378	0.075	49.859	-0.106	0.00	0.00	0.000	0.000
146	7	21	17	ST	215.046	-0.155	44.462	-0.100	0.00	0.00	0.000	0.000
146	7	20	40	ST	215.047	-0.153	44.463	-0.099	0.00	0.00	0.000	0.000
146	7	20	6	ST	214.937	-0.264	44.460	-0.103	0.00	0.00	0.000	0.000
146	7	19	5	ST	215.039	-0.162	44.462	-0.101	0.00	0.00	0.000	0.000
145	11	45	18	AM	123.248	-0.168	49.923	0.009	0.00	0.00	0.000	0.000
145	11	44	54	AM	123.249	-0.168	49.922	0.008	0.00	0.00	0.000	0.000
145	11	44	42	AM	123.249	-0.167	49.922	0.007	0.00	0.00	0.000	0.000
145	6	29	50	ST	215.012	-0.212	44.457	-0.114	0.00	0.00	0.000	0.000
145	6	29	6	ST	215.012	-0.212	44.452	-0.120	0.00	0.00	0.000	0.000
145	6	28	16	ST	215.015	-0.209	44.451	-0.121	0.00	0.00	0.000	0.000
144	11	38	8	AM	123.239	-0.183	49.909	-0.016	0.00	0.00	0.000	0.000
144	11	37	56	AM	123.239	-0.182	49.908	-0.017	0.00	0.00	0.000	0.000
144	11	37	32	AM	123.239	-0.182	49.908	-0.018	0.00	0.00	0.000	0.000
144	11	37	21	AM	123.239	-0.182	49.907	-0.018	0.00	0.00	0.000	0.000
144	11	37	8	AM	123.241	-0.180	49.907	-0.018	0.00	0.00	0.000	0.000
144	9	20	1	MH	245.873	-0.090	15.601	0.034	39998.69	1.19	-0.451	-0.764
144	9	19	31	MH	245.867	-0.096	15.604	0.037	39998.70	1.21	-0.450	-0.762
144	9	18	49	MH	245.870	-0.093	15.601	0.033	39998.70	1.22	-0.447	-0.759
144	9	17	57	MH	245.860	-0.103	15.600	0.032	39998.73	1.26	-0.445	-0.757
144	9	17	6	MH	245.858	-0.106	15.593	0.025	39998.69	1.23	-0.443	-0.754
				RMS RESIDUALS:		0.146		0.085		6.297		0.734

CURRENT AND INITIAL ELEMENTS, IDNO= 8838

EPOCH	INCL	RAN	ECC	W	M	A
145.00000000	0.0130	265.4063	0.0000181	75.7576	132.5701	42166.386
	0.00000	-0.01341	0.0000000	0.02683	1.0027267	0.0000000
148.67384768	0.0870	86.6390	0.0000648	245.5860	27.7000	42165.674
	0.00000	-0.01341	0.0000000	0.02683	1.0027215	0.0000000

NUMBER ACCEPTED/REJECTED: 30/ 0, 30/ 0, 10/ 0, 10/ 0,
SIGMA MULTIPLIERS: 100.0 100.0 100.0 100.0

CORRECTIONS:
-0.16921 -2.16924 -.0000791 17.37781-15.13521 1.42807030

ITERATION CPU TIME (MSEC)= 663

IDNO= 8838 ITERATION NUMBER 5

L 8838 1976 134 042A USA PL AC COMSTAR 1-D1//WAS 83592 80103

OBSERVATIONS AND RESIDUALS:
DAY START: 144 END: 149 NUMBER: 30

DAY	HH	MM	SS	SITE	AZ (DEG)		EL (DEG)		RNG (KM)		RDOT (M/SEC)	
149	1	26	9	MH	245.871	-0.002	15.524	0.003	40002.15	-1.86	0.456	0.067
149	1	25	27	MH	245.879	0.006	15.517	-0.004	40001.95	-2.03*	0.456	0.066
149	1	24	45	MH	245.872	-0.002	15.518	-0.003	40001.80	-2.17	0.461	0.070
149	1	23	52	MH	245.881	0.007	15.519	-0.002	40002.01	-1.93*	0.465	0.073
149	1	23	10	MH	245.864	-0.010	15.534	0.012	40002.01	-1.92	0.466	0.073
146	8	10	12	AM	123.379	0.001	49.860	-0.009	0.00	0.00	0.000	0.000
146	8	10	0	AM	123.379	0.000	49.860	-0.010	0.00	0.00	0.000	0.000
146	8	9	48	AM	123.378	0.000	49.859	-0.010	0.00	0.00	0.000	0.000
146	8	9	24	AM	123.378	-0.001	49.859	-0.010	0.00	0.00	0.000	0.000
146	8	9	12	AM	123.378	-0.001	49.859	-0.010	0.00	0.00	0.000	0.000
146	7	21	17	ST	215.046	-0.011	44.462	-0.008	0.00	0.00	0.000	0.000
146	7	20	40	ST	215.047	-0.010	44.463	-0.007	0.00	0.00	0.000	0.000
146	7	20	6	ST	214.937	-0.120	44.460	-0.010	0.00	0.00	0.000	0.000
146	7	19	5	ST	215.039	-0.018	44.462	-0.008	0.00	0.00	0.000	0.000
145	11	45	18	AM	123.248	-0.016	49.923	0.005	0.00	0.00	0.000	0.000
145	11	44	54	AM	123.249	-0.016	49.922	0.005	0.00	0.00	0.000	0.000
145	11	44	42	AM	123.249	-0.016	49.922	0.004	0.00	0.00	0.000	0.000
145	6	29	50	ST	215.012	-0.019	44.457	-0.006	0.00	0.00	0.000	0.000
145	6	29	6	ST	215.012	-0.018	44.452	-0.012	0.00	0.00	0.000	0.000
145	6	28	16	ST	215.015	-0.015	44.451	-0.013	0.00	0.00	0.000	0.000
144	11	38	8	AM	123.239	-0.019	49.909	0.005	0.00	0.00	0.000	0.000
144	11	37	56	AM	123.239	-0.018	49.908	0.004	0.00	0.00	0.000	0.000
144	11	37	32	AM	123.239	-0.019	49.908	0.003	0.00	0.00	0.000	0.000
144	11	37	21	AM	123.239	-0.019	49.907	0.003	0.00	0.00	0.000	0.000
144	11	37	8	AM	123.241	-0.017	49.907	0.003	0.00	0.00	0.000	0.000
144	9	20	1	MH	245.873	0.005	15.601	0.010	39998.69	-0.36	-0.451	0.004
144	9	19	31	MH	245.867	-0.001	15.604	0.014	39998.70	-0.36	-0.450	0.004
144	9	18	49	MH	245.870	0.002	15.601	0.011	39998.70	-0.38	-0.447	0.007
144	9	17	57	MH	245.860	-0.007	15.600	0.010	39998.73	-0.37	-0.445	0.008
144	9	17	6	MH	245.858	-0.009	15.593	0.003	39998.69	-0.44	-0.443	0.010
RMS RESIDUALS:						0.025		0.008		1.431		0.050

CURRENT AND INITIAL ELEMENTS, IDNO= 8838

EPOCH	INCL	RAN	ECC	W	M	A
145.00000000	0.0766	263.3919	0.0000732	143.2526	67.1196	42167.211
	0.00000	-0.01341	0.0000000	0.02683	1.0026701	0.0000000
148.67384768	0.0870	86.6390	0.0000648	245.5860	27.7000	42165.674
	0.00000	-0.01341	0.0000000	0.02683	1.0027215	0.0000000

NUMBER ACCEPTED/REJECTED: 30/ 0, 30/ 0, 8/ 2, 10/ 0,
SIGMA MULTIPLIERS: 8.0 8.0 8.0 8.0

CORRECTIONS:
-0.00971 -4.38598 0.0000302-11.34959 15.74850 0.08264673

ITERATION CPU TIME (MSEC)= 657

IDNO= 8838 ITERATION NUMBER 9

L 8838 1976 134 042A USA PL AC COMSTAR 1-D1//WAS 83592 80103

OBSERVATIONS AND RESIDUALS:
DAY START: 144 END: 149 NUMBER: 30

DAY	HH	MM	SS	SITE	AZ (DEG)		EL (DEG)		RNG (KM)		RDOT (M/SEC)	
149	1	26	9	MH	245.871	0.007	15.524	-0.006	40002.15	0.19	0.456	0.064
149	1	25	27	MH	245.879	0.015	15.517	-0.013	40001.95	0.01	0.456	0.064
149	1	24	45	MH	245.872	0.008	15.518	-0.012	40001.80	-0.13	0.461	0.068
149	1	23	52	MH	245.881	0.017	15.519	-0.011	40002.01	0.11	0.465	0.071
149	1	23	10	MH	245.864	0.000	15.534	0.004	40002.01	0.13	0.466	0.071
146	8	10	12	AM	123.379	0.024	49.860	-0.003	0.00	0.00	0.000	0.000
146	8	10	0	AM	123.379	0.023	49.860	-0.004	0.00	0.00	0.000	0.000
146	8	9	48	AM	123.378	0.023	49.859	-0.004	0.00	0.00	0.000	0.000
146	8	9	24	AM	123.378	0.022	49.859	-0.004	0.00	0.00	0.000	0.000
146	8	9	12	AM	123.378	0.022	49.859	-0.005	0.00	0.00	0.000	0.000
146	7	21	17	ST	215.046	0.001	44.462	-0.022	0.00	0.00	0.000	0.000
146	7	20	40	ST	215.047	0.003	44.463	-0.021	0.00	0.00	0.000	0.000
146	7	20	6	ST	214.937	-0.107	44.460	-0.024	0.00	0.00	0.000	0.000
146	7	19	5	ST	215.039	-0.005	44.462	-0.022	0.00	0.00	0.000	0.000
145	11	45	18	AM	123.248	-0.001	49.923	0.012	0.00	0.00	0.000	0.000
145	11	44	54	AM	123.249	-0.001	49.922	0.011	0.00	0.00	0.000	0.000
145	11	44	42	AM	123.249	-0.001	49.922	0.011	0.00	0.00	0.000	0.000
145	6	29	50	ST	215.012	-0.004	44.457	-0.020	0.00	0.00	0.000	0.000
145	6	29	6	ST	215.012	-0.004	44.452	-0.026	0.00	0.00	0.000	0.000
145	6	28	16	ST	215.015	-0.001	44.451	-0.027	0.00	0.00	0.000	0.000
144	11	38	8	AM	123.239	-0.004	49.909	0.011	0.00	0.00	0.000	0.000
144	11	37	56	AM	123.239	-0.003	49.908	0.010	0.00	0.00	0.000	0.000
144	11	37	32	AM	123.239	-0.003	49.908	0.010	0.00	0.00	0.000	0.000
144	11	37	21	AM	123.239	-0.003	49.907	0.009	0.00	0.00	0.000	0.000
144	11	37	8	AM	123.241	-0.002	49.907	0.009	0.00	0.00	0.000	0.000
144	9	20	1	MH	245.873	0.010	15.601	-0.003	39998.69	0.00	-0.451	-0.053
144	9	19	31	MH	245.867	0.004	15.604	0.000	39998.70	0.01	-0.450	-0.053
144	9	18	49	MH	245.870	0.007	15.601	-0.002	39998.70	-0.02	-0.447	-0.050
144	9	17	57	MH	245.860	-0.003	15.600	-0.003	39998.73	0.00	-0.445	-0.049
144	9	17	6	MH	245.858	-0.004	15.593	-0.010	39998.69	-0.06	-0.443	-0.048
RMS RESIDUALS:						0.022		0.013		0.092		0.060

CURRENT AND INITIAL ELEMENTS, IDNO= 8838

EPOCH	INCL	RAN	ECC	W	M	A
145.00000000	0.0820	264.1362	0.0000656	175.9763	33.6486	42167.147
	0.00000	-0.01341	0.0000000	0.02683	1.0026695	0.0000000
148.67384768	0.0870	86.6390	0.0000648	245.5860	27.7000	42165.674
	0.00000	-0.01341	0.0000000	0.02683	1.0027215	0.0000000

NUMBER ACCEPTED/REJECTED: 30/ 0, 30/ 0, 10/ 0, 10/ 0,
SIGMA MULTIPLIERS: 2.0 2.0 2.0 2.0

CORRECTIONS:
0.00018 0.03479 -.0000008 -0.26897 0.23365 0.00224057

ITERATION CPU TIME (MSEC)= 663

*** SOLUTION HAS CONVERGED ***

IDNO= 9411 ITERATION NUMBER 1

L 9411 1976 071 021D SOV RB NA MOLNIYA 1-23//SDC 8741 80103

OBSERVATIONS AND RESIDUALS:
DAY START: 125 END: 144 NUMBER: 41

DAY	HH	MM	SS	SITE	AZ (DEG)		EL (DEG)		RNG (KM)		RDOT (M/SEC)	
144	4	25	50	MH	233.700	-0.208	71.415	-0.359	15732.73	-30.58	0.000	0.000
144	4	24	58	MH	232.715	-0.169	70.907	-0.369	15580.97	-30.24	0.000	0.000
144	4	24	7	MH	231.754	-0.139	70.392	-0.367	15428.83	-29.91	0.000	0.000
144	4	23	22	MH	230.910	-0.145	69.931	-0.363	15295.82	-29.81*	0.000	0.000
144	4	22	33	MH	230.045	-0.129	69.405	-0.368	15151.37	-29.74	0.000	0.000
141	3	53	14	ST	57.147	0.151	44.980	0.089	0.00	0.00	0.000	0.000
141	3	52	14	ST	57.590	0.153	44.978	0.094	0.00	0.00	0.000	0.000
141	3	50	54	ST	58.192	0.155	44.964	0.093	0.00	0.00	0.000	0.000
134	10	52	50	MH	106.555	-0.069	7.208	0.241	15081.60	44.61	0.000	0.000
134	10	51	24	MH	105.797	-0.073	8.603	0.239	15268.84	44.87	0.000	0.000
134	10	50	6	MH	105.110	-0.082	9.825	0.244	15442.08	45.18	0.000	0.000
134	10	48	40	MH	104.387	-0.062	11.074	0.202	15636.17	44.67*	0.000	0.000
134	10	47	23	MH	103.728	-0.058	12.189	0.201	15813.65	44.44	0.000	0.000
133	13	44	12	AM	329.380	-0.178	39.456	-0.047	0.00	0.00	0.000	0.000
133	13	44	0	AM	329.337	-0.179	39.467	-0.047	0.00	0.00	0.000	0.000
133	13	43	36	AM	329.252	-0.179	39.488	-0.047	0.00	0.00	0.000	0.000
133	13	43	24	AM	329.208	-0.180	39.500	-0.047	0.00	0.00	0.000	0.000
133	13	43	0	AM	329.122	-0.180	39.521	-0.047	0.00	0.00	0.000	0.000
133	12	14	12	AM	281.560	-0.542	35.586	-0.393	0.00	0.00	0.000	0.000
133	12	13	48	AM	281.121	-0.543	35.383	-0.399	0.00	0.00	0.000	0.000
133	12	13	36	AM	280.892	-0.543	35.275	-0.403	0.00	0.00	0.000	0.000
133	12	13	12	AM	280.436	-0.544	35.058	-0.410	0.00	0.00	0.000	0.000
133	12	13	0	AM	280.212	-0.545	34.950	-0.412	0.00	0.00	0.000	0.000
132	13	49	59	AM	338.147	-0.151	40.930	-0.024	0.00	0.00	0.000	0.000
132	13	49	34	AM	338.090	-0.151	40.955	-0.024	0.00	0.00	0.000	0.000
132	13	49	16	AM	338.048	-0.152	40.973	-0.025	0.00	0.00	0.000	0.000
132	13	49	2	AM	338.015	-0.152	40.987	-0.025	0.00	0.00	0.000	0.000
132	13	48	42	AM	337.968	-0.154	41.007	-0.026	0.00	0.00	0.000	0.000
132	12	36	44	AM	319.078	-0.374	46.810	-0.067	0.00	0.00	0.000	0.000
132	12	36	14	AM	318.841	-0.376	46.848	-0.068	0.00	0.00	0.000	0.000
132	12	35	57	AM	318.701	-0.378	46.871	-0.068	0.00	0.00	0.000	0.000
132	12	35	41	AM	318.570	-0.379	46.893	-0.068	0.00	0.00	0.000	0.000
132	12	35	14	AM	318.342	-0.383	46.928	-0.069	0.00	0.00	0.000	0.000
126	9	31	4	ED	247.878	-0.487	35.988	-1.110	0.00	0.00	0.000	0.000
126	9	30	48	ED	247.614	-0.490	35.648	-1.119	0.00	0.00	0.000	0.000
126	9	30	32	ED	247.352	-0.490	35.307	-1.125	0.00	0.00	0.000	0.000
126	9	30	16	ED	247.085	-0.497	34.961	-1.133	0.00	0.00	0.000	0.000
126	9	30	0	ED	246.820	-0.502	34.614	-1.138	0.00	0.00	0.000	0.000
125	11	10	54	ST	327.221	-0.186	53.183	-0.052	0.00	0.00	0.000	0.000
125	11	10	27	ST	327.126	-0.183	53.202	-0.051	0.00	0.00	0.000	0.000
125	11	9	57	ST	327.017	-0.182	53.221	-0.052	0.00	0.00	0.000	0.000
RMS RESIDUALS:						0.313		0.445		38.121		0.000

CURRENT AND INITIAL ELEMENTS, IDNO= 9411

EPOCH	INCL	RAN	ECC	W	M	A
133.00000000	64.0970	205.1639	0.6961770	276.6852	24.9413	26881.111
	0.00000	-0.10741	0.0000000	-0.00530	1.9697150	0.0000000
139.07799053	64.0560	204.5090	0.6970514	276.6870	14.9840	26881.438
	0.00000	-0.10741	0.0000000	-0.00529	1.9697050	0.0000000

NUMBER ACCEPTED/REJECTED:	41/ 0,	41/ 0,	8/ 2,	0/ 0,
SIGMA MULTIPLIERS:	100.0	100.0	100.0	100.0

CORRECTIONS:
0.04099 0.00202 -.0008745 -0.03394 -0.17569 -0.24256227

ITERATION CPU TIME (MSEC)= 828

IDNO= 9411 ITERATION NUMBER 2

L 9411 1976 071 021D SOV RB NA MOLNIYA 1-23//SDC 8741 80103

OBSERVATIONS AND RESIDUALS:
DAY START: 125 END: 144 NUMBER: 41

DAY	HH	MM	SS	SITE	AZ (DEG)		EL (DEG)		RNG (KM)		RDOT (M/SEC)	
144	4	25	50	MH	233.700	-0.030	71.415	-0.014	15732.73	0.02	0.000	0.000
144	4	24	58	MH	232.715	-0.008	70.907	-0.019	15580.97	0.00	0.000	0.000
144	4	24	7	MH	231.754	0.007	70.392	-0.013	15428.83	-0.04	0.000	0.000
144	4	23	22	MH	230.910	-0.012	69.931	-0.004	15295.82	-0.27	0.000	0.000
144	4	22	33	MH	230.045	-0.009	69.405	-0.005	15151.37	-0.59	0.000	0.000
141	3	53	14	ST	57.147	-0.071	44.980	-0.077	0.00	0.00	0.000	0.000
141	3	52	14	ST	57.590	-0.074	44.978	-0.072	0.00	0.00	0.000	0.000
141	3	50	54	ST	58.192	-0.078	44.964	-0.072	0.00	0.00	0.000	0.000
134	10	52	50	MH	106.555	-0.003	7.208	0.002	15081.60	0.23	0.000	0.000
134	10	51	24	MH	105.797	-0.007	8.603	0.012	15268.84	0.24	0.000	0.000
134	10	50	6	MH	105.110	-0.017	9.825	0.027	15442.08	0.39	0.000	0.000
134	10	48	40	MH	104.387	0.003	11.074	-0.005	15636.17	-0.24	0.000	0.000
134	10	47	23	MH	103.728	0.007	12.189	0.003	15813.65	-0.52	0.000	0.000
133	13	44	12	AM	329.380	0.095	39.456	0.049	0.00	0.00	0.000	0.000
133	13	44	0	AM	329.337	0.095	39.467	0.049	0.00	0.00	0.000	0.000
133	13	43	36	AM	329.252	0.096	39.488	0.049	0.00	0.00	0.000	0.000
133	13	43	24	AM	329.208	0.095	39.500	0.049	0.00	0.00	0.000	0.000
133	13	43	0	AM	329.122	0.097	39.521	0.048	0.00	0.00	0.000	0.000
133	12	14	12	AM	281.560	0.093	35.586	0.044	0.00	0.00	0.000	0.000
133	12	13	48	AM	281.121	0.093	35.383	0.044	0.00	0.00	0.000	0.000
133	12	13	36	AM	280.892	0.093	35.275	0.043	0.00	0.00	0.000	0.000
133	12	13	12	AM	280.436	0.093	35.058	0.042	0.00	0.00	0.000	0.000
133	12	13	0	AM	280.212	0.093	34.950	0.043	0.00	0.00	0.000	0.000
132	13	49	59	AM	338.147	0.098	40.930	0.044	0.00	0.00	0.000	0.000
132	13	49	34	AM	338.090	0.099	40.955	0.044	0.00	0.00	0.000	0.000
132	13	49	16	AM	338.048	0.099	40.973	0.043	0.00	0.00	0.000	0.000
132	13	49	2	AM	338.015	0.099	40.987	0.043	0.00	0.00	0.000	0.000
132	13	48	42	AM	337.968	0.098	41.007	0.042	0.00	0.00	0.000	0.000
132	12	36	44	AM	319.078	0.118	46.810	0.028	0.00	0.00	0.000	0.000
132	12	36	14	AM	318.841	0.119	46.848	0.028	0.00	0.00	0.000	0.000
132	12	35	57	AM	318.701	0.118	46.871	0.029	0.00	0.00	0.000	0.000
132	12	35	41	AM	318.570	0.119	46.893	0.030	0.00	0.00	0.000	0.000
132	12	35	14	AM	318.342	0.118	46.928	0.029	0.00	0.00	0.000	0.000
126	9	31	4	ED	247.878	-0.003	35.988	-0.115	0.00	0.00	0.000	0.000
126	9	30	48	ED	247.614	-0.007	35.648	-0.117	0.00	0.00	0.000	0.000
126	9	30	32	ED	247.352	-0.011	35.307	-0.116	0.00	0.00	0.000	0.000
126	9	30	16	ED	247.085	-0.020	34.961	-0.117	0.00	0.00	0.000	0.000
126	9	30	0	ED	246.820	-0.028	34.614	-0.115	0.00	0.00	0.000	0.000
125	11	10	54	ST	327.221	0.163	53.183	0.076	0.00	0.00	0.000	0.000
125	11	10	27	ST	327.126	0.167	53.202	0.077	0.00	0.00	0.000	0.000
125	11	9	57	ST	327.017	0.170	53.221	0.076	0.00	0.00	0.000	0.000
RMS RESIDUALS:						0.087		0.058		0.318		0.000

CURRENT AND INITIAL ELEMENTS, IDNO= 9411

EPOCH	INCL	RAN	ECC	W	M	A
133.00000000	64.0961	205.1638	0.6961836	276.6852	24.9416	26881.114
	0.00000	-0.10675	0.0000000	-0.00561	1.9697416	0.0000000
139.07799053	64.0560	204.5090	0.6970514	276.6870	14.9840	26881.438
	0.00000	-0.10741	0.0000000	-0.00529	1.9697050	0.0000000

NUMBER ACCEPTED/REJECTED: 41/ 0, 41/ 0, 10/ 0, 0/ 0,
SIGMA MULTIPLIERS: 10.0 10.0 10.0 10.0

CORRECTIONS:
-0.00088 -0.00002 0.0000067 -0.00007 0.00036 0.00260054

ITERATION CPU TIME (MSEC)= 832

IDNO= 9411 ITERATION NUMBER 3

L 9411 1976 071 021D SOV RB NA MOLNIYA 1-23//SDC 8741 80103

OBSERVATIONS AND RESIDUALS:
DAY START: 125 END: 144 NUMBER: 41

DAY	HH	MM	SS	SITE	AZ (DEG)		EL (DEG)		RNG (KM)		RDOT (M/SEC)	
144	4	25	50	MH	233.700	-0.028	71.415	-0.014	15732.73	0.23	0.000	0.000
144	4	24	58	MH	232.715	-0.006	70.907	-0.019	15580.97	0.22	0.000	0.000
144	4	24	7	MH	231.754	0.009	70.392	-0.013	15428.83	0.18	0.000	0.000
144	4	23	22	MH	230.910	-0.010	69.931	-0.004	15295.82	-0.06	0.000	0.000
144	4	22	33	MH	230.045	-0.007	69.405	-0.005	15151.37	-0.37	0.000	0.000
141	3	53	14	ST	57.147	-0.071	44.980	-0.077	0.00	0.00	0.000	0.000
141	3	52	14	ST	57.590	-0.074	44.978	-0.071	0.00	0.00	0.000	0.000
141	3	50	54	ST	58.192	-0.079	44.964	-0.071	0.00	0.00	0.000	0.000
134	10	52	50	MH	106.555	-0.003	7.208	0.001	15081.60	0.37	0.000	0.000
134	10	51	24	MH	105.797	-0.007	8.603	0.011	15268.84	0.38	0.000	0.000
134	10	50	6	MH	105.110	-0.016	9.825	0.026	15442.08	0.53	0.000	0.000
134	10	48	40	MH	104.387	0.003	11.074	-0.006	15636.17	-0.11	0.000	0.000
134	10	47	23	MH	103.728	0.007	12.189	0.002	15813.65	-0.39	0.000	0.000
133	13	44	12	AM	329.380	0.095	39.456	0.048	0.00	0.00	0.000	0.000
133	13	44	0	AM	329.337	0.095	39.467	0.048	0.00	0.00	0.000	0.000
133	13	43	36	AM	329.252	0.095	39.488	0.048	0.00	0.00	0.000	0.000
133	13	43	24	AM	329.208	0.095	39.500	0.048	0.00	0.00	0.000	0.000
133	13	43	0	AM	329.122	0.096	39.521	0.047	0.00	0.00	0.000	0.000
133	12	14	12	AM	281.560	0.091	35.586	0.042	0.00	0.00	0.000	0.000
133	12	13	48	AM	281.121	0.091	35.383	0.042	0.00	0.00	0.000	0.000
133	12	13	36	AM	280.892	0.091	35.275	0.041	0.00	0.00	0.000	0.000
133	12	13	12	AM	280.436	0.091	35.058	0.041	0.00	0.00	0.000	0.000
133	12	13	0	AM	280.212	0.091	34.950	0.041	0.00	0.00	0.000	0.000
132	13	49	59	AM	338.147	0.097	40.930	0.043	0.00	0.00	0.000	0.000
132	13	49	34	AM	338.090	0.098	40.955	0.043	0.00	0.00	0.000	0.000
132	13	49	16	AM	338.048	0.098	40.973	0.042	0.00	0.00	0.000	0.000
132	13	49	2	AM	338.015	0.098	40.987	0.042	0.00	0.00	0.000	0.000
132	13	48	42	AM	337.968	0.097	41.007	0.041	0.00	0.00	0.000	0.000
132	12	36	44	AM	319.078	0.116	46.810	0.027	0.00	0.00	0.000	0.000
132	12	36	14	AM	318.841	0.117	46.848	0.027	0.00	0.00	0.000	0.000
132	12	35	57	AM	318.701	0.117	46.871	0.028	0.00	0.00	0.000	0.000
132	12	35	41	AM	318.570	0.118	46.893	0.028	0.00	0.00	0.000	0.000
132	12	35	14	AM	318.342	0.116	46.928	0.028	0.00	0.00	0.000	0.000
126	9	31	4	ED	247.878	-0.004	35.988	-0.120	0.00	0.00	0.000	0.000
126	9	30	48	ED	247.614	-0.009	35.648	-0.121	0.00	0.00	0.000	0.000
126	9	30	32	ED	247.352	-0.013	35.307	-0.121	0.00	0.00	0.000	0.000
126	9	30	16	ED	247.085	-0.022	34.961	-0.122	0.00	0.00	0.000	0.000
126	9	30	0	ED	246.820	-0.030	34.614	-0.120	0.00	0.00	0.000	0.000
125	11	10	54	ST	327.221	0.162	53.183	0.074	0.00	0.00	0.000	0.000
125	11	10	27	ST	327.126	0.166	53.202	0.076	0.00	0.00	0.000	0.000
125	11	9	57	ST	327.017	0.169	53.221	0.075	0.00	0.00	0.000	0.000
RMS RESIDUALS:						0.086		0.058		0.316		0.000

CURRENT AND INITIAL ELEMENTS, IDNO= 9411

EPOCH	INCL	RAN	ECC	W	M	A
133.00000000	64.0961	205.1638	0.6961836	276.6852	24.9416	26881.114
	0.00000	-0.10676	0.0000000	-0.00561	1.9697413	0.0000000
139.07799053	64.0560	204.5090	0.6970514	276.6870	14.9840	26881.438
	0.00000	-0.10741	0.0000000	-0.00529	1.9697050	0.0000000

NUMBER ACCEPTED/REJECTED: 41/ 0, 41/ 0, 10/ 0, 0/ 0,
SIGMA MULTIPLIERS: 2.0 2.0 2.0 2.0

CORRECTIONS:
0.00000 0.00000 -.0000000 0.00000 0.00000 -0.00000090

ITERATION CPU TIME (MSEC)= 831

*** SOLUTION HAS CONVERGED ***

IDNO= 11141 ITERATION NUMBER 1

L 11141 1978 345 112A USA PL AC GPS-4 80103

OBSERVATIONS AND RESIDUALS:
DAY START: 127 END: 149 NUMBER: 58

DAY	HH	MM	SS	SITE	AZ (DEG)		EL (DEG)		RNG (KM)		RDOT (M/SEC)	
149	4	25	12	ST	79.253	0.412	70.560	0.107	0.00	0.00	0.000	0.000
149	4	24	34	ST	80.289	0.419	70.621	0.107	0.00	0.00	0.000	0.000
149	4	23	5	ST	82.755	0.446	70.731	0.101	0.00	0.00	0.000	0.000
149	2	42	6	MH	201.097	0.038	21.903	-0.139	23478.11	14.20	-731.095	-1.372
149	2	41	27	MH	200.991	0.041	21.600	-0.133	23507.00	14.18	-732.988	-1.358
149	2	40	38	MH	200.861	0.042	21.232	-0.124	23542.46	14.35	-735.252	-1.341
149	2	39	58	MH	200.742	0.033	20.926	-0.113	23572.28	14.28	-737.130	-1.326
149	2	38	26	MH	200.499	0.032	20.197	-0.129	23639.98	14.42*	-741.248	-1.293
141	5	56	33	MH	355.339	-0.262	71.145	0.025	20449.18	-6.47	155.391	-1.111
141	5	55	55	MH	354.543	-0.273	71.350	0.023	20443.36	-6.38	152.413	-1.123
141	5	55	25	MH	353.917	-0.275	71.518	0.031	20438.86	-6.33	150.071	-1.133
141	5	54	46	MH	353.109	-0.253	71.715	0.020	20433.03	-6.32	146.995	-1.145
141	5	5	56	ST	66.750	0.176	69.226	0.084	0.00	0.00	0.000	0.000
141	5	5	6	ST	67.929	0.188	69.419	0.090	0.00	0.00	0.000	0.000
141	5	4	16	ST	69.130	0.199	69.601	0.095	0.00	0.00	0.000	0.000
138	14	1	36	MJ	235.928	-0.103	19.985	-0.027	0.00	0.00	0.000	0.000
138	14	1	12	MJ	235.741	-0.096	20.023	-0.019	0.00	0.00	0.000	0.000
138	14	0	48	MJ	235.536	-0.108	20.055	-0.018	0.00	0.00	0.000	0.000
138	14	0	24	MJ	235.338	-0.113	20.082	-0.021	0.00	0.00	0.000	0.000
138	14	0	0	MJ	235.146	-0.111	20.103	-0.029	0.00	0.00	0.000	0.000
137	14	2	2	MJ	234.146	-0.114	20.226	-0.037	0.00	0.00	0.000	0.000
137	14	1	32	MJ	233.895	-0.123	20.259	-0.033	0.00	0.00	0.000	0.000
137	14	1	0	MJ	233.654	-0.108	20.291	-0.030	0.00	0.00	0.000	0.000
137	14	0	30	MJ	233.417	-0.103	20.314	-0.034	0.00	0.00	0.000	0.000
137	14	0	0	MJ	233.188	-0.087	20.333	-0.042	0.00	0.00	0.000	0.000
137	3	47	45	MH	204.340	0.024	29.841	-0.099	22771.44	8.96	-673.593	-1.515
137	3	46	28	MH	204.069	0.026	29.220	-0.102	22823.67	8.98	-678.631	-1.496
137	3	45	11	MH	203.795	0.020	28.599	-0.107	22876.17	8.87	-683.571	-1.478
137	3	43	52	MH	203.520	0.010	27.969	-0.115	22929.73	8.97	-688.452	-1.460
137	3	42	35	MH	203.257	0.005	27.351	-0.119	22983.23	9.20	-693.179	-1.441
136	14	7	36	MJ	234.909	-0.073	20.126	-0.036	0.00	0.00	0.000	0.000
136	14	7	12	MJ	234.698	-0.091	20.163	-0.025	0.00	0.00	0.000	0.000
136	14	6	48	MJ	234.494	-0.100	20.197	-0.018	0.00	0.00	0.000	0.000
136	14	6	24	MJ	234.296	-0.106	20.224	-0.016	0.00	0.00	0.000	0.000
136	14	6	0	MJ	234.082	-0.124	20.245	-0.019	0.00	0.00	0.000	0.000
136	4	55	39	ED	103.500	0.203	56.711	0.037	0.00	0.00	0.000	0.000
136	4	55	20	ED	103.833	0.242	56.626	0.025	0.00	0.00	0.000	0.000
136	4	55	0	ED	104.142	0.243	56.521	-0.002	0.00	0.00	0.000	0.000
136	4	54	40	ED	104.436	0.236	56.467	0.021	0.00	0.00	0.000	0.000
136	4	54	20	ED	104.718	0.219	56.370	0.003	0.00	0.00	0.000	0.000
136	4	7	19	ED	133.281	0.123	38.958	-0.023	0.00	0.00	0.000	0.000
136	4	6	59	ED	133.422	0.135	38.811	-0.023	0.00	0.00	0.000	0.000
136	4	6	40	ED	133.537	0.125	38.691	0.001	0.00	0.00	0.000	0.000
136	4	6	21	ED	133.707	0.174	38.519	-0.032	0.00	0.00	0.000	0.000
136	4	6	9	ED	133.752	0.147	38.462	-0.006	0.00	0.00	0.000	0.000
134	4	16	23	MH	208.224	-0.069	37.690	-0.150	22142.60	6.22	-601.141	-1.677
134	4	15	26	MH	207.965	-0.069	37.222	-0.150	22177.34	6.11	-605.807	-1.666
134	4	14	19	MH	207.657	-0.083	36.775	-0.060	22217.98	6.38	-611.112	-1.657
134	4	13	8	MH	207.348	-0.084	36.201	-0.060	22261.39	6.25	-616.709	-1.644
134	4	8	21	MH	206.156	-0.085	33.895	-0.059	22440.45	5.96	-638.460	-1.566
133	4	43	1	ST	138.044	0.183	58.585	-0.032	0.00	0.00	0.000	0.000
133	4	42	20	ST	138.453	0.181	58.267	-0.032	0.00	0.00	0.000	0.000
133	4	41	32	ST	138.920	0.177	57.894	-0.031	0.00	0.00	0.000	0.000
127	5	4	7	MH	214.400	0.017	47.061	-0.063	21507.15	1.90	-499.176	-1.697
127	5	3	30	MH	214.165	0.009	46.758	-0.063	21526.08	2.07	-502.747	-1.695
127	5	2	56	MH	213.978	0.023	46.491	-0.058	21543.12	2.19	-505.934	-1.692
127	5	2	22	MH	213.786	0.035	46.207	-0.063	21560.51	2.12	-509.190	-1.689
127	5	1	44	MH	213.564	0.033	45.904	-0.063	21579.99	2.48	-512.715	-1.686
				RMS RESIDUALS:		0.166		0.071		8.666		1.483

```
CURRENT AND INITIAL ELEMENTS, IDNO=  11141
   EPOCH            INCL      RAN       ECC          W         M          A
 137.00000000     63.2428  202.9729  0.0008949    1.8685  240.8545   26559.723
                   0.00000  -0.03046  0.0000000   0.00051   2.0056805   0.0000000

 141.15109873     63.2280  202.8500  0.0009339  347.9090   12.1390   26559.721
                   0.00000  -0.03046  0.0000000   0.00051   2.0056704   0.0000000


NUMBER ACCEPTED/REJECTED:      58/  0,      58/  0,      23/  1,      24/  0,
SIGMA MULTIPLIERS:              100.0        100.0        100.0        100.0

CORRECTIONS:
  0.01484 -0.00352 -.0000390 13.96162-14.01861   0.08497302

ITERATION CPU TIME (MSEC)=    1199
```

IDNO= 11141   ITERATION NUMBER 3

L 11141 1978 345 112A USA PL AC GPS-4   80103

OBSERVATIONS AND RESIDUALS:
DAY START: 127 END: 149 NUMBER: 58

DAY	HH	MM	SS	SITE	AZ (DEG)		EL (DEG)		RNG (KM)		RDOT (M/SEC)	
149	4	25	12	ST	79.253	0.054	70.560	0.005	0.00	0.00	0.000	0.000
149	4	24	34	ST	80.289	0.053	70.621	0.007	0.00	0.00	0.000	0.000
149	4	23	5	ST	82.755	0.063	70.731	0.007	0.00	0.00	0.000	0.000
149	2	42	6	MH	201.097	0.011	21.903	-0.001	23478.11	0.15	-731.095	0.136
149	2	41	27	MH	200.991	0.014	21.600	0.005	23507.00	0.06	-732.988	0.136
149	2	40	38	MH	200.861	0.016	21.232	0.013	23542.46	0.16	-735.252	0.137
149	2	39	58	MH	200.742	0.006	20.926	0.024	23572.28	0.04	-737.130	0.138
149	2	38	26	MH	200.499	0.005	20.197	0.008	23639.98	0.04	-741.248	0.139
141	5	56	33	MH	355.339	0.066*	71.145	-0.001	20449.18	0.23	155.391	0.118
141	5	55	55	MH	354.543	0.061	71.350	-0.002	20443.36	0.27	152.413	0.118
141	5	55	25	MH	353.917	0.063	71.518	0.007	20438.86	0.27	150.071	0.117
141	5	54	46	MH	353.109	0.090	71.715	-0.003	20433.03	0.24	146.995	0.116
141	5	5	56	ST	66.750	-0.011	69.226	-0.016	0.00	0.00	0.000	0.000
141	5	5	6	ST	67.929	-0.007	69.419	-0.009	0.00	0.00	0.000	0.000
141	5	4	16	ST	69.130	-0.005	69.601	-0.002	0.00	0.00	0.000	0.000
138	14	1	36	MJ	235.928	-0.004	19.985	-0.034	0.00	0.00	0.000	0.000
138	14	1	12	MJ	235.741	0.002	20.023	-0.026	0.00	0.00	0.000	0.000
138	14	0	48	MJ	235.536	-0.009	20.055	-0.025	0.00	0.00	0.000	0.000
138	14	0	24	MJ	235.338	-0.014	20.082	-0.028	0.00	0.00	0.000	0.000
138	14	0	0	MJ	235.146	-0.012	20.103	-0.035	0.00	0.00	0.000	0.000
137	14	2	2	MJ	234.146	-0.020	20.226	-0.042	0.00	0.00	0.000	0.000
137	14	1	32	MJ	233.895	-0.028	20.259	-0.038	0.00	0.00	0.000	0.000
137	14	1	0	MJ	233.654	-0.013	20.291	-0.036	0.00	0.00	0.000	0.000
137	14	0	30	MJ	233.417	-0.008	20.314	-0.039	0.00	0.00	0.000	0.000
137	14	0	0	MJ	233.188	0.007	20.333	-0.046	0.00	0.00	0.000	0.000
137	3	47	45	MH	204.340	0.006	29.841	-0.001	22771.44	0.51	-673.593	0.031
137	3	46	28	MH	204.069	0.008	29.220	-0.005	22823.67	0.41	-678.631	0.032
137	3	45	11	MH	203.795	0.002	28.599	-0.010	22876.17	0.18	-683.571	0.034
137	3	43	52	MH	203.520	-0.008	27.969	-0.019	22929.73	0.17	-688.452	0.033
137	3	42	35	MH	203.257	-0.013	27.351	-0.023	22983.23	0.28	-693.179	0.034
136	14	7	36	MJ	234.909	0.018	20.126	-0.043	0.00	0.00	0.000	0.000
136	14	7	12	MJ	234.698	0.000	20.163	-0.032	0.00	0.00	0.000	0.000
136	14	6	48	MJ	234.494	-0.009	20.197	-0.025	0.00	0.00	0.000	0.000
136	14	6	24	MJ	234.296	-0.015	20.224	-0.023	0.00	0.00	0.000	0.000
136	14	6	0	MJ	234.082	-0.034	20.245	-0.025	0.00	0.00	0.000	0.000
136	4	55	39	ED	103.500	0.021	56.711	0.020	0.00	0.00	0.000	0.000
136	4	55	20	ED	103.833	0.060	56.626	0.009	0.00	0.00	0.000	0.000
136	4	55	0	ED	104.142	0.061	56.521	-0.017	0.00	0.00	0.000	0.000
136	4	54	40	ED	104.436	0.054	56.467	0.006	0.00	0.00	0.000	0.000
136	4	54	20	ED	104.718	0.038	56.370	-0.011	0.00	0.00	0.000	0.000
136	4	7	19	ED	133.281	0.006	38.958	0.018	0.00	0.00	0.000	0.000
136	4	6	59	ED	133.422	0.019	38.811	0.018	0.00	0.00	0.000	0.000
136	4	6	40	ED	133.537	0.009	38.691	0.043	0.00	0.00	0.000	0.000
136	4	6	21	ED	133.707	0.059	38.519	0.010	0.00	0.00	0.000	0.000
136	4	6	9	ED	133.752	0.032	38.462	0.036	0.00	0.00	0.000	0.000
134	4	16	23	MH	208.224	-0.086	37.690	-0.060	22142.60	0.29	-601.141	-0.030
134	4	15	26	MH	207.965	-0.085	37.222	-0.061	22177.34	0.09	-605.807	-0.028
134	4	14	19	MH	207.657	-0.100	36.775	0.029	22217.98	0.25	-611.112	-0.029
134	4	13	8	MH	207.348	-0.100	36.201	0.029	22261.39	0.00	-616.709	-0.028
134	4	8	21	MH	206.156	-0.101	3[illegible].895	0.029	22440.45	-0.74	-638.460	0.001
133	4	43	1	ST	138.044	0.020	58.585	0.002	0.00	0.00	0.000	0.000
133	4	42	20	ST	138.453	0.020	58.267	0.003	0.00	0.00	0.000	0.000
133	4	41	32	ST	138.920	0.019	57.894	0.005	0.00	0.00	0.000	0.000
127	5	4	7	MH	214.400	0.002	47.061	0.000	21507.15	-0.23	-499.176	-0.185
127	5	3	30	MH	214.165	-0.007	46.758	0.000	21526.08	-0.11	-502.747	-0.184
127	5	2	56	MH	213.978	0.008	46.491	0.005	21543.12	-0.05	-505.934	-0.183
127	5	2	22	MH	213.786	0.020	46.207	0.000	21560.51	-0.17	-509.190	-0.182
127	5	1	44	MH	213.564	0.018	45.904	0.000	21579.99	0.14	-512.715	-0.181
RMS RESIDUALS:						0.041		0.024		0.267		0.116

CURRENT AND INITIAL ELEMENTS, IDNO= 11141

EPOCH	INCL	RAN	ECC	W	M	A
137.00000000	63.2506	202.9753	0.0009258	2.3994	240.3207	26559.720
	0.00000	-0.03043	0.0000000	0.00043	2.0056712	0.0000000
141.15109873	63.2280	202.8500	0.0009339	347.9090	12.1390	26559.721
	0.00000	-0.03046	0.0000000	0.00051	2.0056704	0.0000000

NUMBER ACCEPTED/REJECTED:	57/ 1,	58/ 0,	24/ 0,	24/ 0,
SIGMA MULTIPLIERS:	2.0	2.0	2.0	2.0

CORRECTIONS:
0.00130 -0.00026 0.0000037 -0.21658 0.21516 -0.00055953

ITERATION CPU TIME (MSEC)= 1200

IDNO= 11141   ITERATION NUMBER 5

L 11141 1978 345 112A USA PL AC GPS-4   80103

OBSERVATIONS AND RESIDUALS:
DAY START: 127 END: 149 NUMBER: 58

DAY	HH	MM	SS	SITE	AZ (DEG)		EL (DEG)		RNG (KM)		RDOT (M/SEC)	
149	4	25	12	ST	79.253	0.052	70.560	0.002	0.00	0.00	0.000	0.000
149	4	24	34	ST	80.289	0.052	70.621	0.004	0.00	0.00	0.000	0.000
149	4	23	5	ST	82.755	0.061	70.731	0.004	0.00	0.00	0.000	0.000
149	2	42	6	MH	201.097	0.010	21.903	0.001	23478.11	0.15	-731.095	0.149
149	2	41	27	MH	200.991	0.013	21.600	0.008	23507.00	0.07	-732.988	0.150
149	2	40	38	MH	200.861	0.015	21.232	0.015	23542.46	0.17	-735.252	0.150
149	2	39	58	MH	200.742	0.005	20.926	0.027	23572.28	0.04	-737.130	0.152
149	2	38	26	MH	200.499	0.004	20.197	0.010	23639.98	0.04	-741.248	0.154
141	5	56	33	MH	355.339	0.076*	71.145	0.000	20449.18	0.13	155.391	0.103
141	5	55	55	MH	354.543	0.071*	71.350	0.000	20443.36	0.17	152.413	0.102
141	5	55	25	MH	353.917	0.073	71.518	0.008	20438.86	0.17	150.071	0.101
141	5	54	46	MH	353.109	0.100	71.715	-0.002	20433.03	0.14	146.995	0.100
141	5	5	56	ST	66.750	-0.010	69.226	-0.019	0.00	0.00	0.000	0.000
141	5	5	6	ST	67.929	-0.007	69.419	-0.012	0.00	0.00	0.000	0.000
141	5	4	16	ST	69.130	-0.005	69.601	-0.006	0.00	0.00	0.000	0.000
138	14	1	36	MJ	235.928	0.000	19.985	-0.034	0.00	0.00	0.000	0.000
138	14	1	12	MJ	235.741	0.006	20.023	-0.027	0.00	0.00	0.000	0.000
138	14	0	48	MJ	235.536	-0.006	20.055	-0.025	0.00	0.00	0.000	0.000
138	14	0	24	MJ	235.338	-0.010	20.082	-0.028	0.00	0.00	0.000	0.000
138	14	0	0	MJ	235.146	-0.008	20.103	-0.035	0.00	0.00	0.000	0.000
137	14	2	2	MJ	234.146	-0.016	20.226	-0.043	0.00	0.00	0.000	0.000
137	14	1	32	MJ	233.895	-0.024	20.259	-0.039	0.00	0.00	0.000	0.000
137	14	1	0	MJ	233.654	-0.010	20.291	-0.036	0.00	0.00	0.000	0.000
137	14	0	30	MJ	233.417	-0.004	20.314	-0.040	0.00	0.00	0.000	0.000
137	14	0	0	MJ	233.188	0.011	20.333	-0.047	0.00	0.00	0.000	0.000
137	3	47	45	MH	204.340	0.004	29.841	0.001	22771.44	0.50	-673.593	0.041
137	3	46	28	MH	204.069	0.007	29.220	-0.003	22823.67	0.40	-678.631	0.042
137	3	45	11	MH	203.795	0.001	28.599	-0.007	22876.17	0.17	-683.571	0.044
137	3	43	52	MH	203.520	-0.009	27.969	-0.016	22929.73	0.16	-688.452	0.044
137	3	42	35	MH	203.257	-0.014	27.351	-0.021	22983.23	0.27	-693.179	0.045
136	14	7	36	MJ	234.909	0.022	20.126	-0.044	0.00	0.00	0.000	0.000
136	14	7	12	MJ	234.698	0.004	20.163	-0.032	0.00	0.00	0.000	0.000
136	14	6	48	MJ	234.494	-0.006	20.197	-0.025	0.00	0.00	0.000	0.000
136	14	6	24	MJ	234.296	-0.011	20.224	-0.023	0.00	0.00	0.000	0.000
136	14	6	0	MJ	234.082	-0.030	20.245	-0.026	0.00	0.00	0.000	0.000
136	4	55	39	ED	103.500	0.017	56.711	0.018	0.00	0.00	0.000	0.000
136	4	55	20	ED	103.833	0.056	56.626	0.007	0.00	0.00	0.000	0.000
136	4	55	0	ED	104.142	0.057	56.521	-0.019	0.00	0.00	0.000	0.000
136	4	54	40	ED	104.436	0.050	56.467	0.005	0.00	0.00	0.000	0.000
136	4	54	20	ED	104.718	0.033	56.370	-0.013	0.00	0.00	0.000	0.000
136	4	7	19	ED	133.281	0.003	38.958	0.019	0.00	0.00	0.000	0.000
136	4	6	59	ED	133.422	0.015	38.811	0.018	0.00	0.00	0.000	0.000
136	4	6	40	ED	133.537	0.005	38.691	0.043	0.00	0.00	0.000	0.000
136	4	6	21	ED	133.707	0.055	38.519	0.010	0.00	0.00	0.000	0.000
136	4	6	9	ED	133.752	0.028	38.462	0.037	0.00	0.00	0.000	0.000
134	4	16	23	MH	208.224	-0.088	37.690	-0.058	22142.60	0.28	-601.141	-0.025
134	4	15	26	MH	207.965	-0.087	37.222	-0.058	22177.34	0.08	-605.807	-0.024
134	4	14	19	MH	207.657	-0.102	36.775	0.032	22217.98	0.24	-611.112	-0.024
134	4	13	8	MH	207.348	-0.102	36.201	0.031	22261.39	-0.01	-616.709	-0.023
134	4	8	21	MH	206.156	-0.103	33.895	0.031	22440.45	-0.75	-638.460	0.008
133	4	43	1	ST	138.044	0.014	58.585	0.002	0.00	0.00	0.000	0.000
133	4	42	20	ST	138.453	0.014	58.267	0.003	0.00	0.00	0.000	0.000
133	4	41	32	ST	138.920	0.013	57.894	0.005	0.00	0.00	0.000	0.000
127	5	4	7	MH	214.400	-0.001	47.061	0.003	21507.15	-0.25	-499.176	-0.186
127	5	3	30	MH	214.165	-0.009	46.758	0.003	21526.08	-0.13	-502.747	-0.185
127	5	2	56	MH	213.978	0.005	46.491	0.008	21543.12	-0.07	-505.934	-0.184
127	5	2	22	MH	213.786	0.018	46.207	0.003	21560.51	-0.19	-509.190	-0.183
127	5	1	44	MH	213.564	0.016	45.904	0.003	21579.99	0.12	-512.715	-0.181
RMS RESIDUALS:						0.042		0.025		0.253		0.118

```
CURRENT AND INITIAL ELEMENTS, IDNO=  11141
   EPOCH            INCL       RAN         ECC          W          M           A
 137.00000000     63.2511   202.9747   0.0009290     2.2519   240.4672   26559.720
                   0.00000  -0.03043   0.0000000    0.00043    2.0056712   0.0000000

 141.15109873     63.2280   202.8500   0.0009339   347.9090    12.1390   26559.721
                   0.00000  -0.03046   0.0000000    0.00051    2.0056704   0.0000000


NUMBER ACCEPTED/REJECTED:      56/  2,      58/  0,      24/  0,      24/  0,
SIGMA MULTIPLIERS:                2.0          2.0          2.0          2.0

CORRECTIONS:
  0.00000  0.00000 0.0000000 -0.00589  0.00588   0.00000153


ITERATION CPU TIME (MSEC)=    1197
```

APPENDIX 6

MASTER OBJECT FILE (MOF) DESCRIPTION

Entries in the MOF consist of 80-character card images. They conform to the general format:

TYPE OBJNO PAR 1, PAR 2, ... PAR N

where TYPE is usually a two character alphanumeric string denoting the type of entry

OBJNO is the 5-digit satellite identification number

PAR 1, PAR 2, etc. are the specific parameters for each type of entry. Included in the description of each entry is the format and description of the parameters, and the entries given here are those affecting the ANODE program.

1. <u>ORBITAL ELEMENT SET</u>

Format: EX IDNUM I RA E W M A TEDAY TEYR (SOURCE)

EY IDNUM II RA1 E1 W1 N (N1/2)

Parameters:

IDNUM: 1-5 digit object ID number

TEDAY: Element set epoch time (day number)

TEYR: Last two digits of the year

SOURCE: 1-4 character code (ex: LLA, SDC)

I, II: Inclination and Inc. rate (deg, deg/day)

RA,RA1: Right ascension

W, W1: Argument of perigee (deg, deg/day)

E, E1: Eccentricity

A: Semi-major axis (ER or KM)

M, N,
N1/2: Mean anomaly, mean motion, and NDOT/2 (deg, rev/day, rev/day^2)

2. <u>ORBITAL ELEMENT FIT INPUT CARD</u>

This entry contains the information used to drive the automatic fit processors.

Format: EI OBJNO MXITER TSPAN MINSIG MINTRK

Parameters:

- MXITER: maximum number of iterations to perform
- TSPAN: number of days of metric data to attempt to fit if no previous orbit fits were done
- MINSIG: 4 digit code indicating the minimum final sigma multiplier. The thousands, hundreds, tens and units digit represent the AZ, EL, Range and Range Rate multiplier, respectively.
- MINTRK: Minimum number of tracks to try to fit, if initial data span cannot be successfully fit.

3. ORBITAL ELEMENT FIT OUTPUT CARD

This entry will describe the results of the last orbit fit performed on this object.

Format: EO OBJNO QUAL DATE SPAN SRCE DAY1 DAY2

Parameters:

- QUAL: Quality factor associated with element set (nominal or generated by orbit processor)
- DATE: Year day of last orbit fit
- SPAN: Recommended time span for next track
- SRCE: Processor performing this orbit fit ('A' indicates ANODE)
- DAY1: YR-DAY of earliest observation included in this fit
- DAY2: YR-DAY of latest observation included in this fit.