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Differential Orbit Correction And Station Locator Program

"DOC - II"

By
Richard M. Moroney
Isabel M. Hussey

FEBRUARY 1964

Prepared for
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS
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ABSTRACT

The analysis and programming associated with performing a differential correction to orbital elements and/or station positions from weighted observations of range, range rate, azimuth-elevation and/or right ascension-declination on close earth satellites are described. The ephemeris computation considers perturbations due to the earth's gravitational potential as described by a spherical harmonic representation through \( n = m = 5 \), the lunar gravitational potential, air drag and radiation pressure. All observations may be simulated in punched card form for the purposes of conducting geometric studies.
This contract was administered under the direction of the project scientists, Mr. A. Mancini and Captain L.L. Sheldon, of the Geodesy and Gravity Branch, Terrestrial Sciences Laboratory.
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I INTRODUCTION

The multi-purpose program described herein, "DOC II," has been developed primarily to obtain geocentric positions of ground-based instrumentation sites from observations made on close earth satellites. The observations may be in the form of range, range rate, and/or directions (right ascension and declination, azimuth and elevation). Provision for weighting observations is included.

This program utilizes the analysis and much of the programming associated with the ephemeris computation and differential correction theory that is described in AFCRL 62-892, Research in Geodesy and Gravity, Computer Programs for Orbit Correction and Station Location. For ready reference this portion of 62-892 is contained in Appendix A. This original ephemeris computation has been modified to consider the following additional perturbations.

1. the sectorial and tesseral terms in the earth's gravitational potential (thru n = m = 5)
2. the lunar gravitational potential
3. solar radiation pressure

The station locator portion of 62-892 was completely reworked and is described in the body of this report. Further modifications made to the original program now allows one to:

1. Correct the orbital elements and station positions simultaneously.
2. Simulate observations in the form of punched card output. Using this as input allows one to observe the effect that varying amounts, distribution, accuracy, and types of data has on the end results.
3. Correct the six orbital elements only, applying from one to nine corrections.
4. Correct the station positions only for a number of stations contained in up to six different datums.
5. Generate orbital elements for each time step specified by a \( \Delta t \) from input.
II FORMULATION

A. General

1. Standard Keplerian elements are obtained by inverting:

\[ \begin{align*}
L_0 &= M_0 + \omega + \Omega \\
A_x &= e \cos \omega \\
A_y &= e \sin \omega \\
H_x &= \sqrt{a(1-e^2)} \sin \Omega \sin i \\
H_y &= -\sqrt{a(1-e^2)} \cos \Omega \sin i \\
H_z &= \sqrt{a(1-e^2)} \cos i
\end{align*} \]

2. Greenwich sidereal time in degrees for January 0.0 is selected internally from a table for the years 1958 to 1977. The present table for 0g is:

\[
\begin{align*}
(1960) &= 98.67401 \\
(1961) &= 99.420937 \\
(1962) &= 99.1822167 \\
(1963) &= 98.943500314
\end{align*}
\]

Greenwich sidereal time at the time of an observation is obtained by applying a mean rotation to GST of January 0.0 and then adding on the equation of equinoxes from a table. In the original ephemeris computation (Appendix A), the equation of equinoxes was not added.

3. The maximum size of the matrix is 24 x 24. This allows for correcting the 6 orbital elements and up to 6 different non-zero datums.

4. Observation sigmas are selected internally if none are given from input.

The program will use the following nominal values:

- 10 meters for Range Observations
- 10.0 cps for Range Rate Observations
- 0.0001 radians for Optical Observations
B. **Observation Weighting and Calculation of Standard Deviation (σ) in Satellite Position**

1. **Preliminaries**

As noted in the writeup of the Station Corrector Portion (pg 6),

each observation leads to a condition equation of the form

\[ Q_{\text{obs}} - Q_{\text{comp}} = C_{\Delta i} \Delta i + \ldots + C_{\Delta Z} \Delta Z \]  

(1)

Here \( Q \) just denotes some quantity. The actual quantity used for \( Q \) varies with the type of observation as follows:

<table>
<thead>
<tr>
<th>Observation Type</th>
<th>( Q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range rate</td>
<td>( p \cdot \dot{p} )</td>
</tr>
<tr>
<td>Range</td>
<td>( \sqrt{p \cdot \dot{p}} )</td>
</tr>
<tr>
<td>Azimuth or Right Ascension</td>
<td>( p \cdot \Delta )</td>
</tr>
<tr>
<td>Elevation or Declination</td>
<td>( p \cdot D )</td>
</tr>
</tbody>
</table>

The basis of the entire differential correction method is the assumption that

\[ Q_{\text{obs}} = Q_{\text{true}} + \varepsilon \]  

(2)

where \( \varepsilon \) is a sample from a distribution with zero mean and known standard deviation. Since some observations are more accurate than others, i.e., have smaller \( \sigma \)'s, the condition equations are weighted by dividing by a \( \sigma \) for the error in that observation.

An additional advantage of this weighting, aside from the obvious one of being able to take account of variable observational accuracy, is that the diagonal elements of the least-squares matrix can be interpreted as variances in the computed corrections \( \Delta i, \Delta \Omega, \ldots, \Delta X, \Delta Y, \Delta Z \). An additional assumption is necessary here, namely that the errors in different observations are independent.
The estimates of the variances in the elements at epoch can be converted into estimates of the variances in the computed $x$, $y$, $z$ coordinates of the satellite.

2 Theory

a) Variances for $x$, $y$, $z$ coordinates of satellite.

Formulas for converting $\Delta a_0$, $\Delta i_0$, ..., $\Delta \Omega_0$ to $\Delta x(t_1)$, $\Delta y(t_1)$, $\Delta z(t_1)$ for each observation time $t_1$ are given in Reference 2. A standard technique then gives the variances for the conversion matrix $A$.

$$
\begin{bmatrix}
\Delta x \\
\Delta y \\
\Delta z
\end{bmatrix}
= 
A
\begin{bmatrix}
\Delta a_0 \\
\Delta i_0 \\
\vdots \\
\Delta \Omega_0
\end{bmatrix}
$$

A covariance matrix $C$ for $[\Delta x, \Delta y, \Delta z]$ is then related to the covariance matrix for $[\Delta a_0, \Delta i_0, \ldots, \Delta \Omega_0]$ by

$$
C = ADA^T
$$

b) Observational Sigmas

In order to get a $\sigma$ for the $\epsilon$ in (2) one must take account of the nature of the observed quantities, $Q$. It is easy to see that

$$
(\rho \cdot \dot{\rho}) = r \dot{r},
$$

$$
\sqrt{\rho \cdot \dot{\rho}} = r,
$$

$$
\Delta (\rho \cdot \dot{a}) = \rho \cos \delta \Delta a,
$$

$$
\Delta (\rho \cdot \dot{\Delta}) = \rho \Delta \delta,
$$

Thus appropriate sigmas are

$$
(\rho \cdot \dot{\rho}) : r \sigma_r,
$$

$$
\sqrt{\rho \cdot \dot{\rho}} : \sigma_r,
$$

$$
\Delta (\rho \cdot \dot{a}) : \rho \cos \delta \sigma_a,
$$

$$
\Delta (\rho \cdot \dot{\Delta}) : \rho \sigma_\delta.
$$
3 Additional Features

a) Nominal values of the sigmas for each station's observations of range rate, range and angles are accepted from the station data cards. If the appropriate columns of a station's card are zero the program uses, for that station, a set of arbitrarily chosen values. When an observation card is read the program checks to see whether a sigma for the observation is on the card. If there is such a sigma it is the one used. If the appropriate columns are zero the nominal sigma for the observing station is used.

b) The subroutine which forms the condition equations divides them by the appropriate $\sigma$ as determined in the theory section.

c) At each observation time the program saves on tape those values necessary for computing the matrix $A$ mentioned in the theory section.

d) At the conclusion of a run the tape record mentioned in (c) is read, and sigmas for $x$, $y$ and $z$ at each observation time computed.

e) In order to be assured of getting sigmas in $x$, $y$, and $z$ at epoch — even when this is not an observation time — a record, as in paragraph (c) is written at the start of the run, i.e., at epoch.

f) Simulated data is available in punched card form. Format is that required for input to the simulated run with toggles set as noted in the section on input.
C. Station - Corrector Portion

1 Preliminaries

Let \( x, y, z \) be the inertial coordinates of the satellite at some sidereal time \( \theta \) and \( X, Y, Z \) be the earth-fixed coordinates of an observing station. The inertial coordinates of this station, \( \hat{X}, \hat{Y}, \hat{Z} \), are given by

\[
\begin{align*}
\hat{X} &= X \cos \theta - Y \sin \theta \\
\hat{Y} &= X \sin \theta + Y \cos \theta \\
\hat{Z} &= Z
\end{align*}
\]

(1)

The station-satellite vector, \( \rho \), is

\[
\rho = (x - \hat{X})i + (y - \hat{Y})j + (z - \hat{Z})k
\]

(2)

The time derivative of this vector, \( \dot{\rho} \), is

\[
\dot{\rho} = (\dot{x} - \hat{X})i + (\dot{y} - \hat{Y})j + (\dot{z} - \hat{Z})k
\]

(3)

If we let the earth's rotation rate be \( \omega \) and differentiate (1) we get

\[
\begin{align*}
\dot{\hat{X}} &= (-X \sin \theta - Y \cos \theta) \omega \\
\dot{\hat{Y}} &= (X \cos \theta - Y \sin \theta) \omega \\
\dot{\hat{Z}} &= 0
\end{align*}
\]

(4)

Using (1) and (4) to get rid of the hat variables in (2) and (3) gives

\[
\begin{align*}
\rho &= (x - X \cos \theta + Y \sin \theta) i + (y - X \sin \theta - Y \cos \theta) j + (z - Z) k
\end{align*}
\]

(5)

\[
\begin{align*}
\dot{\rho} &= (\dot{x} + \{ X \sin \theta + Y \cos \theta \} \omega) i + (\dot{y} - \{ Y \sin \theta - X \cos \theta \} \omega) j + \dot{z} k
\end{align*}
\]

(6)
Thus

\[ \frac{\partial \rho}{\partial X} = -\cos \theta \mathbf{i} - \sin \theta \mathbf{j} \]
\[ \frac{\partial \rho}{\partial Y} = \sin \theta \mathbf{i} - \cos \theta \mathbf{j} \]
\[ \frac{\partial \rho}{\partial Z} = -k \]

Also

\[ (\rho \cdot \hat{\rho}) = (x - X \cos \theta + Y \sin \theta)(\dot{x} + [X \sin \theta + Y \cos \theta] \omega) \]
+ \( (y - X \sin \theta - Y \cos \theta)(\dot{y} + [Y \sin \theta - X \cos \theta] \omega) \)
+ \( (z - Z) \dot{z} \)

\[ = X (-\cos \theta \dot{x} + \omega \sin \theta x - \sin \theta \dot{y} - \omega \cos \theta y) \]
+ \( Y (\sin \theta \dot{x} + \omega \cos \theta x - \cos \theta \dot{y} + \omega \sin \theta y) \)
+ \( Z (-\dot{z}) \)
+ terms independent of X, Y, Z.

Notice that

\[ (\rho \cdot \dot{\rho}) = \frac{1}{2} \frac{d}{dt} (\rho \cdot \rho) = \frac{1}{2} \frac{d}{dt} (\text{range})^2 = (\text{range})(\text{range rate}). \]

Here

\[ \frac{\partial (\rho \cdot \dot{\rho})}{\partial X} = -\cos \theta (\dot{x} + \omega y) + \sin \theta (\omega x - \dot{y}) \]
\[ \frac{\partial (\rho \cdot \dot{\rho})}{\partial Y} = \cos \theta (\omega x - \dot{y}) + \sin \theta (\dot{x} + \omega y) \]
\[ \frac{\partial (\rho \cdot \dot{\rho})}{\partial Z} = -\dot{z} \]

2 Theory

For each type of observation the original program (Appendix A) developed a condition equation. These were of the following forms:
Range Rate Observation

\[
(\mathbf{\dot{r}} \cdot \mathbf{\dot{\hat{r}}})_{\text{obs}} - (\mathbf{\dot{r}} \cdot \mathbf{\dot{\hat{r}}})_{\text{comp}} = \frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{\hat{r}}})}{\partial i} \Delta i + \ldots + \frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{\hat{r}}})}{\partial \Omega} \Delta \Omega
\]

Azimuth or Right Ascension Observation

\[
(\mathbf{\dot{r}} \cdot \mathbf{\dot{A}})_{\text{obs}} - (\mathbf{\dot{r}} \cdot \mathbf{\dot{A}})_{\text{comp}} = \frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{A}})}{\partial i} \Delta i + \ldots + \frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{A}})}{\partial \Omega} \Delta \Omega
\]

Elevation or Declination Observation

\[
(\mathbf{\dot{r}} \cdot \mathbf{\dot{D}})_{\text{obs}} - (\mathbf{\dot{r}} \cdot \mathbf{\dot{D}})_{\text{comp}} = \frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{D}})}{\partial i} \Delta i + \ldots + \frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{D}})}{\partial \Omega} \Delta \Omega
\]

Range Observation

\[
\sqrt{\mathbf{r} \cdot \mathbf{\dot{r}}}_{\text{obs}} - \sqrt{\mathbf{r} \cdot \mathbf{\dot{r}}}_{\text{comp}} = \frac{\partial \sqrt{\mathbf{r} \cdot \mathbf{\dot{r}}}}{\partial i} \Delta i + \ldots + \frac{\partial \sqrt{\mathbf{r} \cdot \mathbf{\dot{r}}}}{\partial \Omega} \Delta \Omega
\]

Here the subscripts "obs" and "comp" denote "observed" and "computed" respectively. \( \mathbf{\dot{A}} \) and \( \mathbf{\dot{D}} \) are unit vectors in a plane perpendicular to \( \mathbf{\dot{r}}_{\text{obs}} \) and perpendicular to each other (Appendix A).

To modify these condition equations when \( X, Y \) and \( Z \) are also unknown, we must add to the right side the partials of the relevant quantity with respect to \( X, Y, \) and \( Z \). We have already computed \( \frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{r}})}{\partial X}, \frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{r}})}{\partial Y}, \) and \( \frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{r}})}{\partial Z} \) with respect to \( X, Y \) and \( Z \). In the case of \( (\mathbf{\dot{r}} \cdot \mathbf{\dot{A}}) \) or \( (\mathbf{\dot{r}} \cdot \mathbf{\dot{D}}) \)

\[
\frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{A}})}{\partial X} = \left( \frac{\partial \mathbf{r}}{\partial X} \cdot \mathbf{\dot{A}} \right)
\]

\[
\frac{\partial (\mathbf{\dot{r}} \cdot \mathbf{\dot{D}})}{\partial Y} = \left( \frac{\partial \mathbf{r}}{\partial Y} \cdot \mathbf{\dot{D}} \right)
\]

etc. and the partials of \( \mathbf{r} \) are known. Finally,

\[
\frac{\partial \sqrt{\mathbf{r} \cdot \mathbf{\dot{r}}}}{\partial X} = \frac{1}{2 \sqrt{\mathbf{r} \cdot \mathbf{\dot{r}}}} \frac{\partial \mathbf{r} \cdot \mathbf{\dot{r}}}{\partial X}
\]

\[
= \frac{1}{2 \sqrt{\mathbf{r} \cdot \mathbf{\dot{r}}}} \left( \frac{\partial \mathbf{r}}{\partial X} \cdot \mathbf{\dot{r}} \right)
\]
\[ L = \frac{\mathbf{p}}{\|\mathbf{p}\|} \]

where \( L = \frac{\mathbf{p}}{\sqrt{\mathbf{p} \cdot \mathbf{p}}} \) is a unit vector from station to satellite.

X \rightarrow Y, Z.

3. Modifications To AFCRL 62-892

a) The first change in the program causes it to accept a datum number on each station card. Up to six different non-zero datum numbers may appear in the deck of station cards for any run. (These need not be numbered in order such as 1, 2, 3. The program reassigns internal datum numbers so that the input datum numbers could be 12, 24, 268 etc.) A zero datum number indicates that a station is to be held fixed. All stations in the same datum are moved together.

The program counts the number of non-zero datums present, say \( n \), and sets the number of unknowns equal to \( 6 + 3n \).

b) The second change is a revision of the routine which forms the condition equations. These are enlarged as described in the theory section. An essential part of this step is to determine the datum number of the observing station, so as to make the partials with respect to \( X, Y \) and \( Z \) refer to \( X, Y \) and \( Z \) of the relevant datum.

To make clear what is meant here, suppose that there are two non-zero datums numbered 1 and 2. There are twelve unknowns, \( \Delta a, \Delta i, \ldots, \Delta \Omega, \Delta X_1, \Delta Y_1, \Delta Z_1, \Delta X_2, \Delta Y_2, \Delta Z_2 \).

Each individual observation is made by a station in datum zero or one or two. If the station is in datum zero the coefficients of \( \Delta X_1, \Delta Y_1, \ldots, \Delta Z_2 \) are all zero. If the station is in datum one the coefficients of \( \Delta X_2, \Delta Y_2 \) and \( \Delta Z_2 \) are zero but the coefficients of \( \Delta X_1, \Delta Y_1, \Delta Z_1 \) are those we just derived.

c) A third change in the program consists of a bookkeeping chore. After a set of datum shifts is determined, the stations in non-zero datums must have their \( X, Y, Z \) coordinates updated. This involves rewriting the observation tape.
III PROCESSING

A. The general flow of the program during execution is:

1. Set up constants; read in the first five specification cards.
2. Compute, for epoch, the values of inclination, node, W Bar, mean motion, A Bar.
3. Set up to integrate ephemeris.
4. Write parameters used in computing standard deviations in satellite position at epoch on Tape 11.
5. Integrate ephemeris:
   a. Compute time derivatives of A Bar, H Bar, and XL.
   b. Compute perturbative accelerations and relate to orbital elements.
   c. Compute required derivatives.
   d. After each perigee passage, correct orbit parameters for atmospheric drag.
   e. Transfer current values of A Bar, H Bar, and XL to ephemeris buffer.
   f. Determine what to print for output.
   g. Write ephemeris buffer on Tape 3 whenever it is filled.

6. Determine if Simulation Run or Differential Correction Run.

If Simulation Run

   Compute and print simulated observations for each station - Range, Range Rate, Right Ascension/Declination, Azimuth/Elevation.

If Differential Correction Run

1. Read station cards.
2. Set up least squares routine for matrix size.
3. For each observation card perform the following:
a. Read an observation card.
b. Match station number on observation card with station card.
c. Check if observation time is within ephemeris time, i.e., between $T_0$ and $T_f$.
d. Compute L Bar, etc.
e. Save observation data on Tape 9.

4. When all observation cards have been read in, continue processing each observation:
   a. Find observation time in ephemeris.
   b. Interpolate to get parameters from ephemeris.
   c. Compute $x$, $y$, $z$, and related parameters.
   d. Save $x$, $y$, $z$, $\hat{x}$, $\hat{y}$, $\hat{z}$ on Tape 6.
   e. Write parameters for standard deviation for each observation time on Tape 11.
   f. Compute correction equation coefficients and residuals.
   g. Update sum of squares of residuals and normal equations.

5. Save matrix $A$ and $B$ as determined by input code to correct both elements and station positions, elements only, or station positions only.


7. Compute root mean square of residuals; reset limit for acceptance of residuals.

8. Determine whether or not to do another pass.

9. Apply correction to elements.

10. Apply correction to station position.

11. Determine whether or not to do another correction.
12. Compute the sigmas in x, y, and z (position of observer).
13. Output
14. Exit
B. **Error Indicators**

1. **Subroutine Error**
   This is a general error exit from any subroutine and causes the execution of the program to stop. Location SUBER 1 contains the address within the subroutine from which the exit occurred.

2. **Altitude Below 50000 Meters**
   Program exits. The internal table of altitudes has a lower limit of 50000 meters and an upper limit of 900000 meters.

3. **Kepler's Equation Not Converging For "e"**
   Program exits. This error occurs as the value of eccentricity approaches 1.0.

4. **Error in Range Kutta Routine**
   Program exits.

5. **Number of Unknowns Exceeds Number of Observations**
   Program exits. This error exit is executed when the program does not have enough good observations, i.e., observations that pass the maximum residual test.

6. **Error in Testing Time Points**
   Program exits. The count of the number of records on the ephemeris tape (Tape 3) is held in location NTAPE3. The value in NTAPE3 is tested before the program tries to find the observation time in the ephemeris. If NTAPE3 ≤ 0 at this time, this error exit occurs.

7. If the value for XNY in the XYZSB Subroutine is zero, the program will exit.

8. **Observation Out of Time Range**
   This is printed when the observation time is not within $T_o$ to $T_f$. Program continues.
9. Station XXX Not Found

This is printed out when the program is unable to match the station number on the observation card with the station number on the station card.
IV  INPUT

1. Specification Cards

For all runs the program requires 5 specification cards.

Cards 1 and 2 — used for headings of output pages.

Card 3 — tells program to start at time 0 minutes and in time steps of $\Delta t$, compute the ephemeris for $t_f$ minutes.

This card gives diameter (m.) and mass (kg.) of satellite.

Card 4 — This card inputs the elements. A minus sign in column 1 indicates that standard Keplerian elements are being used. Otherwise the elements are taken as those of Reference 1.

Card 5 — Information given on this card controls the type of execution. However, for all runs, the following columns are common:

Col. 1 has code for printed output — Code of 1 prints sub-satellite positions; Code of 2 prints $x, y, z, \dot{x}, \dot{y}, \dot{z}$; Code of 3 prints both; Code of 0 will suppress this printing.

Epoch day given must correspond to that of Keplerian elements. Restart day must be equal to or later than $t_f$ from epoch.

Col. 21 must be 0.

Year of epoch is based on 1958 = 01.

Simulation — Code 0 in column 19.

Differential Correction

Card 5 Col. 20 tells program how many times to repeat correction.
Col. 38 is coded I when user wishes to correct both the elements and station positions. (Such stations must have non-zero datum.)

Col. 39 is coded I when user wishes to correct the station positions only.

Col. 40 is coded I when user wishes to correct the orbital elements only.

The maximum limits for the residuals are left to the discretion of the user, as are the sigmas.

2. Observation Cards

It is preferable that observations be ordered by time. This shortens the running time by eliminating rewind orders.

A card following the last observation card must have "END" punched inCols. 1-3.

3. Station Cards

The station number must agree inCols. 1-4 to the station number on the observation card inCols. 11-14.

The sigmas that may be put in on the station cards are sigmas associated with the observations, not with station position. Observational sigmas on the Observation Cards will take precedence over those on the Station Cards. Also if no sigmas are given on the Station Card, nominal values will be used (ASIG).

4. Options By Means Of Toggle Settings

The program user has options available to him by requesting certain toggles to be set manually by the computer operator at run time. The request is specified on the Request Card and on a card inserted in the data deck immediately following the Job Card, punched as shown below.

<table>
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<th>Col.</th>
<th>Col.</th>
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<tbody>
<tr>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>HLT</td>
<td></td>
</tr>
</tbody>
</table>

HLT PLEASE PUT ON TOGGLES X, X, etc.

The HLT card causes the message to be printed on the flexo when the run starts.
Toggles 30, 31, 32 and 33 are on for generating simulated observations on punched cards in ANNA format. Any number of these may be specified during a run for the following:

- 30 for Azimuth and Elevation,
- 31 for Right Ascension and Declination,
- 32 for Range,
- 33 for Range Rate.

Toggle 35 on will cause program to print out Keplerian elements for each time step.
**INPUT FORMAT FOR A SIMULATION RUN**

May be run with or without station cards.  
Without station cards output results on print option.  
With station cards output includes look angles.

**CARD 1**

<table>
<thead>
<tr>
<th>Col.</th>
<th>1-72</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINE 1 - HEADING FOR OUTPUT PAGES</td>
<td></td>
</tr>
</tbody>
</table>

**CARD 2**

<table>
<thead>
<tr>
<th>Col.</th>
<th>1-72</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINE 2 - HEADING FOR OUTPUT PAGES</td>
<td></td>
</tr>
</tbody>
</table>

**CARD 3**

<table>
<thead>
<tr>
<th>Col.</th>
<th>1-12</th>
<th>±</th>
<th>13-24</th>
<th>±</th>
<th>25-36</th>
<th>±</th>
<th>37-48</th>
<th>±</th>
<th>49-60</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>±</th>
<th>13-24</th>
<th>±</th>
<th>25-36</th>
<th>±</th>
<th>37-48</th>
<th>±</th>
<th>49-60</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔT (minutes)</td>
<td>Minutes from Epoch to Final Time</td>
<td>Diameter of Satellite (meters)</td>
<td>Mass of Satellite (kilograms)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CARD 4**

<table>
<thead>
<tr>
<th>Col.</th>
<th>1-12</th>
<th>±</th>
<th>13-24</th>
<th>±</th>
<th>25-36</th>
<th>±</th>
<th>37-48</th>
<th>±</th>
<th>49-60</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>±</th>
<th>13-24</th>
<th>±</th>
<th>25-36</th>
<th>±</th>
<th>37-48</th>
<th>±</th>
<th>49-60</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axis (nautical miles)</td>
<td>Eccentricity</td>
<td>Inclination (degrees)</td>
<td>Mean Anomaly (degrees)</td>
<td>Arg. of Perigee (degrees)</td>
<td>Right ascension of node (degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CARD 5**

<table>
<thead>
<tr>
<th>Col.</th>
<th>1-12</th>
<th>±</th>
<th>13-24</th>
<th>±</th>
<th>25-36</th>
<th>±</th>
<th>37-48</th>
<th>±</th>
<th>49-60</th>
<th>±</th>
<th>61-72</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Print Option: 1 gives time, \( \phi, \lambda, h \); 2 gives \( x, y, z, \dot{x}, \dot{y}, \dot{z} \); 3 gives both |

<table>
<thead>
<tr>
<th>7-10</th>
<th>±</th>
<th>11-18</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoch Day</td>
<td>Minutes from Epoch Day to Epoch</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>19-21</th>
<th>±</th>
<th>25-26</th>
<th>±</th>
<th>29-37</th>
<th>±</th>
<th>41-42</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0</td>
<td>Restart Day</td>
<td>Minutes from Restart Day to Restart Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year (1963 = 0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**STATION DATA**

<table>
<thead>
<tr>
<th>Col.</th>
<th>STAT</th>
<th>LATITUDE (F8.5)</th>
<th>LONGITUDE (F9.5)</th>
<th>Alt. meters (F6.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>13</td>
<td>22</td>
<td>27</td>
</tr>
</tbody>
</table>


## INPUT FORMAT FOR SPECIFICATION CARDS PROGRAM

**Differential Correction**

### Differential Correction Card

<table>
<thead>
<tr>
<th>CARD</th>
<th>Heading for Output Line 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9-72</td>
</tr>
<tr>
<td>2</td>
<td>25-72</td>
</tr>
</tbody>
</table>

### Differential Correction Card (Cont.)

<table>
<thead>
<tr>
<th>3°</th>
<th>Heading (Line 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-12</td>
<td>+0 0 0 0 0 0 0 0 0 + 0 0</td>
</tr>
<tr>
<td>13-24</td>
<td>T0</td>
</tr>
<tr>
<td>25-36</td>
<td>ΔT (minutes)</td>
</tr>
<tr>
<td>37-48</td>
<td>Time from Epoch to Final Time (minutes)</td>
</tr>
<tr>
<td>49-60</td>
<td>Diameter of Vehicle (meters)</td>
</tr>
<tr>
<td>61-72</td>
<td>Mass of Vehicle (kilograms)</td>
</tr>
</tbody>
</table>

### OPTION - Use if only Keplerian elements are available; code with a Minus (-) in Col. 1.

<table>
<thead>
<tr>
<th>4a</th>
<th>Heading (Line 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-12</td>
<td>-</td>
</tr>
<tr>
<td>13-24</td>
<td>Axis (nautical miles)</td>
</tr>
<tr>
<td>25-36</td>
<td>Eccentricity</td>
</tr>
<tr>
<td>37-48</td>
<td>Inclination (degrees)</td>
</tr>
<tr>
<td>49-60</td>
<td>Mean Anomaly (degrees)</td>
</tr>
<tr>
<td>61-72</td>
<td>Arg. of Perigee (degrees)</td>
</tr>
<tr>
<td></td>
<td>Rt Asc of Node (degrees)</td>
</tr>
</tbody>
</table>

### OPTION - Use if the following values are supplies as input; otherwise, see 4a.

<table>
<thead>
<tr>
<th>4b</th>
<th>Heading (Line 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-12</td>
<td>L0 (radians)</td>
</tr>
<tr>
<td>13-24</td>
<td>Axn</td>
</tr>
<tr>
<td>25-36</td>
<td>Ayn</td>
</tr>
<tr>
<td>37-48</td>
<td>Hx Earth radii</td>
</tr>
<tr>
<td>49-60</td>
<td>Hy &quot;</td>
</tr>
<tr>
<td>61-72</td>
<td>Hz &quot;</td>
</tr>
</tbody>
</table>

### Option 5

<table>
<thead>
<tr>
<th>5</th>
<th>Heading (Line 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>Print Option (1 for Time, φ, λ, h; 2 for Time, x, y, z, x, y, z; 3 for both)</td>
</tr>
<tr>
<td>7-10</td>
<td>Epoch (Day of Year; integer)</td>
</tr>
<tr>
<td>11-18</td>
<td>Time; from beginning of Epoch Day to Epoch = minutes</td>
</tr>
<tr>
<td>19</td>
<td>Blank for differential correction; 0 (zero) for simulation</td>
</tr>
<tr>
<td>20</td>
<td>Number of times to repeat correction</td>
</tr>
<tr>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>22-24</td>
<td>Sigma 1</td>
</tr>
<tr>
<td>25-26</td>
<td>Restart Time (day of year)</td>
</tr>
<tr>
<td>29-33</td>
<td>Restart Time (minutes)</td>
</tr>
<tr>
<td>38</td>
<td>Code 1 to correct both elements and station positions. Use 1 of 3 only</td>
</tr>
<tr>
<td>39</td>
<td>Code 1 to correct station positions only</td>
</tr>
<tr>
<td>40</td>
<td>Code 1 to correct orbital elements only</td>
</tr>
<tr>
<td>41-42</td>
<td>Year - 1958 = 01; 1959 = 02; 1960 = 03; 1961 = 04; 1962 = 05; 1963 = 06; etc</td>
</tr>
<tr>
<td>43-48</td>
<td>Max. for angle and range residuals</td>
</tr>
<tr>
<td>49-53</td>
<td>Sigma 2</td>
</tr>
<tr>
<td>52-56</td>
<td>Sigma 3</td>
</tr>
<tr>
<td>55-57</td>
<td>Sigma 4</td>
</tr>
<tr>
<td>58-60</td>
<td>Sigma 5</td>
</tr>
<tr>
<td>61-63</td>
<td>Sigma 6</td>
</tr>
<tr>
<td>64-66</td>
<td>Sigma 7</td>
</tr>
<tr>
<td>67-69</td>
<td>Sigma 8</td>
</tr>
<tr>
<td>70-72</td>
<td>Sigma 9</td>
</tr>
<tr>
<td>73-78</td>
<td>Max. for range rate residuals</td>
</tr>
</tbody>
</table>

*Format (xxxxxxx)xx*
Input Format for OPTICAL Observations

* Code 2 identifies observation as Optical
** Sigmas have decimal point assumed to be between col. 60 & 61
and col. 64 & 65

<table>
<thead>
<tr>
<th>YR</th>
<th>SAT.</th>
<th>I.D.</th>
<th>STATION I.D.</th>
<th>OBSERVATION TIME</th>
<th>AZIMUTH</th>
<th>ELEVATION</th>
<th>RT ASC (in Col. 30) hrs</th>
<th>DECL.</th>
<th>Sigma**</th>
<th>Sigma**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>6</td>
<td>11</td>
<td>15 16 18 20 22 24 26 29 30 33 35 37</td>
<td>39 43 45 47</td>
<td>59 60 61 62 63 64 65 66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Input Format for RANGE RATE Observations**

* Code 4 identifies data as a Base Frequency
  Code 3 identifies data as a Received Frequency

** Sigma has decimal point assumed to be between Col. 50 and 51

<table>
<thead>
<tr>
<th>YR</th>
<th>SAT I. D.</th>
<th>STATION I. D.</th>
<th>OBSERVATION TIME</th>
<th>BASE OR REC'D FREQUENCY</th>
<th>Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>6.11</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>yjr mo day hr min sec .0001 sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>cycles per second</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>49</td>
</tr>
</tbody>
</table>
Input Format for RANGE Observations

* Code 1 identifies the type of observation as range

** The sigma for range is given in col 49-51 with decimal point assumed between col 50&51

<table>
<thead>
<tr>
<th>YR</th>
<th>SAT I.D.</th>
<th>STATION I.D.</th>
<th>OBSERVATION TIME</th>
<th>FORMATTED RANGE (meters)</th>
<th>Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col 1</td>
<td>3</td>
<td>6</td>
<td>11</td>
<td>15/16</td>
<td>18</td>
</tr>
<tr>
<td>SAT I.D.</td>
<td>LATITUDE (degrees)</td>
<td>LONGITUDE (degrees)</td>
<td>HEIGHT (meters)</td>
<td>Datum no.</td>
<td>ρ abs</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------</td>
<td>---------------------</td>
<td>-----------------</td>
<td>-----------</td>
<td>-------</td>
</tr>
<tr>
<td>1-4</td>
<td>5-12 (F8.5)</td>
<td>13-21 (F9.5)</td>
<td>22-27 (F6.0)</td>
<td>ASIG 1</td>
<td>38-45</td>
</tr>
</tbody>
</table>
V COMPILATION PROCEDURE

The program must be compiled on the Philco "2000" under the system called "Altac 2". This system requires that all tape units used be specified according to their use in an "lounits" statement.

Decimal Input Tapes are LTO and LT10
Intermediate Binary Tapes are LT3, LT6, LT9, LT11, LT13, LT14, and LT15
Decimal Output Tape is LT5, Data Select 0
Punched Card Output is LT13, Data Select 10

The program uses approximately 100 RPL block. Compilation time is about 20 minutes. The source deck consists of approximately 5000 cards (2 1/2 boxes).
VI EXECUTION OF DATA RUN

Col.  Col.
17     25
JOB XXX (Identify run)
REWIND 0, 3, 6, 9, 10, 11, 13
RPL 1, DATA, GO
TAPE 0

For all runs, insert 5 specification or control cards here. For
differential correction runs, the 5 specification cards are followed by the
observation cards. The last observation card must be followed by a card
with "END" inCols. 1-3.

ENDDATA
REWIND 0
JMP *
TAPE 10

Station cards are inserted here. The run must have a card with "END"
inCols. 1-3 before the following:

ENDDATA
REWIND 10
JPL 4, XXXX, GO (ID of program)

TAPE UNITS Requiring Write Rings

1. Input
   TAPE 0 5 specification cards and observation cards.
   TAPE 10 station cards

2. Output
   TAPE 5 printed output
   TAPE 13 punched cards using data select 10 when making
   a simulation run.
3. **Binary**

TAPE 3 saves time and sub-satellite positions

TAPE 6 saves time, $x$, $y$, $z$, $\dot{x}$, $\dot{y}$, $\dot{z}$.

TAPE 9 saves observations after processing

TAPE 11 saves data used in computing sigmas

TAPE 14 saves data used in computing the corrected latitude, longitude, and height of the observing station (spheroid specified).

TAPE 15 saves elements at every time step if Toggle switch 35 is on.
VII OUTPUT

A. Printed Output:

1. Input data from the 5 specification cards.

2. $L_0$, $A_{Xn}$, $A_{yn}$, $H_x$, $H_y$, $H_z$ if input is in form of Keplerian elements.

3. Time and satellite position in latitude, longitude, and altitude above a specified reference spheroid for each integration step. This is available with a print option of 1 or 3.

4. Time and inertial position and velocity $(x, y, z, x', y', z')$ of satellite for each integration step. This is available with a print option of 2 or 3.

5. Input data from station cards.

6. Input data from observation cards.

7. Station number, time, and residual for each observation.

8. Root-mean-square of the non-rejected residuals (SUM and SUM2) and the corrections to the orbital parameters ($\Delta A/A$, $\Delta AXN$, $\Delta AYN$, $\Delta L_0$, $\Delta NODE$, $\Delta I$). The SUM2 column contains range rate residuals.

9. Suggested changes in coordinates of datum in earth-fixed coordinates ($\Delta X$, $\Delta Y$, and $\Delta Z$).

10. The differentially corrected Keplerian elements, differentially corrected $L_0$, $A_{Xn}$, $A_{yn}$, $H_x$, $H_y$, $H_z$, and the corrected $x$, $y$, $z$, $x'$, $y'$, $z'$ at epoch.

11. New positions for stations in non-zero datums, station number, latitude, longitude, elevation, and earth fixed rectangular coordinates $(x, y, z)$ of station. Latitude, longitude and elevation are referenced to the spheroid whose parameters are specified in the Table of Program Constants.
12. The standard deviation (sigma) for DELTA A/A, DELTA AXN, DELTA AYN, DELTA L₀, DELTA NODE, DELTA I at epoch.

13. The standard deviation (sigma) in the observation station position (SIGMA X, SIGMA Y, and SIGMA Z).

14. Time and the satellite position (x, y, z) with the associated standard deviation are given at epoch and for each observation time.

B. Punched Card Output

An optional feature of DOC II will produce observation cards punched in correct format for use as input in the differential correction portion of the program.

These cards can be generated during a simulation run by toggle settings on the console. The settings are made manually by the computer operator as specified by the program user on the Computer Request Card, and by the insertion of a card in the run deck, immediately following the job card, as follows:

(Col. 17) HLT       (Col. 25) PUT ON TOGGLES X, X, ETC.

This card will be printed out on the flexo-writer at run time for instruction to the operator.

Set Toggle 30 for azimuth and elevation observations
Set Toggle 31 for right ascension and declination observations
Set Toggle 32 for range observations
Set Toggle 33 for range rate observations
FLOW CHART OF SUBROUTINES
Subroutine BETAE

\[
\begin{align*}
\text{ALFA}(k,3) &= 1.25 \times 10^{-6} \quad \text{ALFA}(3,3) = 1.25 \times 10^{-6} \\
\text{ALFA}(4,2) &= 1.25 \times 10^{-6} \\
\text{ALFA}(4,3) &= 2.10 \times 10^{-6} \\
\text{ALFA}(4,4) &= 1.12 \times 10^{-6} \\
\text{ALFA}(5,2) &= 4.05 \times 10^{-6} \\
\text{ALFA}(5,3) &= 1.07 \times 10^{-6} \\
\text{ALFA}(5,4) &= 1.06 \times 10^{-6} \\
\text{ALFA}(5,5) &= 1.00 \times 10^{-6}
\end{align*}
\]
\[
\begin{align*}
D(3, 2) &= \sqrt{a(T_{1}/R_{01})} \\
D(1, 1) &= x/r \\
D(2, 1) &= y/r \\
D(3, 1) &= z/r \\
D(1, 2) &= -y/t \perp \\
D(2, 2) &= x/t \perp \\
D(3, 3) &= 0 \\
P(1, 1) &= 1 \\
P(2, 1) &= T \\
P(1, 2) &= 0 \\
P(2, 2) &= 1 \\
\end{align*}
\]

**FORM LEGENDRE POLYNOMIALS**

\[
\begin{align*}
P(N, N) &= (2 \times X_{N-1}) \times P(N-1, N-1) \\
P(N, 1) &= (2 \times X_{N-1}) \times T \times P(N-1, 1) / \\
&\quad X_{N-1} \times (X_{N-1}) \times P(N-2, 1) / X_N \\
X_N &= N-1 \\
N &= M-1 \\
L &= M+1 \\
M &= 2, 6 \\
DO M = 2, 6 \\
X_M &= M-1 \\
L &= M+1 \\
DO N = L, 6 \\
X_N &= N-1 \\
P(N, M) &= (2 \times X_{N-1}) \times T \times P(N-1, M) / \\
&\quad X_N \times (L \times X_{N-1}) \times M \times \\
P(N-1, M-1) / X_N \\
S_0 \rightarrow N = M-1 \\
S_0 \rightarrow 3 \\
P(N, M) &= P(N, M) - (X_{N-1}) \\
&\quad \times P(N-2, M) / X_N \\
\end{align*}
\]
BELGE (cont.)

\[ x = 1 \]

**INSERT THE COS(PHI) TO THE M TERMS**

\[ \text{DO } M = 1, 6 \]
\[ Z = Z + C \]
\[ \text{DO } N = 2, 4 \]
\[ P(N, M) = P(N, M) * Z \]

**INITIALIZE**

\[ FR(N) \]
\[ N = 1, 4 \]

\[ xL = \tan^{-1} \frac{y}{x} \]

**STOP**

\[ xL = \pi - xL \]

\[ xL = 2\pi + xL \]

\[ xL = \text{PROPR}(xL) \]
\[ CL = \cos F(xL) \]
\[ SL = \sin F(xL) \]
\[ u = R \]

C
BELGE (cont.)

\[ T4(M) = 0, \]

\[ \text{DO } N \geq 1,3 \]

\[ T4(M) = T4(M) + \\
\quad D(M,N) \times FR(N) \]

\[ A = T4(1) \times CT - T4(2) \times ST \\
B = T4(1) \times ST + T4(2) \times CT \\
C = T4(3) \]

\text{Return}
Subroutine BESSEL

\[ E_{xy} = \exp(-xye) \]

\[ xxaesr = xxae \]

\[ temp = xxocns = xxaesq \]

\[ do 10 = 2, 15 \]

\[ temp = temp + xxocns (i) \]

\[ i = i + 1 \]

\[ temp = xxocns (i) \]

\[ do 4 = 2, 12 \]

\[ temp = temp + xxocns (i) \]

\[ i = i + 1 \]

\[ temp = xxocns (i) \]

\[ do 2 = 0, 1 \]

\[ temp = (temp) \%
\]

\[ temp = xxocns (i) \]

\[ i = i + 1 \]

\[ temp = xxocns (i) \]

\[ do 1 = 0, 12 \]

\[ temp = temp + xxocns (i) \]

\[ i = i + 1 \]

\[ temp = xxocns (i) \]

\[ goto 17 \]

\[ temp = xxocns (i) \]

\[ goto 17 \]
COEFF (cont)

COMPUTE:
C_{2}, C_{OC}, C_{AN}
C_{A}, C_{An}, C_{Al}
AND STORE IN
TERMS (K), K = 1, 4

COMPUTE
RESIDUAL

DON = ASG (K)
RHO =
39921/31058

TERMS (LSTOUT + I) = Resid * RHO / DON

Resid = Resid^2

DO K = 1, 6
TERMS (K) = TERMS (K) / DON

CALL
SETG
TO GET INDEXING OF I

COMPUTE:
TERMS (I), (= +1),
(I = 2), AND APPLY
WEIGHT (DON)

STOP
Subroutine MONEF

Set up constants:
\[
\begin{align*}
\text{RAD} & = 57.29577935 \\
\text{SEC} & = 206265.0 \\
\text{TP} & = 6.283185307 \\
\text{PI} & = 3.14159265
\end{align*}
\]

Y

\[ \begin{align*}
Y & < 0 \\
\text{ZYR} & = 6 \\
Y & > 0 \\
34 & \sqrt{\text{TP DAY} + 1461.5}
\end{align*} \]

\[ \begin{align*}
Y & < 0 \\
\text{TODAY} & = \text{TODAY} + 1461.5 \\
Y & > 0
\end{align*} \]

Y

Compute:
\[
\begin{align*}
X_L, FL, FLP, FX, D, E, & \\
G, H, CLON, S, CLAT, & \\
CA, CB, SA, SB, SD, & \\
CDCA, CDDA, CDS & 
\end{align*}
\]

ABS F (CDSA) - ABS F (CDDA)

\[ \begin{align*}
R & < 0 \\
\text{RELATANF (CDDA, CDSA)} & = R = 1.570796 - R \\
R & > 0 \\
\text{RELATANF (CDDA)} & = R
\end{align*} \]

Y

\[ \begin{align*}
L & < 0 \\
\text{CDCA} & = \text{CDCA} + 5 \\
L & > 0 \\
\text{DEG} & = \text{ATANF} \left( \frac{30}{\sqrt{1-0.52}} \right)
\end{align*} \]

STOP
Subroutine PRESS

Set up constants
\[ C1 = 0.9856472 \]
\[ PL = 0.456E-6 \]
\[ P2 = 1.004814784 \]
\[ PI = 3.141592653 \]
\[ HRK = 0.0 \]

Set \( I = 1 \) for 1962
\( I = 2 \) for 1963
\( I = 3 \) for 1964

**COMPUTE:**
\[ SOL = SUNL(I) + C1*T + C15(I) \ast SINF(C1 \ast T - C14(I)) \]
\[ RA = SOL - C14(I) \ast SINF(SOL + SOL) \]
\[ DEC = ATANF(P2 \ast C17(I) \ast SINF(RA)) \]
\[ CRA = COSF(RA) \]
\[ CDEC = COSF(DEC) \]
\[ SRA = SINF(RA) \]
\[ SDEC = SINF(DEC) \]

**COMPUTE:**
\[ U1 = CRA \ast CDEC \]
\[ U2 = SRA \ast CDEC \]
\[ U3 = CDEC \]

\[ RL = \sqrt{X(1)^2 + X(2)^2 + X(3)^2} \]
\[ V1 = X(1)/RL; V2 = X(2)/RL; V3 = X(3)/RL \]
\[ TT = U1 \ast V1 + U2 \ast V2 + U3 \ast V3 \]

\[ A \]
PRESS (cont.)

(A)

1. IF
   \[ \text{ABS}(TT) - \text{SQRT}(RI-1)/R2 < 0.0 \]

2. V = 1.0

3. V = 0.0

4. \[ XSFCT \times D \times \pi / 4.0 \]
   \[ VV = XECT/XM \times PE \times V \times HRK \]

(Return)
SUBROUTINE: REARD

Read and convert an observation card

READ

READ ANY OBSERVATION CARD

INITIALIZE:
ALPHA, DELTA, READS, RANGE, 
ASIG(i), I = 1, 4

YES  END

No

NCARD = 2
RETURN

NCARD = 1

TYPE = 4

BASE FREQ CARD, GO TO CORRD

YES

No

CHECK IF LEAD YEAR; CONVERT OBS TIME TO
MINUTES = UTIME

NCARD

Col. 36-48 = EFREQ

TYPE

= 1

= 2

= 3

RANGE OBS; GO TO FOR I

OPTICAL OBS; GO TO REARD

REFERENCES

44
Subroutine RECTFY

DO K=6,8
RSTO(K) = FPDRAG + RSTO(K)
PDRA = PDRA + RSTO(K)

IF PDRA > 1
PDRA = 1
endif

K = K + 1

CALL INTO

CALL Bessel

CALL IODRAG

PDRA = A(1) + ADRAG
XNDRAG = XDRAG / ADRA
RSTO(K) = RSTO(K) - XNDRAG

TP = XMEAN
FP311 = (1 - PERG * QDRA) / ADRAG
PDRA = 0
Subroutine SETI

1. $J = 0$
2. $J = J + 1$
3. If $\text{AND} - J > 0$
   - Go to COEFF.
   - If $J = 0$
     - $J = J + 3$
   - $\text{RETURN}$
SUBROUTINE STARTER
READ 1ST FIVE CONTROL CARDS

STARTER

READ IN 2 HEADING CARDS

READ IN TO, DT, TF, T, XM

READ IN 4th CARD

YES

NO

KEPLERIAN ELEMENTS
GIVEN AS INPUT.
CONVERT TO
LO, AX, A1M, HX
HY, HZ.

READ IN 5th CONTROL CARD

WRITE ON
OUTPUT TAPE:
TITLE,
ELEMENTS,
ETC

RETURN
Subroutine SUM:

\[ \text{DO } L = 1, L0 \]

\[ \text{DO } J = 1, K \]

\[ \text{TEMP} = a \times \text{TEMP} + Acos(n) \]

\[ N = N + 1 \]

\[ B(n) = \text{TEMP} \]

\[ M = M + 1 \]

\[ \text{RETURN} \]
Subroutine TBIINT

\[ T = 2 \]

\[ T = 2 \]

\[ H = 900,000 \]

\[ H = \text{HSGME}(J) \]

\[ J = 1, 2, 3 \]

\[ J = 1, 2, 3 \]

\[ J = 1, 2, 3 \]

\[ J = 1, 2, 3 \]

WRITE OUTPUT
"Altitude below 50000 feet"

\[ H = \text{HSGME}(J) - \text{HSGME}(J-1) \]

\[ H = \text{HSGME}(J) - \text{HSGME}(J-1) \]

\[ \text{SIGMA} = \text{SIGMA} / \text{H} \text{MM} \]

\[ \text{SIGMA} = \text{SIGMA} / \text{H} \text{MM} \]

\[ \text{XME} = \text{H} \text{MM} \text{H} \text{MM} \text{XME}(J-1) \]

\[ \text{XME} = \text{H} \text{MM} \text{H} \text{MM} \text{XME}(J-1) \]

\[ \text{XME} = \text{H} \text{MM} \text{H} \text{MM} \text{XME}(J-1) \]

\[ \text{Ratio} = \exp(\text{SIGMA}) \]

\[ \text{IT} = 1 \]
\( \Psi \) = \( S \) (cont.)

\[
\begin{align*}
\text{COMPUTE:} & \quad \cos \Psi, \sin \Psi, \cosh \Psi, \\
\text{DO } & \quad i = 1, 3 \\
\text{Compute position vectors:} & \quad u(x), v(x), w(x) \\
\text{DO } & \quad j = 1, 3 \\
\text{Compute velocity vector:} & \quad x + \dot{u}(x) \times (i, j)
\end{align*}
\]
Let's suppose a flowchart with the following steps:

1. **LSQ**
2. **CLEAR MATRIX**
3. **AREA TO 0.0**
4. **RETURN**
5. **LSQR**
   - **BUILD**
   - **QLSQ4 AND QLSQ8**
   - **RETURN**
6. **LSQSL**
   - **FILL IN**
   - **QLSQ4 AND QLSQ8**
   - **RETURN**
PROPERIZES ANGLE GIVEN IN RADIANS

FUNCTION

PROPR (x)

x > 0

x = x - 2π

x = x + 2π

x IS PROPERIZED

RETURN

PROPERIZES ANGLE GIVEN IN DEGREES

FUNCTION

APROPR (x)

APROPR = 57.2957795 *

x

PROPR (\frac{x}{57.2957795})

RETURN
FLOW CHART OF MAIN PROGRAM
ID
77
7-4A'~;
7-
P
4P7-JSi=
ajop
TZ)
38
TEST PRINT
OPTION
=0
LINE?
=0
TEST IF
THRU
INTEGRATING
YES
NO
GO TO
71
GO TO
SEND
31
OFF
SL 10
WRITE TAPE 6
X, Y, Z, X, Y, Z
NTAPE 6 = NTAPE 6 + 1
PUT SL 10 ON
ON
SL 35
CALL XEL
TO COMPUTE ELEMENTS FOR CURRENT TIME
WRITE TAPE 15 ELEMENTS FOR CURRENT TIME
NTAPE 15 = NTAPE 6
41
PREPARE
LATITUDE, LONGITUDE
AND HEIGHT
FOR PRINT-OUT
WRITE SATELLITE
POSITION
40 TO
71
SET Diagonal Elements after 1st 6 to 1.0
Clear Matrix B after 1st 6 Elem.

LMODE = 3

NO

747

RESTORE MATRIX
SQMC → AL5QA
SQCL → QL5QB

GOTO LSQS

737

WRITE:
"Corrections made to Orb. Elem. only"

GOTO EFFECT

GOTO LSQS

GOTO
A = ZDOT
A20 = ARMA
RSIBU = A20R = ESINE.
UMR2 = U(0) + (-3/4)
ROA2 = Y/A
RVN = (AXN - COSO) * A20R
RVN = (AXN - SINE) * A20R
USBU = RTESQ + A20R
US3A = USIBU + MUO
DENOM = XLGR - RTESQ
TEMP = (XLGR * ECOSO) * (-1) - ESQ + (1)
UYN = (TEMP/DENOM) + ESINE
UXN = UYN * AXN
ROA = 1.0 + ROA
UXN = UXN + ROA * SINEO
UXN = (-AXN/UXR) + UXN + A20R
UYN = UYN * AXN - ROA * (AXN/UXR) + UXN
PHOC = 0.

DO K+5,3
PHOX[K] = WSTO(K) + X(K)
PHOC + PHOE + PHOX(K)
PHOC = VRHOC
XLX(K) = PHOX(K)/PHOC
DELT X(K) = WSTO(K+13) - XLX(K)

B
WRITE TAPE II
PARAMETERS FOR
STANDARD
DEVIATION
DETERMINATION

CALL COEFF

DO $i = 1, 3$
\text{ARRAY} (i) = \text{WSTC}(7+i)

CALL COEFF

GO TO BADGB

GO TO 180

GO TO BADGB

GO TO 180
FROM 6 VECTORS FOR X, Y, AND Z
XVEC(I), I = 1, 6
YVEC(I), I = 1, 6
ZVEC(I), I = 1, 6

TRANSPOSE MATRIXES
XVEC, YVEC, ZVEC

MULTIPLY:
XVEC · CVERT → XVEC; CVERT · XVEC → X
YVEC · CVERT → YVEC; CVERT · YVEC → Y
ZVEC · CVERT → ZVEC; CVERT · ZVEC → Z

COMPUTE SIGMAS
IN METERS:

σx · XVEC · METERS
σy · YVEC · METERS
σz · ZVEC · METERS

PRINT SATELLITE POSITION SIGMAS

GO TO始め
\begin{align*}
\text{173} & \text{ \quad CNTWD (10)} \quad \text{\circ} \quad \text{\circ} \\
& \text{175} \quad \text{\circ} \quad \text{\circ} \quad \text{\circ} \quad \text{\circ} \quad \text{\circ} \quad \text{\circ} \quad \text{\circ} \quad \text{\circ} \\
& \text{GO TO} \quad \text{START} \\
& \text{TEMP} = \text{CUTWD (10) \times (-.25068448) - THGR + 360.0} \\
& \text{LO \quad XIT} \quad \text{TEMP} \quad \text{SO} \\
& \text{TEMP} = \text{TEMP} + 360.0 \\
& \text{THGR} = \text{- (TEMP - 360.0)} \\
& \text{WRITE OUTPUT \quad \"RESTART INFORMATION\"} \\
& \text{GO TO START}
\end{align*}
GLOSSARY

A. Subroutines Used in Computation
B. Important Mneumonic Codes
C. Table of Program Constants
A. Subroutines Used In Computations

ALTAC Language

AQDRAG       Computes drag term
CALH         Computes height in meters above oblate earth
COEF         Computes the coefficients of the current correction
equation and stores them in an array called Terms
GTOBS        Processes an observation card
RCTFY        Applies corrections for atmospheric drag during the
intergration of the ephemeris
SETI         Used during COEF routine to store coefficients in proper
locations in array
TBINT        Interpolates in a table
XYZSB        Computes intermediate orbit parameters and satellite
positions and velocity vectors
BESSEL       Computes Bessel functions used in drag computation

TAC Language

CHGNXN       Establishes size of matrix as NXN. N can be any size
             from 6 x 6, 9 x 9, 12 x 12, ..., 24 x 24
LSQ          Initialices matrix area to zero
LSQR, LSQS1   Builds and fills in Matrix A and Matrix B
LSQS         Inverts matrix, saves diagonals, relocates 6 x 6 matrix,
             and then multiplies the inverted Matrix A by Matrix B

ALTAC Input-Output Subroutines

HEAD         Output routine to print headings on output pages
PRINT        Output routine to print ephemeris
PRINTO       Output routine to print x, y, z, SDOT, YDOT, ZDOT
RCARD        Input-output routine to read in observation cards from
             Tape 0, and print out this input
READER  Input-output routine to read in station cards from Tape 10 and print out this input

STARTER Input-output routine to read in 5 specification cards from Tape 0, compute LSUBO, AXN, AYN, HX, HY, HZ, and print out the input and computed elements

ALTAC FUNCTIONS

PROPR(X) Properizes an angle given in radians
APROP(X) Properizes an angle given in degrees
B. **Glossary of Important Symbols**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Semi-major axis</td>
</tr>
<tr>
<td>A+1</td>
<td>Semi-major axis</td>
</tr>
<tr>
<td>ABSMX</td>
<td>Absolute maximum for angle and range residuals</td>
</tr>
<tr>
<td>ABMX2</td>
<td>Absolute maximum for range rate residual reject criteria</td>
</tr>
<tr>
<td>ALPHA</td>
<td>Minus RA or azimuth in degrees</td>
</tr>
<tr>
<td>ASIG1</td>
<td>Std deviation of observed range</td>
</tr>
<tr>
<td>ASIG2</td>
<td>Std deviation of observed range rate</td>
</tr>
<tr>
<td>ASIG3</td>
<td>Std deviation of observed right ascension or azimuth</td>
</tr>
<tr>
<td>ASIG4</td>
<td>Std deviation of observed declination or elevation</td>
</tr>
<tr>
<td>AX</td>
<td>X component of a bar</td>
</tr>
<tr>
<td>AY</td>
<td>Y component of a bar</td>
</tr>
<tr>
<td>AZ</td>
<td>Z component of a bar</td>
</tr>
<tr>
<td>AXNI</td>
<td>X comp in orbit plane (on N bar) of a bar</td>
</tr>
<tr>
<td>AYNI</td>
<td>Y comp in orbit plane of a bar</td>
</tr>
<tr>
<td>AXI</td>
<td>Same as RKSTO+5</td>
</tr>
<tr>
<td>AZI</td>
<td>Same as RKSTO+7</td>
</tr>
<tr>
<td>CASE</td>
<td>Case number in BCD, T35</td>
</tr>
<tr>
<td>CASE2</td>
<td>Case number in BCD, T23</td>
</tr>
<tr>
<td>CD</td>
<td>Initial approximation to the drag coefficient</td>
</tr>
<tr>
<td>CDO</td>
<td>Empirically-determined constant to evaluate drag coefficient</td>
</tr>
<tr>
<td>CHED1</td>
<td>Constant heading array; Time lat; long; altitude</td>
</tr>
<tr>
<td>CNTWD</td>
<td>Col 19 of control card 5 in BCD, T47</td>
</tr>
<tr>
<td>CNTWD+1</td>
<td>Epoch, day of year, in BCD W 4 trailing blanks</td>
</tr>
<tr>
<td>CNTWD</td>
<td>XL, at new epoch (or restart time)</td>
</tr>
<tr>
<td>CNTWD+2</td>
<td>Epoch time of day in minutes --- BCD, T47</td>
</tr>
<tr>
<td>CNTWD+3</td>
<td>Number of times to repeat correction - T15 - Same as IRPT</td>
</tr>
<tr>
<td>CNTWD+4</td>
<td>REFDA in BCD; 4 trailing blanks</td>
</tr>
<tr>
<td>CNTWD+5</td>
<td>REFTM in BCD, T47</td>
</tr>
<tr>
<td>CNTWD+10</td>
<td>Minutes difference new epoch minus old epoch (0 if no new ep</td>
</tr>
<tr>
<td>CNTWD+14</td>
<td>1st character of 2nd card, T15</td>
</tr>
<tr>
<td>CNTWD+15</td>
<td>AXN at new epoch (or restart time)</td>
</tr>
<tr>
<td></td>
<td>AYN at new epoch (or restart time)</td>
</tr>
</tbody>
</table>
CNTWD+16  HX, at new epoch (or restart time)
CNTWD+21-26  Position + vel vectors for sat. for transfer to tape 6
COND  Intermediate drag term; constant for object
CONTSS  Intermediate drag term, Constant = (VCO)**3/(4*EPS*SI
COSI  Cosine (Inclination)
COSO  Cosine of right ascension of node
COUNT  Number of iteration steps in ephemeris
D  Reference diameter of vehicle in meters
DELTA  Elevation or declination of observation in degrees
DD  Day of observation --- Floating point
DT  Time interval used in Runge Kutta integration
ECOSE  ECC* Cos (ECC ANOM)
EFLAG  Column 21 of 5th control card (flo pt integer)
EMIS  Emissivity of the satellite
EO1  Eccentric anomaly + argument of perigee
EPHEM  Core buffer for ephemeris
EPSQD  Square of eccentricity of the terrestrial ellipsoid
ESINE  ECC * SIN (ECC ANOM)
ESQ  1 - Eccentricity **2
F  Flattening of the earth
FLP25  Neg of rot. rate of earth in degrees per minute
HDNG  Array contains output page heading for entire run
HH  Hour of observation  (Floating point)
HMPRM  3rd harmonic of the earths gravitational potential
HI XI  Same as RKSTO+8
HYI  Same as RKSTO+9
HIZI  Same as RKSTO+10
IBMUTH  Obs code/ = 0 if RA-DEC / = 1 if AZ-ALT
IPGCNT  Current page number
IPNTFL  Print option as ALTAC integer
IRPT  Same as CNTWD+3 (Number of times to repeat correction
ISTCNT  Number of stations in starc buffer --- ALTAC integer
IXXX  Size of ephemeris buffer
IYI  Year of observation since 1960, T15
LINE  Line count on page
LO  Mean longitude at epoch
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCODE</td>
<td>Col 38 of CN CRD 5 - If NE 0, correct elems + sta position</td>
</tr>
<tr>
<td>M1CODE</td>
<td>Col 39 of CN CRD 5 - If NE 0, corr. sta position only</td>
</tr>
<tr>
<td>M2CODE</td>
<td>Col 40 of CN CRD 5 - If NE 0, corr. orbital elements only</td>
</tr>
<tr>
<td>MONTH</td>
<td>Month of observation ----- ALTAC integer</td>
</tr>
<tr>
<td>NCARD</td>
<td>Switch set by RCARD = 2 if no more obs; 1 if obs ready</td>
</tr>
<tr>
<td>NCNTRL</td>
<td>Index for next storage of ephemeris data into ephem buffer</td>
</tr>
<tr>
<td>NTAPE3</td>
<td>Number of records on tape 3</td>
</tr>
<tr>
<td>NTAPE6</td>
<td>Number of records on tape 6</td>
</tr>
<tr>
<td>OALT</td>
<td>Station height in earth radii</td>
</tr>
<tr>
<td>ONEPI</td>
<td>Empirically determined constant to evaluate drag coefficient</td>
</tr>
<tr>
<td>ORGDA</td>
<td>Epoch. Day of year</td>
</tr>
<tr>
<td>ORGTM</td>
<td>Epoch time of day in minutes</td>
</tr>
<tr>
<td>P</td>
<td>Semi-latus rectum</td>
</tr>
<tr>
<td>PHIRD</td>
<td>Station latitude in radians</td>
</tr>
<tr>
<td>QTR</td>
<td>Constant = .25</td>
</tr>
<tr>
<td>R</td>
<td>Magnitude of radius vector to satellite</td>
</tr>
<tr>
<td>R5</td>
<td>R**5; Fifth power of radius vector of satellite</td>
</tr>
<tr>
<td>RADYN</td>
<td>Degrees per radian</td>
</tr>
<tr>
<td>RDRDG</td>
<td>Dot product of RDOT and perturbations vector</td>
</tr>
<tr>
<td>RECTI</td>
<td>Switch = 1 if recification for drag has occured; = 0 if not</td>
</tr>
<tr>
<td>REFDA</td>
<td>Restart, day of year (new epoch for new elements)</td>
</tr>
<tr>
<td>REFTM</td>
<td>Restart time of day</td>
</tr>
<tr>
<td>RHOO</td>
<td>Atmos. density at surface of the earth in grams per cubic cm.</td>
</tr>
<tr>
<td>RKCNT</td>
<td>Control array for Runge-Kutta integration</td>
</tr>
<tr>
<td>RKSTO</td>
<td>Current time (since epoch) of this integration step</td>
</tr>
<tr>
<td>RKSTO+3</td>
<td>Time interval for Runge-Kutta integration</td>
</tr>
<tr>
<td>RKSTO+4</td>
<td>L, Mean longitude at this integration step</td>
</tr>
<tr>
<td>RKSTO+5</td>
<td>X comp. of A bar at this integration step</td>
</tr>
<tr>
<td>RKSTO+6</td>
<td>Y comp. of A bar at this integration step</td>
</tr>
<tr>
<td>RKSTO+7</td>
<td>Z comp. of A bar at this integration step</td>
</tr>
<tr>
<td>RKSTO+8</td>
<td>X comp. of H bar, at this integration step</td>
</tr>
<tr>
<td>RKSTO+9</td>
<td>Y comp. of H bar, at this integration step</td>
</tr>
<tr>
<td>RKSTO+10</td>
<td>Z comp. of H bar, at this integration step</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>RRDGR</td>
<td>Dot product of R bar and total perturbation vector</td>
</tr>
<tr>
<td>RRDOT</td>
<td>Dot product of R bar and R bar dot</td>
</tr>
<tr>
<td>RSQR</td>
<td>$R^2$ Square of radius vector of satellite</td>
</tr>
<tr>
<td>RTA</td>
<td>Square root of semi-major axis</td>
</tr>
<tr>
<td>RTESQ</td>
<td>SQRT $(1-Eccentricity)^2$</td>
</tr>
<tr>
<td>RTP</td>
<td>Square root of semi-latus rectum; magnitude of H bar</td>
</tr>
<tr>
<td>SATEL</td>
<td>Satellite ID on obs card ---- BCD, trailing blanks</td>
</tr>
<tr>
<td>SENSE LIGHT 1</td>
<td>Used by XYZSB to indicate when 1st time thru</td>
</tr>
<tr>
<td>SENSE LIGHT 2</td>
<td>On if obs on tape 9 in binary format; Off if not</td>
</tr>
<tr>
<td>SENSE LIGHT 3</td>
<td>On, we are processing RA-AZ portion of angle obs.</td>
</tr>
<tr>
<td>SENSE LIGHT 4</td>
<td>On if ephemeris is on tape 3; Off if not</td>
</tr>
<tr>
<td>SENSE LIGHT 5</td>
<td>Used by GTOBS to signal when obs card are all on tape 9</td>
</tr>
<tr>
<td>SENSE LIGHT 10</td>
<td>Used internally in CNTRL</td>
</tr>
<tr>
<td>SI</td>
<td>Second of observation (Floating point)</td>
</tr>
<tr>
<td>SIDRT</td>
<td>(Rot. rate of earth in deg/mean solar day) minus 360 degrees</td>
</tr>
<tr>
<td>SIGS</td>
<td>The Stefan-Boltzmann constant</td>
</tr>
<tr>
<td>SINI</td>
<td>Sine of inclination</td>
</tr>
<tr>
<td>SINO</td>
<td>Sine of right ascension of node</td>
</tr>
<tr>
<td>SIXP9</td>
<td>Empirically determined constant to evaluate drag coefficient</td>
</tr>
<tr>
<td>STAID</td>
<td>Station ID from obs card ---- BCD, leading zeroes</td>
</tr>
<tr>
<td>STARC</td>
<td>Start of station info buffer - Station ID, BCD, T47</td>
</tr>
<tr>
<td>STARC+1</td>
<td>Station latitude in radians</td>
</tr>
<tr>
<td>STARC+2</td>
<td>Station east longitude in radians</td>
</tr>
<tr>
<td>STARC+3</td>
<td>Station height in earth radii</td>
</tr>
<tr>
<td>STARC+4</td>
<td>Station datum number</td>
</tr>
<tr>
<td>STARC+5-7</td>
<td>Std. dev. of range, R-Rate, RA-AZ, Decl-Elev</td>
</tr>
<tr>
<td>SUM</td>
<td>Sum of squares of residuals of range or angle observations</td>
</tr>
<tr>
<td>SUM2</td>
<td>Sum of squares of residuals of range-rate observations</td>
</tr>
<tr>
<td>TF</td>
<td>Time after epoch to stop ephemeris calculation</td>
</tr>
<tr>
<td>THDOT</td>
<td>Rotation of earth in radians per kemin</td>
</tr>
<tr>
<td>TO</td>
<td>Time after epoch to begin ephemeris calculation</td>
</tr>
<tr>
<td>U</td>
<td>Mean argument of latitude at time, t.</td>
</tr>
<tr>
<td>UO</td>
<td>Mean argument of latitude at epoch</td>
</tr>
<tr>
<td>UO+1</td>
<td>$U \mod 2\pi$</td>
</tr>
<tr>
<td>UTIME</td>
<td>Time of observation in minutes</td>
</tr>
<tr>
<td>UZSQR</td>
<td>$UZ^2$: the square of Z component of U bar</td>
</tr>
</tbody>
</table>
VCO3  Cube of speed of satellite in circular orbit with \( r = 1 \)
earth radii in cent. cubed per sec cubed

WX  X component of W bar
WZ  Z component of W bar \( \rightarrow \) WX+2
X1STSG  1st reject factor for residuals
X2NDSG  2nd reject factor for residuals
X3RDSG  3rd reject factor for residuals
X4THSG  4th reject factor for residuals
X5THSG  5th reject factor for residuals
X6THSG  6th reject factor for residuals
X7THSG  7th reject factor for residuals
X8THSG  8th reject factor for residuals
X9THSG  Max no. of times to pass thru obs. before correcting
XBDGR  Partial derivative with respect to bulge of XDOT
XDGR  X component of total perturbations vector (excluding drag)
XINCL  Inclination
XJAY5  5th harmonic of the earth's gravitational potential
XJMPRM  2nd harmonic of the earth's gravitational potential
XK  Drag conversion constant
XK2ER  Meters per earth radii
XKMPRM  4th harmonic of the earth's gravitational potential
XLAMBA  Station east longitude
XLAT  Latitude of sub-satellite point
XLGR  \( 1 + \sqrt{I - \text{eccentricity}^{**2}} \)
XLO  Same as LO; mean longitude at epoch
XLONG  East longitude of sub-satellite point
XM  Mass of vehicle in kilograms
XMM  Minute of observation (floating point)
XNPDA  Constant (minutes per day)
XMNPDA  Constant (minutes per day)
XMPER  Meters per earth radii
XMX  X component of M bar
XMY  Y component of M bar
XMZ  Z component of M bar
XN  Mean motion
XNODE  Right ascension of node
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>XNX</td>
<td>X component of N bar</td>
</tr>
<tr>
<td>XNY</td>
<td>Y component of N bar</td>
</tr>
<tr>
<td>XOVR5</td>
<td>((X/R)^5)</td>
</tr>
<tr>
<td>YBDGR</td>
<td>Partial derivative of Y dot with respect to bulge; same as XBDRG+1</td>
</tr>
<tr>
<td>YDGR</td>
<td>Y component of total perturbations vector; same as XDGR+1</td>
</tr>
<tr>
<td>ZBDGR</td>
<td>Partial derivative of Z dot with respect to bulge; same as XBDRG+2</td>
</tr>
<tr>
<td>ZDGR</td>
<td>Z component of total perturbations vector; same as XDGR+2</td>
</tr>
<tr>
<td>ZOVR5</td>
<td>((Z/R)^2)</td>
</tr>
</tbody>
</table>
C. **Program Constants**

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>Initial approx to drag coefficient</td>
</tr>
<tr>
<td>2.504742E10</td>
<td>Constant used in drag calculation</td>
</tr>
<tr>
<td>92</td>
<td>Empirical constant used in drag calculation</td>
</tr>
<tr>
<td>6.972E4</td>
<td>Empirical constant used in drag calculation</td>
</tr>
<tr>
<td>1.173913</td>
<td>Empirical constant used in drag calculation</td>
</tr>
<tr>
<td>0.033523299</td>
<td>Flattening</td>
</tr>
<tr>
<td>1.685717364E-4</td>
<td>Flattening constant ( (3/2F)^2 )</td>
</tr>
<tr>
<td>3.3691870736E-2</td>
<td>Flattening constant ( F + (3/2F)^2 )</td>
</tr>
<tr>
<td>1.62341E-3</td>
<td>2nd harmonic of earth's gravitational potential</td>
</tr>
<tr>
<td>-6.0E-6</td>
<td>3rd harmonic of earth's gravitational potential</td>
</tr>
<tr>
<td>9.09E-6</td>
<td>4th harmonic of earth's gravitational potential</td>
</tr>
<tr>
<td>-0.2E-6</td>
<td>5th harmonic of earth's gravitational potential</td>
</tr>
<tr>
<td>0.001225</td>
<td>Atmospheric density at surface of earth in gms/cm³</td>
</tr>
<tr>
<td>3.141592653</td>
<td>PI</td>
</tr>
<tr>
<td>6.283185306</td>
<td>2 PI</td>
</tr>
<tr>
<td>57.2957795</td>
<td>Degrees per radian</td>
</tr>
<tr>
<td>0.1745329251</td>
<td>Radians per degree</td>
</tr>
<tr>
<td>1.570796326</td>
<td>( \pi )</td>
</tr>
<tr>
<td>4.712388978</td>
<td>( 3/2 \pi )</td>
</tr>
<tr>
<td>0.378273</td>
<td>Meters per earth radius</td>
</tr>
<tr>
<td>3441.605067</td>
<td>Nautical miles per earth radius</td>
</tr>
<tr>
<td>1.5678527E-6</td>
<td>Earth radii per meter</td>
</tr>
<tr>
<td>1.5078527</td>
<td>Earth radii per megameter</td>
</tr>
<tr>
<td>7.9048</td>
<td>( \text{km/sec per earth radius/kemin} )</td>
</tr>
<tr>
<td>0.05883447</td>
<td>Rotation rate of earth in radians/kemin</td>
</tr>
<tr>
<td>9.856472</td>
<td>Rotation rate of earth in degrees per day minus 360</td>
</tr>
<tr>
<td>-0.25068448</td>
<td>Negative rotation rate</td>
</tr>
<tr>
<td>.9</td>
<td>Emissivity of satellite</td>
</tr>
<tr>
<td>4.9397574E18</td>
<td>Speed (cubed) of circ satellite at 1 E. R. in meters/second</td>
</tr>
<tr>
<td>5.072E-4</td>
<td>Stefan-Boltzmann constant</td>
</tr>
<tr>
<td>0.07436574</td>
<td>kemins per minute</td>
</tr>
<tr>
<td>0.7986580E-3</td>
<td>Square of eccentricity of terrestrial ellipsoid</td>
</tr>
</tbody>
</table>
98.67401
99.420937
99.1822167
98.943500314
$1 \times 10^{-6}$ E.R.
10.0 cps
.00001 radians
-37922.43

Theta Greenwich for 1960
Theta Greenwich for 1961
Theta Greenwich for 1962
Theta Greenwich for 1963
Sigma for range observations
Sigma for doppler observations
Sigma for optical observations
Speed of light
APPENDIX A

EPHEMERIS COMPUTATION

and

DIFFERENTIAL CORRECTION THEORY

*From AFCRL 62-892
The Orbit Correction Program employs two computational techniques which speed the computation without loss of accuracy:

1. The satellite motion is numerically integrated by the variation of parameters formulation, thereby eliminating from the integrands the large central acceleration term.

2. The differential correction uses analytical differential expressions, thereby eliminating the need for more than one numerical integration over the observation period.

By developing the differential equations of motion in terms of parameters which remain invariant in the absence of perturbations to the two-body motion, the dominant two-body term is suppressed. The parameters employed in this formulation are:

- \( a = e \mathbf{P} \) \quad a vector defining eccentricity and perigee location
- \( h = \sqrt{p} \mathbf{W} \) \quad the orbital angular momentum
- \( L_0 = M_0 + \omega + \Omega \) \quad the mean longitude of the object at some epoch

These parameters are valid, in the formulation employed here, for all satellite eccentricities and for all inclinations, including zero in either case.

The differential characteristics of a slightly-perturbed satellite orbit are, to a first order, identical to those of the osculating orbit. Thus the cause-and-effect linear relationships needed for differential correction may be developed analytically, rather than by the alternate "variant calculation" procedure where neighboring ephemerides are integrated, in each case with one of the parameters modified by a small amount. The parameters employed in the development of the differential expressions resemble those used in the variation-of-parameters ephemeris program, i.e.:

- \( a = e \mathbf{P} \) \quad a vector defining eccentricity and perigee location
- \( a \) \quad semi-major axis
- \( U_0 = M_0 + \omega \) \quad the mean argument of the latitude at some epoch
- \( \Omega \) \quad nodal longitude
- \( i \) \quad inclination
The adoption of $\Omega$ and $i$ to describe the orbit plane orientation and of $U_{0}$ to denote initial position, restricts the development to non-equatorial orbits. In addition, the vector $a$ is described in terms of two components in the orbit plane to avoid redundancy; these components are designated $a_{xN}$ and $a_{yN}$, with the former in the direction of the ascending node.

Any observation $0_i$ by an earth-fixed observer may be expressed in terms of these six parameters or elements describing the orbit and the time. First order differential expressions relating observation and parameter follow from the leading term in a Taylor expansion, i.e.,

$$\Delta 0_i = \sum_j \frac{\partial 0_i}{\partial X_j} \Delta X_j$$

where the $X_i$ are the six orbit parameters. Where there are $m$ observations available to define the six parameters, a set of $m$ differential expressions may be written; in matrix form, this set is

$$(\Delta 0_i) = (C_{ij}) (\Delta X_i)$$

where $(C_{ij})$ is the $m \times 6$ matrix with typical element,

$$C_{ij} = \frac{\partial 0_i}{\partial X_j}$$

The $(\Delta X_i)$ is a six component vector, and $(\Delta 0_i)$ is an $m$ component vector.

The elements of the $(C_{ij})$ matrix are the partial derivatives of the observed quantities with respect to the orbit parameters and may be determined analytically or by variant trajectory calculations, wherein the parameters are varied, one by one, and the resulting changes in the observations are noted.

If there are more observed quantities $0_i$ than parameters $X_j$, that is, when $m > 6$, the system is overdetermined and the number of equations may be reduced by the method of least squares. The solution takes the form

$$(\Delta X_j) = \left[ (C_{ij})^T (C_{ij}) \right]^{-1} (C_{ij})^T (\Delta 0_i)$$
where the -1 and T superscripts denote inverse matrix and transpose matrix, respectively. The bracketed quantity in (4) is the so-called least square matrix, N:

\[ N = (C_{ij})^T C_{ij} \]  

(5)

In the interest of achieving efficiency, the \( C_{ij} \) are evaluated from analytical expressions, which are detailed in the following section presenting the formulation of the program.

FORMULATION

The Orbit Correction Program can be conveniently divided into three parts, one concerned with the correction process, another concerned with the generation of different types of ephemerides, and, most important, that portion necessary for both, (mainly concerned with the integration of the equations of motion). These parts will be documented below in the inverse order.

VARIATIONS OF THE PARAMETERS

The major portion of the Orbit Correction Program is spent in generating position and velocity of the satellite at successive times by numerically integrating the equations of motion. This integration process is started by generating the initial values of the integrands and other quantities:

Given \( a_{xN_0}, a_{yN_0}, h_0, L_0 \) (subscript \( o \) indicates epoch), the following procedure is common to both the simulation and differential correction portions of the program:

(a) Compute Greenwich sidereal time at epoch, \( \Theta_{SK} \):
\[ e_\text{gr} \text{ (in degrees)} = D \left( \dot{\Theta} - 360^\circ \right) + \dot{\Theta} f + \Theta_\text{gr} \]

where \( D \) is epoch day number, \( f \) is the fraction of a day elapsed from start of epoch day to epoch, \( \dot{\Theta}_\text{gr} \) is Greenwich sidereal time at the beginning of epoch year, and \( \dot{\Theta} = 360^\circ/9856472 \), the rotation rate of the earth in degrees per mean solar day.

(b) Compute the semi-latus rectum:

\[ p_o = h_0 \cdot h_o \]

(c) Compute the orientation vector, \( \mathbf{W}_o \):

\[ \mathbf{W}_o = \frac{h_o}{p_o} \]

(d) Compute the orientation angles, \( i_o \), \( \omega_o \), and \( \Upsilon_o \):

\[ \sin i_o = \sqrt{1 - \frac{W_o^2}{z_o^2}} \]

\[ \cos i_o = \frac{W_o}{z_o} \]

\[ i_o = \tan^{-1} \left( \frac{\sin i_o}{\cos i_o} \right) \quad 0 \leq i_o < \pi \]

\[ \sin \Upsilon_o = \frac{\mathbf{W}_o \cdot \mathbf{v}_o}{\sin i_o} \]

\[ \cos \Upsilon_o = \frac{-W_o}{\sin i_o} \]

\[ \Upsilon_o = \tan^{-1} \left( \frac{\sin \Upsilon_o}{\cos \Upsilon_o} \right) \quad 0 \leq \Upsilon_o < 2\pi \]
\[ U_0 = L_0 + \omega_0 \text{ if } W > 0 \text{ (retrograde motion)} \]

\[ U_0 = L_0 - \omega_0 \text{ if } W < 0 \text{ (direct motion)} \]

(e) Compute the equatorial coordinates of \( a_0 \):

\[
\begin{align*}
    x_0 &= a x_0^0 \cos \delta_0 - \cos \iota_0 a y_0^0 \sin \delta_0 \\
    y_0 &= a x_0^0 \sin \delta_0 + \cos \iota_0 a y_0^0 \cos \delta_0 \\
    z_0 &= a y_0^0 \sin \iota
\end{align*}
\]

(f) Compute the eccentricity, \( e_0 \), and the semi-major axis, \( a_0 \):

\[ e_0^2 = a_x^2 + a_y^2 + a_z^2 \]

\[ a_0 = \frac{p_0}{1 - e_0^2} \]

Also common to both simulation and differential correction is the numerical integration. The equations to be integrated are of the form:

\[ \frac{dy_i}{dt} = f_i (t, y_1, y_2, \ldots, y_6, y_7) \quad i = 1, 2, \ldots, 7 \]

where the \( y_i \) equal \( a_x, a_y, a_z, h_x, h_y, h_z \), and \( L \).

The numerical integration scheme used is based on the following fourth order Runge-Kutta method:

\[ y_i^{n+1} = y_i^n + \frac{\Delta t}{6} (K_1 + 2K_2 + 2K_3 + K_4) \]

\[ K_1 = f_i (t, y_1, y_2, \ldots, y_6, y_7) \]

\[ K_2 = f_i (t + \frac{\Delta t}{2}, y_1 + \frac{K_1}{2}, y_2 + \frac{K_1}{2}, \ldots, y_6 + \frac{K_1}{2}, y_7 + \frac{K_1}{2}) \]

\[ K_3 = f_i (t + \frac{\Delta t}{2}, y_1 + \frac{K_2}{2}, y_2 + \frac{K_2}{2}, \ldots, y_6 + \frac{K_2}{2}, y_7 + \frac{K_2}{2}) \]

\[ K_4 = f_i (t + \Delta t, y_1 + K_3, y_2 + K_3, \ldots, y_6 + K_3, y_7 + K_3) \]
where \( K_1 = f_i (t^n, y_1^n, \ldots, y_7^n) \)

\[
K_2 = f_i \left( (t^n + \frac{\Delta t}{2}), y_1^n + \frac{K_{11}}{2}, \ldots, y_7^n + \frac{K_{17}}{2} \right)
\]

\[
K_3 = f_i \left( (t^n + \Delta t), y_1^n + \frac{K_{21}}{2}, \ldots, y_7^n + \frac{K_{27}}{2} \right)
\]

\[
K_4 = f_i \left( (t^n + 2\Delta t), y_1^n + K_{31}, \ldots, y_7^n + K_{37} \right)
\]

As can be seen, it is necessary to compute \( \frac{da}{dt}, \frac{dh}{dt}, \) and \( \frac{dL}{dt} \) from \( a, h, \) and \( L, \) several times at each integration step. The first step is to compute position and velocity, \( \xi, \dot{\xi} \) from \( a, h, \) and \( L. \)

Given \( a, h, \) and \( L \) at some time \( t, \) the following procedure is used to derive position, \( \xi, \) and velocity, \( \dot{\xi}. \) Note that whenever the anomalies \( v, E, \) and \( M \) are used, they appear either in a sum with \( \Omega \) or in products with the coefficient \( e. \) Thus, no indeterminacy exists for zero eccentricity. In its present form, precisely equatorial orbits cannot be integrated, since the ascending node is employed as a reference direction.

(a) Compute \( p, e, a, n: \)

\[
p = h \cdot h = h_x^2 + h_y^2 + h_z^2 \\
e^2 = a \cdot a = a_x^2 + a_y^2 + a_z^2 \\
a = \frac{p}{\sqrt{1-e^2}} \\
n = \frac{Ke\sqrt{\mu}}{a^{3/2}} \quad \text{where} \quad Ke\sqrt{\mu} = 0.07436574
\]

(b) Compute the orientation vectors \( \hat{W}, \hat{M}, \) and \( \hat{N}: \)

\[
\hat{W} = \frac{h}{\sqrt{p}} \quad \text{(note} \quad \hat{W}_z = \cos \theta) \\
\hat{M} = \frac{1 - \hat{W}_z^2}{\hat{M}_z} = \sin i \\
\hat{N} = \frac{-\hat{W}_y}{\hat{M}_z} = \cos \Omega
\]
\[ M = N \frac{W}{y} \cos \Omega \cos i \]

\[ N_y = \frac{W}{y} \frac{M}{z} = \sin \Omega \]

\[ M = -N_y \frac{W}{z} = -\sin \Omega \cos i \]

\[ N_z = 0 \]

(c) Compute the components of \( \mathbf{a} \) in the orbit plane, \( a_x N \) and \( a_y N \):

\[ a_x N = a \cdot N \]

\[ a_y N = a \cdot M \]

(d) Compute the orientation angles, \( \Omega \) and \( U \):

\[ \Omega = \tan^{-1}\left( \frac{N_y}{N_x} \right) \quad 0 \leq \Omega \leq 2\pi \]

\[ U = L + \Omega \quad \text{if } W_z < 0 \quad \text{(retrograde motion)} \]

\[ U = L - \Omega \quad \text{if } W_z > 0 \quad \text{(direct motion)} \]

(e) Solve Kepler's equation for \( E + \omega \) by iteration, using a first guess of \( U \) (mod \( 2\pi \)):

\[ E + \omega = U + a_x N \sin (E + \omega) - a_y N \cos (E + \omega) \]

(f) Compute \( r \) and \( \dot{r} \):

\[ e \cos E = a_x N \cos (E + \omega) + a_y N \sin (E + \omega) \]

\[ e \sin E = a_x N \sin (E + \omega) - a_y N \cos (E + \omega) \]

\[ r = a (1 - e \cos E) \]

\[ \dot{r} = \frac{\sqrt{a}}{r} \cdot e \sin E \]
\[
rv = \sqrt{\frac{3a}{r}} \sqrt{1 - e^2}
\]

\[
\cos u = \frac{a}{r} \left[ \cos (E + \omega) - a_N x + a_N y \left( \frac{e \sin E}{1 + \sqrt{1 - e^2}} \right) \right]
\]

\[
\sin u = \frac{a}{r} \left[ \sin (E + \omega) - a_N y - a_N x \left( \frac{e \sin E}{1 + \sqrt{1 - e^2}} \right) \right]
\]

\[
U = \cos u N + \sin u M
\]

\[
V = - \sin u N + \cos u M
\]

\[
\xi = ru
\]

\[
\dot{\xi} = \dot{ru} + rvv
\]

From the position and velocity, it is possible to compute the perturbative accelerations, specifically the bulge perturbation, \( \ddot{\xi}_B \):

\[
\ddot{x}_B = \frac{x}{r^5} J'(5U^2 - 1) + \frac{x}{r^7} \frac{H'}{7U^2 - 3}
\]

\[
+ \frac{x}{6r^7} K'(42U^2 - 63U^4 - 3) + \frac{21xU}{8r^8} J_5 a_e^5 \mu \left( \frac{5 - 30 U^2 + 33U^4}{2} \right)
\]

\[
\ddot{y}_B = \frac{y}{x} \ddot{x}_B
\]
\[ \ddot{z}_B = \frac{z}{r^5} \dot{J} \left( 5U_z^2 - 3 \right) + \frac{3}{5r^5} H' \left( \frac{25}{3} U_z^4 - 10U_z^2 + 1 \right) \]

\[ + \frac{z}{6r^7} K' \left( -63U_z^4 + 70U_z^2 - 15 \right) + \frac{3}{8r^7} J_5 a_e^{5/6} \left( -5 + 105U_z^2 \right) - 315U_z^4 + 231U_z^6 \]

where \( U_z = \frac{z}{r} \) and \( J' = 0.00162341 \)

\[ H' = -0.00006 \]

\[ K' = 0.0000909 \]

\[ J_5 a_e^{5/6} = -0.0000002 \]

At each point during the integration at which the derivatives \( dL/dt, dh/dt, da/dt \), are evaluated, the perturbative accelerations due to drag \( \ddot{x}_D, \ddot{y}_D, \ddot{z}_D \), must be evaluated and added to the bulge accelerations, \( \ddot{x}_B, \ddot{y}_B, \ddot{z}_B \), to obtain the total perturbative accelerations, \( \ddot{x}, \ddot{y}, \ddot{z} \).

Given \( r \) and \( \dot{r} \), and tabulated values of the density ratio and atmospheric molecular weight versus altitude:

(1) Compute the relative air speed vector:

\[ \gamma_x = \dot{x} + y \dot{\phi} \]

\[ \gamma_y = \dot{y} = x \dot{\phi} \]

\[ \gamma_z = \dot{z} \]
Also compute the magnitude of the relative
air speed vector

\[ \gamma = \sqrt{\gamma_x^2 + \gamma_y^2 + \gamma_z^2} \, . \]

\( \dot{\theta} \) in the above equations, is the angular rota-
tion rate of the Earth.

(2) Compute the altitude above the oblate spheroid
in Earth radii:

\[ H = r - 1 - \frac{3}{2} f^2 \left( \frac{\xi}{r} \right)^4 + \left( f + \frac{3}{2} f^2 \right) \left( \frac{\xi}{r} \right)^2, \]

where \( f \) is the flattening of the Earth = 1/298.3.

(3) Look up the density ratio \( \sigma = \sigma(H) \) and the
molecular weight \( M = M(H) \) from the tabulated
data (see Appendix C for the programmed tables),
and calculate the atmospheric density:

\[ \sigma = \rho / \rho_0 \]

where \( \rho_0 \) is the sea level value of the atmos-
pheric density = 0.001225 gm/cm\(^3\).
(4) Compute the skin temperature of the vehicle:

\[ T_s = \left[ \frac{\rho C_D (V_{Co})^3}{4 \varepsilon \sigma_s} + (300)^4 \right]^{1/4} \]

where

- \( \sigma_s \) = Stefan-Boltzmann constant = \( 5.672 \times 10^{-8} \),

and

- \( \varepsilon \) = emissivity of the satellite = .9.

(5) Compute the drag coefficient, \( C_D \), by first computing the auxiliary quantity:

\[ C = \frac{6.972 \times 10^3 \gamma d}{C_{Do} \sqrt{(N \cdot T_s)}} \]

and then

\[ C_D = C_{Do} \left( 1 + 1.1739130 \ e^{-0.07} \right) \]

\( C_{Do} \) being a reference value of the drag coefficient = 0.92.
(6) Compute the drag terms:

\[ \mathbf{x}_D = \chi_x \left[ C_D \left( \frac{1}{2} \rho \mathbf{v} \cdot \mathbf{v} \right) \right] \mathbf{F} \quad \text{for} \quad x, y, z, \]

where \( d \) is the diameter of the satellite, \( m \) is its mass, and \( K \) is a constant relating the units. The program value of \( K \) is \( 2.504742 \times 10^9 \).

Finally we are ready to calculate the integrands \( \frac{da}{dt}, \frac{dh}{dt}, \) and \( \frac{dL}{dt} \):

(a) Determine the total perturbations \( \mathbf{e}^\wedge \):

\[ \mathbf{e}^\wedge = \mathbf{e}_B^\wedge + \mathbf{e}_D^\wedge \]

(b) Compute:

\[ r \mathbf{e}^\wedge = \mathbf{e} \cdot \mathbf{e}^\wedge \]

\[ \mathbf{s} \cdot \mathbf{e}^\wedge = \mathbf{s} \cdot \mathbf{e} \]

\[ r \cdot \mathbf{e} = \mathbf{e} \cdot \mathbf{e} \]

and the auxiliary quantities:
\[ D = \frac{r \cdot \dot{r}}{\dot{\gamma}^2} \]

\[ D' = \frac{r \cdot \dot{r}'}{\dot{\gamma}^2} \]

\[ D'' = \frac{2 \hat{\epsilon} \cdot \hat{\gamma}'}{\dot{\gamma}^2} \]

(c) Compute \( n' \), \( r\theta' \), \( \lambda' \), \( \tilde{a} \), \( e\mathbf{v} \), and \( \mathbf{L} \):

\[ n' = -\frac{3}{2} \alpha \mathbf{D}' \]

\[ r\theta' = \mathbf{W} \cdot \mathbf{\dot{r}} \]

\[ \lambda' = \frac{z (r\theta')}{(1 + W)^2} \]

\[ \tilde{a} = \mathbf{D}_\mathbf{e} - \mathbf{D}_\mathbf{a} - \mathbf{D}_\mathbf{p} \]

\[ eQ = \mathbf{W} \times \tilde{a} \]

\[ -e^2 \mathbf{v} = eQ \cdot \tilde{a} \]
\[ L' = - \frac{2D'}{\sqrt{a}} - \frac{e^{2} \nu'}{1 + \sqrt{1 - e^2}} \]

(d) Compute \( \dot{h} \):

\[ \dot{h} = \frac{\mathbf{a} \times \mathbf{r}'}{r'^3} \]

(e) Compute the derivatives:

\[ \frac{dL}{dt} = k \, L' + n \]

\[ \frac{da}{dt} = k \, a' \]

\[ \frac{dh}{dt} = k \, h' \]

**EPHEMERIDES**

The word ephemeris is defined as a table of the positions of celestial bodies at regular intervals of time. As used here in reference to the Earth satellite ephemerides, the intervals of time are integration steps. The ephemerides are of three kinds.
The first type of ephemeris shows geocentric position and velocity vectors. No additional formulation is needed to produce this.

The second type of ephemeris shows the position of the satellite as latitude, longitude, and height above the geoid. This is the sub-satellite track.

The third type of ephemeris shows acquisition coordinates for a number of designated sensors. These "look angles" show the coordinates at which the satellite would appear to the station if it had started with the given boundary conditions at the epoch. These acquisition coordinates are produced for every integration step at which the satellite is above the horizon of the designated station.

a. Computation of Sub-Satellite Track:

If the option to compute a sub-satellite track consisting of latitude, \( \phi \), East longitude, \( \lambda_E \), and height above the earth, \( H \), is chosen, then these quantities are computed at each point of the ephemeris as follows:

\[
\phi = \tan^{-1} \left[ \frac{U}{\sqrt{(1-f)^2 1 - U^2}} \right] - 90^\circ \leq \phi \leq 90^\circ
\]

where \( f = \frac{1}{298.3} \) is the flattening of the Earth

\[
\lambda_E \text{ (in degrees)} = \theta - \dot{\theta} (t-t_0) - \theta_{gr} \quad \lambda_E \geq 0^\circ
\]
where $\theta = \tan^{-1} \left( \frac{\chi}{x} \right)$, $0^\circ \leq \theta < 360^\circ$

and $\dot{\theta} = 0.250 \, 684 \, 48$ is the rotation rate of the Earth in degrees per solar minute.

$H$ (in Earth radii) = $r - 1 + \left( \frac{3}{2} f^2 + f \right) \frac{U^2}{2} - \frac{3}{2} f^2 \frac{U^4}{2}$

b. Simulation of Acquisition Coordinates:

This part of the program simulates "observations" of the satellite in the orbit specified by the input parameters. Given $\phi$, the latitude of a station in degrees, $\lambda_E$, the East longitude of the station in degrees, $H$, the height of the station above sea level in meters, and $\Omega$, Greenwich Sidereal Time at the initial time, $t_0$, in degrees, the following procedure computes $D$, $f$, $A$, $h$, $\rho$, and $\dot{\varphi}$ for time $t$:

1. Convert $\phi$, $\lambda_E$, and $\Omega$ to radians and $H$ to Earth radii.

2. Compute:

   $C = (1 - \epsilon^2 \sin^2 \phi)^{-1/2}$

   where $\epsilon^2 = 2f - f^2$, $f = \frac{1}{298.3} = \text{the flattening of the Earth.}$

   $S = C \left( 1 - \epsilon^2 \right)$

3. Compute:

   $\varphi = 0.004 \, 375 \, 269 \, \left( t-t_0 \right) + \Omega + \lambda_E$

4. Compute the station vector, $R$: 

A-10
X = - (C + H) cos φ cos Θ
Y = - (C + H) cos φ sin Θ
Z = - (S + H) sin φ

(5) Compute the slant range ρ:
ρ = z + R
ρ = \sqrt{\rho^2} = \sqrt{(x + X)^2 + (y + Y)^2 + (z + Z)^2}

(6) Compute azimuth, A, and elevation angle, h, of object as "seen" from the observation station:

L_{xh} = \frac{(x+X) \cos \Theta \sin \phi + (y+Y) \sin \Theta \sin \phi - (z+Z) \cos \phi}{\rho}

L_{yh} = \frac{-(x+X) \sin \Theta + (y+Y) \cos \Theta}{\rho}

L_{zh} = \frac{(x+X) \cos \Theta \cos \phi + (y+Y) \sin \Theta \cos \phi + (z+Z) \sin \phi}{\rho}

h = \tan^{-1} \left( \frac{L_{zh}}{1-L_{zh}} \right), \quad -\pi/2 \leq h \leq \pi/2

If h < 0 (i.e., the object is below the local horizon) the output for this time is omitted.

A = \tan^{-1} \left( \frac{L_{yh}}{1-L_{xh}} \right), \quad 0 \leq A < 2\pi

The quadrant is determined from an examination of the sign of the numerator and denominator.

(7) Compute topocentric right ascension, α, and declination, δ:
\[
L = (L_x, L_y, L_z) = \frac{\overline{C}}{\rho}
\]

\[
\delta = \tan^{-1}\left(\frac{L_z}{\sqrt{L_x^2 - L_z^2}}\right) \quad -\pi/2 \leq \delta \leq \pi/2
\]

\[
\alpha = \tan^{-1}\left(\frac{L_y}{L_z}\right) \quad 0 \leq \alpha < 2\pi
\]

The quadrant is determined from sign of numerator and denominator.

(8) Compute the slant range rate, \( \dot{\rho} \):

\[
\begin{align*}
\dot{x} &= -y \dot{\theta} \\
\dot{y} &= x \dot{\theta} \\
\dot{z} &= \dot{\rho} = 0
\end{align*}
\]

\[
\dot{\rho} = \dot{x} + \dot{\rho} = L_x (\dot{x} + \dot{\rho}) + L_y (\dot{y} + \dot{\rho}) + L_z (\dot{z} + \dot{\rho})
\]

**Differential Correction of Orbital Elements:**

This part of the program relates residuals in the observations at time \( t \) to corrections to be applied to the initial orbital parameters at time \( t_o \).

The procedure calculates the orbital parameters and quantities associated with the station coordinates at the observation time. It combines these quantities to obtain the coefficients of the linear relationships relating residuals to any combination of \( \Delta a_o/a_o, \Delta a_N, \Delta a_{\dot{N}} \), \( \Delta U, \Delta \dot{U}, \Delta \dot{U} \), and represents the observations to determine the residuals. Finally, the corrections to be applied to the parameters are determined by solving the (usually overdetermined) system of linear correction equations.
a. Forming the Linear Correction Equations

Given:

1. \( \phi \), the latitude in degrees
2. \( \lambda_E \), the longitude in degrees
3. \( H \), meters above sea level
4. \( \Theta \), Greenwich Sidereal time at epoch in degrees
5. \( t \), the time of the observation in minutes, and
6. one or more observed quantities at this time,

the following will compute one line of the above-mentioned system for each observed quantity.

1. Repeat steps 1 through 4 under simulation to obtain \( \Theta \) and \( \phi \) in radians and the station vector \( \mathbf{R} \).

2. Compute the coefficients \( R \) and \( U \) where:

\[
\begin{align*}
R_u &= \left( \frac{a^2}{r} \right) e \sin E \\
R_a &= r - \frac{3}{2} (U - U_0) R_u \\
R_{xN} &= \left( \frac{a^2}{r} \right) \left[ a_{xN} \cos (E + \omega) \right] \\
R_{yN} &= \left( \frac{a^2}{r} \right) \left[ a_{yN} \sin (E + \omega) \right] \\
U_u &= \left( \frac{a^2}{r} \right) \sqrt{1 - e^2} \\
U_a &= - \frac{3}{2} (U - U_0) U_u
\end{align*}
\]
\[ U_{xN} = \frac{a^2}{r} \begin{cases} \left( 1 + \frac{e}{a} \right) \sin (E+\omega) + a_{xN} e \sin E \\ \left[ \frac{e^2 - (1 + \sqrt{1 - e^2}) e \cos E}{\sqrt{1 - e^2} (1 + \sqrt{1 - e^2})^2} - \frac{a_{yN}}{1 + \sqrt{1 - e^2}} \right] \end{cases} \]

\[ U_{yN} = \frac{a^2}{r} \begin{cases} \left( 1 + \frac{e}{a} \right) \cos (E+\omega) + a_{yN} e \sin E \\ \left[ \frac{e^2 - (1 + \sqrt{1 - e^2}) e \cos E}{\sqrt{1 - e^2} (1 + \sqrt{1 - e^2})^2} + \frac{a_{xN}}{1 + \sqrt{1 - e^2}} \right] \end{cases} \]

(3) Compute:

\[ \rho_c = \rho + \mathbf{R} \]

\[ \rho_c = \sqrt{\mathbf{R} \cdot \mathbf{R}} \]

\[ \mathbf{L}_c = \frac{\mathbf{R}}{\rho_c} \]

(4) If \( \rho \), the slant range is observed, compute

\[ \Delta \rho = \rho - \rho_c \]

Form the coefficients:

\[ C_{a} = (\mathbf{L}_c \cdot \mathbf{U}) R_a + (\mathbf{L}_c \cdot \mathbf{V}) U_a \]

\[ C_{a_{xN}} = (\mathbf{L}_c \cdot \mathbf{U}) R_{xN} + (\mathbf{L}_c \cdot \mathbf{V}) U_{xN} \]

\[ C_{a_{yN}} = (\mathbf{L}_c \cdot \mathbf{U}) R_{yN} + (\mathbf{L}_c \cdot \mathbf{V}) U_{yN} \]

\[ C_{U_c} = (\mathbf{L}_c \cdot \mathbf{U}) R_{u} + (\mathbf{L}_c \cdot \mathbf{V}) U_{u} \]
\[ c_{\Delta i} = (L_c \cdot W) r \sin u \]

Enter the following linear correction equation into the system of such equations:

\[ \Delta \rho = c_{\Delta a} \frac{\Delta a_o}{a_o} + c_{\Delta a} \Delta a_{xN} + c_{\Delta a} \Delta a_{yN} + c_{\Delta a} \Delta a_{iN} \]

\[ + c_{\Delta U} \Delta U_o + c_{\Delta U} \Delta U_o + c_{\Delta i} \Delta i_o \]

(5) If \( A \), azimuth, and \( h \), elevation angle are observed, compute:

\[
\begin{align*}
S_x &= \sin \phi \cos \Theta \\
S_y &= \sin \phi \sin \Theta \\
S_z &= -\cos \phi
\end{align*}
\]

\[
\begin{align*}
E_x &= -\sin \Theta \\
E_y &= \cos \Theta \\
E_z &= 0
\end{align*}
\]

\[
\begin{align*}
Z_x &= \cos \phi \cos \Theta \\
Z_y &= \cos \phi \sin \Theta \\
Z_z &= \sin \phi
\end{align*}
\]
\[
L_{xh} = - \cos A \cos h \\
L_{yh} = \sin A \cos h \\
L_{zh} = \sin h \\
\]
\[
A_{xh} = \sin A \\
A_{yh} = \cos A \\
A_{zh} = 0 \\
\]
\[
D_{xh} = c \cos A \sin h \\
D_{yh} = -\sin A \sin h \\
D_{zh} = \cos h \\
\]
\[
L_{\text{obs}} = L_{xh} S + L_{yh} E + L_{zh} Z \\
\sim A_{\text{obs}} = A_{xh} S + A_{yh} E + A_{zh} Z \\
\sim D_{\text{obs}} = D_{xh} S + D_{yh} E + D_{zh} Z \\
\]
Compute \( \Delta L = L_{\text{obs}} - L_{c} \)

Form the coefficients as in (4) with \( \sim A_{\text{obs}} \) replacing \( L_{c} \) and enter the following linear correction equation into the system of such equations:
Again form the coefficients as in (4), this time with \( D \) replacing \( L \), and enter the following linear correction equation into the system of such equations:

\[
\rho \frac{\Delta a}{a} \cdot \Delta L = C \frac{\Delta a}{a} + C \Delta a_x \Delta a_x \Delta N_o
\]

\[
+ C \Delta a_y \Delta a_y \Delta N_o + C \Delta U_o \Delta U_o + C \Delta i \Delta i_o
\]

(6) If \( \alpha \), topocentric right ascension, and \( \delta \), topocentric declination are observed, compute:

\[
\begin{align*}
L_x &= \cos \delta \cos \alpha \\
L_y &= \cos \delta \sin \alpha \\
L_z &= \sin \delta
\end{align*}
\]

\[
\begin{align*}
A_x &= -\sin \alpha \\
A_y &= \cos \alpha \\
A_z &= 0
\end{align*}
\]
\[
\begin{align*}
D_x &= -\sin \delta \cos \alpha \\
D_y &= -\sin \delta \sin \alpha \\
D_z &= \cos \delta
\end{align*}
\]

Compute \( \Delta L = L_{\text{obs}} - L_c \)

Form the coefficients and compute the linear correction equations as in (5), substituting \( \Delta_{\text{obs}} \) for \( \tilde{\Delta}_{\text{obs}} \) and \( D_{\text{obs}} \) for \( \tilde{D}_{\text{obs}} \)

(7) If \( \dot{\phi} \), the slant range rate, is observed, compute:

\[
\begin{align*}
\dot{x} &= -y \dot{\phi} \\
\dot{y} &= x \dot{\phi} \\
\dot{z} &= 0
\end{align*}
\]

\[
\begin{align*}
\dot{\phi}_c &= \dot{x} + \dot{y} \\
\dot{\phi}_c &= L_c \cdot \dot{\phi}_c
\end{align*}
\]

\[
\begin{align*}
ex &= a \left( e \cos E - e^2 \right) \\
cy &= a \sqrt{1 - e^2} e \sin E \\
\dot{\psi} &= \frac{e \psi}{r}
\end{align*}
\]

Compute the coefficients \( \dot{R} \) and \( \dot{U} \) where:

\[
\begin{align*}
\dot{R}_u &= \sqrt{\mu} a^{3/2} \frac{ex}{r^3} \\
\dot{R}_a &= -\frac{\dot{r}}{2} - 3/2 \left( U - U_o \right) \dot{R}_u
\end{align*}
\]
\[ \ddot{R}_{xN} = \left( \frac{a^{5/2}}{r^3} \right) \left\{ \sin (E + \omega) - a_{xN} \cos E - a_{yN} \right\} \]

\[ \ddot{R}_{yN} = \left( \frac{a^{5/2}}{r^3} \right) \left\{ - \cos (E + \omega) - a_{yN} \cos E + a_{xN} \right\} \]

\[ \ddot{U}_u = -\frac{a}{r^3} \frac{3}{2} \left( \ddot{U} - \dot{U}_0 \right) \ddot{U}_u \]

\[ \ddot{U}_{xN} = \left( \frac{a^{5/2}}{r^3} \right) \sqrt{1 - e^2} \left\{ \cos (E + \omega) - a_{xN} \left( 1 + \frac{r}{a \omega} \right) \right\} \]

\[ \ddot{U}_{yN} = \left( \frac{a^{5/2}}{r^3} \right) \sqrt{1 - e^2} \left\{ \sin (E + \omega) - a_{yN} \left( 1 + \frac{r}{a \omega} \right) \right\} \]

(8) Form the coefficients:

\[ C_{\Delta a} = (L_c \cdot U) \left[ \rho_c (\dot{R}_a - \dot{U}_a) - \dot{\rho}_c R_a \right] + (\dot{\rho}_c \cdot U) R_a \]

\[ + (L_c \cdot U) \left[ \rho_c (\ddot{U}_a + \dot{r} \ddot{U}_a) - \dot{\rho}_c U_a \right] + (\dot{\rho}_c \cdot U) U_a \]

\[ C_{\Delta a_{xN}} = (L_c \cdot U) \left[ \rho_c (\dot{R}_{xN} - \dot{U}_{xN}) - \dot{\rho}_c R_{xN} \right] + (\dot{\rho}_c \cdot U) R_{xN} \]

\[ + (L_c \cdot U) \left[ \rho_c (\ddot{U}_{xN} + \dot{r} \ddot{U}_{xN}) - \dot{\rho}_c U_{xN} \right] + (\dot{\rho}_c \cdot U) U_{xN} \]

\[ C_{\Delta a_{yN}} = (L_c \cdot U) \left[ \rho_c (\dot{R}_{yN} - \dot{U}_{yN}) - \dot{\rho}_c R_{yN} \right] + (\dot{\rho}_c \cdot U) R_{yN} \]

\[ + (L_c \cdot U) \left[ \rho_c (\ddot{U}_{yN} + \dot{r} \ddot{U}_{yN}) - \dot{\rho}_c U_{yN} \right] + (\dot{\rho}_c \cdot U) U_{yN} \]

\[ C_{\Delta U_o} = (L_c \cdot U) \left[ \rho_c (\dot{R}_u - \dot{U}_u) - \dot{\rho}_c R_u \right] + (\dot{\rho}_c \cdot U) R_u \]

\[ + (L_c \cdot U) \left[ \rho_c (\ddot{U}_u + \dot{r} \ddot{U}_u) - \dot{\rho}_c U_u \right] + (\dot{\rho}_c \cdot U) U_u \]
\[ c_{\Delta R} = (L_c \cdot W) c_{\Delta R} r \cos i + (L_c \cdot W) \cos i (p_c - \dot{p}_c) \]
\[ + (\dot{L}_c \cdot W) r \cos i + (L_c \cdot W) \sin i (p_c - \dot{p}_c) \]
\[ + \dot{p}_c r \cos u - (\dot{L}_c \cdot W) r \sin i \sin u \]

\[ c_{\Delta i} = (L_c \cdot W) [p_c (r \cos u + \dot{r} \sin u) - \dot{p}_c r \sin u] \]
\[ + (\dot{L}_c \cdot W) r \sin u \]

Compute \[ \Delta \dot{p} = \dot{\rho}_{\text{obs}} - \dot{p}_c \]

Enter the following linear correction equation into the system of such equations:
\[ \rho_c \Delta \dot{p} = \Delta a_0 \frac{a}{a_0} + \Delta a_x \Delta x_0 + \Delta a_y \Delta y_0 + \Delta a_z \Delta z_0 + \Delta U \Delta U_0 \]
\[ + C_{\Delta i} \Delta i \Delta i \]

b. Computing the Corrected \( L_c, a_x, a_y, a_z, h_x, h_y, h_z \)

Let \( \sum_{j=1}^{N} C_{ij} \Delta X_j = \Delta 0_i, i = 1, 2, 3, \ldots \) represent all of the linear correction equations (i.e., the \( C_{ij} \)'s are the coefficients, the \( \Delta X_j \)'s are the corrections to the orbital parameters at time \( t_0 \), the \( \Delta 0_i \) being corrected). The following matrix equation is solved to give the corrections, in a least squares sense, to the orbital parameters at time \( t_0 \).
\[
\begin{bmatrix}
\sum c_{i1}^2 & \sum c_{i1} c_{i2} & \cdots & \sum c_{i1} c_{iN} \\
\sum c_{i1} c_{i2} & \sum c_{i2}^2 & \cdots & \sum c_{i2} c_{iN} \\
\vdots & \vdots & \ddots & \vdots \\
\sum c_{i1} c_{iN} & \sum c_{i2} c_{iN} & \cdots & \sum c_{iN}^2
\end{bmatrix}
\begin{bmatrix}
\Delta x_1 \\
\Delta x_2 \\
\vdots \\
\Delta x_N
\end{bmatrix} =
\begin{bmatrix}
\sum c_{i1} & \Delta a_{i1} \\
\sum c_{i2} & \Delta a_{i2} \\
\vdots & \vdots \\
\sum c_{iN} & \Delta a_{iN}
\end{bmatrix}
\begin{bmatrix}
\Delta \theta_1 \\
\Delta \theta_2 \\
\vdots \\
\Delta \theta_N
\end{bmatrix}
\]

These corrections are applied as follows (a prime means that the element is a corrected element):

\[
a''_{xN} = a'_{xN} + \Delta a_{xN}
\]

\[
a''_{yN} = a'_{yN} + \Delta a_{yN}
\]

\[
a''_o = a_o (1 + \frac{\Delta a_o}{a_o})
\]

\[
\theta''_o = \theta'_o + \Delta \theta'_o
\]

\[
i''_o = i'_o + \Delta i'_o \quad 0 \leq i'_o < \pi
\]

\[
L''_o = L'_o + \Delta L_o - \Delta \theta'_o \text{ if } \cos i'_o < 0
\]

\[
L''_o = L'_o + \Delta L_o + \Delta \theta'_o \text{ if } \cos i'_o > 0
\]

\[
W''_x = \sin i'_o \sin \theta'_o
\]

\[
W''_y = -\sin i'_o \cos \theta'_o
\]

\[
W''_z = \cos i'_o
\]
\[ e'_o^2 = a'_x N'_o + a'_y N'_o \]
\[ p'_o = a'_o (1 - e'_o^2) \]
\[ h'_o = \sqrt{p'_o h'_o} \]
\[
\begin{align*}
  a'_x &= a'_x \cos i'_o \sin \beta'_o - a'_x \cos \beta'_o \\
  a'_y &= a'_y \cos i'_o \cos \beta'_o + a'_x \sin \beta'_o \\
  a'_z &= a'_y \sin i'_o
\end{align*}
\]
Changes made to preceding ephemeris computation (See Appendix B, C, D).

1. Two subroutines, LUPER and MONEF, have been incorporated into the program to account for lunar perturbations.

2. A subroutine, BELGE, has been added to account for the perturbations due to higher order harmonics in the earth's gravitational potential.

3. A subroutine PRESS accounts for perturbations due to radiation pressure.
APPENDIX B

ANALYSIS FOR INCLUSION OF HIGHER ORDER GRAVITY HARMONICS
The earth's gravitational potential is

\[ \phi = \frac{\mu}{r} \sum_{n=0}^{\infty} \sum_{m=0}^{n} \left( \frac{a_n \cos m \lambda + b_n \sin m \lambda}{r^n} \right) P_n^m (\sin \phi) \]

Here

- \( \phi \) = geocentric latitude
- \( \lambda \) = east longitude
- \( P_n^m (x) = (1-x^2)^{m/2} \frac{d^m}{dx^m} P_n (x) \)
- \( P_n (x) \) = Legendre polynomial of degree \( n \); \( P_n (1) = 1 \)
- \( r \) = geocentric radius in earth radii

Symmetry considerations give

\[ a_n^0 = a_n^1 = b_n^0 = b_n^1 = 0 \]
\[ a_0^0 = 1 \]

The potential accounted for by the original program is

\[ \frac{\mu}{r} \sum_{n=0}^{5} \frac{a_n^0}{r^n} P_n^0 (\sin \phi) \]

The remaining potential is

\[ \frac{\mu}{r} \sum_{n=0}^{\infty} \sum_{m=1}^{n} \left( \frac{a_n \cos m \lambda + b_n \sin m \lambda}{r^n} \right) P_n^m (\sin \phi) \]

The first line of this expression was added to the original potential.
APPENDIX C

ANALYSIS FOR INCLUSION OF LUNAR PERTURBATIONS
The perturbing function of the moon is

\[ R = \frac{m}{r} \left[ 1 + \left( \frac{r}{r_s} \right)^2 \left( \frac{3}{2} S^2 - \frac{1}{2} \right) \right] \]

where

- \( r \) = distance of satellite from center of earth, in earth radii
- \( r_s \) = distance of moon from center of earth in earth radii
  \[ r_s = 384,403/6,371 \]
- \( m \) = ratio of moon mass to earth mass
  \[ m = \frac{7.35}{5.97 \times 10^{-2}} \]
- \( S = u_1 v_1 + u_2 v_2 + u_3 v_3 \)

and

- \( u_1 = \cos \phi \cos \lambda \) (Satellite)
- \( u_2 = \cos \phi \sin \lambda \)
- \( u_3 = \sin \phi \)
- \( v_1 = \cos \phi \cos \lambda \) (Moon)
- \( v_2 = \cos \phi \sin \lambda \)
- \( v_3 = \sin \phi \)

The moon ephemeris is computed as described in (5). These equations have been truncated to save computer time. The effect of this truncation is minor as far as computing the perturbing acceleration. The values from the truncated version and the full - terms vary around 20 seconds of arc.
Form $\mathbf{U}_\odot$, a unit vector from satellite to sun.

$$\mathbf{U}_\odot = \cos \alpha \cos \delta \mathbf{i} + \sin \alpha \cos \delta \mathbf{j} + \sin \delta \mathbf{k}$$

where

a) right ascension of sun, $\alpha = \xi - C_{16} \sin 2\phi$
b) declination of sun, $\delta = C_{17} \sin \alpha$
c) $\xi = L_\odot + C_2 (t - t_0) + C_{15} \sin [C_2 (t - t_0) - C_{14}]$
d) $L_\odot = \text{longitude of sun at Jan } 0.0 \text{ of year of interest}$
e) $C_2 = 360.98564724$
f) $C_{14} = (\text{longitude of perigee of sun minus longitude of}$ $\text{sun at Jan } 0.0 \text{ for year of interest})$
g) $C_{15} = 2(\text{eccentricity of earth's orbit})$
h) $C_{16} = \tan^2 \text{ (mean obliquity of ecliptic + 2)}$
i) $C_{17} = \tan \text{ (mean obliquity of ecliptic)}$

Form

$$V = -\frac{A}{m} \rho \gamma \nu$$

where

$A = \text{area of satellite}$
$m = \text{mass of satellite}$
$\rho = 4.355 \times 10^{-7} \text{ earth radii/kemin}^2$
$\gamma = \text{emissivity factor of satellite}$
$\nu = \text{eclipse factor}$

If the satellite is illuminated by the Sun, the angle $I$ must be positive.
$\nu$ is 1 if $I$ positive, 0 if $I$ negative.

$$I = 180 - d - A$$

$$A = \sin^{-1} \left( \frac{R_e}{T} \right)$$
$$d = \cos^{-1} (\sin \phi \sin \phi + \cos \phi \cos \phi \cos H)$$

where: $\phi$ denotes satellite
$H = |RA - RA|$
Form

\[ \dot{x} = VU_1 \]
\[ \dot{y} = VU_2 \]
\[ \dot{z} = VU_3 \]

and add to the other perturbative accelerations.
SUBROUTINE BELGE(I, TT, W, TH, A, B, C)

DIMENSION D(3,3), P(6,6), PR(4), ALFA(6,6), BETA(6,6), T4(3), W(3)

DO (ABC) J=1, 6
DO (ABC) K=1, 6
ALFA(K,J)=0.0
BETA(K,J)=0.0
CONTINUE

ALFA(3,3)=1.836E-6
ALFA(5,3)=-.6786E-6
ALFA(5,4)=.1011E-6
ALFA(5,4)=.07425E-6
BETA(3,3)=-.9874E-6
BETA(5,2)=-.3757E-6
BETA(5,3)=.2688E-6
BETA(5,4)=.01569E-6

CT=COSF(TH)
ST=SINF(TH)
X=W(1)*CT+W(2)*ST
Y=-W(1)*ST+W(2)*CT
Z=W(3)

QMU=1.0
RSQ=T1 + Z * Z
T2=Z/SQRTF(T1)
D(1,2)=-T2* X/RSQ
D(2,2)=T2* Y/RSQ
R=SQRTF(RSQ)
F=ATANF(T2)
C=COSF(F)
T=SINF(F)
D(3,1)=SQRTF(T1)/R=Q
D(1,1)=X/R
D(2,1)=Y/R
D(3,1)=Z/R
D(4,1)=-Y/T1
D(5,1)=X/T1
D(3,3)=0.
P(1,1) = 1,
P(2,1) = T
P(1,2) = 1,
P(2,2) = 1,
DO 1 1 = 1,6
XN = -1
P(.,n) = (2*XR-1,)*F(-1,n-1)
DO 6 1 = -1,3
P(.,n) = P(.-1,n) + P(.-1,1)/XR-(Xi-1)*P(N-2,1)/XN
DO 6 M = 1,6
XN = -1
L = -1 + 1
DO 2 N = 1,6
XN = -1
P(.,n) = (2*XR-1,)*T*P(-1,1)/XN/(2*XN-1,)*X2*P(N-1,M-1)/XN
IF(N = 1,3,6
P(.,n) = P(N,1) = (XN-1,)*P(N-2,M)/XN
CONTINUE
INPUT THE COS(PHI) TO THE N TERMS
Z = 1
DO 4 M = 1,6
Z = Z + C
DO 4 N = 1,6
P(.,n) = P(N,1)
FOR P = 0 TO 6
DO 3 N = 1,4
FR(0) = 0
XL = TA(Y/Y)
IF(XL) = 7,7
XL = XL + 3.1415926543
XL = PROXY(XL)
CL = COS(XL)
SL = SINP(XL)
USR
DO 0 N = 3,6
XN = -1
U = XM
T1 = 1,
T2 = 1
DO 0 N = 1,6
T3 = (T1 - T2) + T2*SL
T2 = T1 + T2*CL
T1 = T3
XN = -1 :
FR(4) = FR(4) + (UFA(N,M)*T1+BETA(N,M)*T2)/(USR)*P(N,M)
FR(1) = FR(1) - XR/USR*(UFA(M,N)*T1+BETA(M,N)*T2)*P(N,M)
FR(3) = FR(3) - (X*ALFA(M,N)*T1+X*BETA(M,N)*T1)*P(N,M)/USR
FR(2) = FR(2) - (X*P(M,N)*T1+R(N,M+1))*ALFA(M,M)*T1+BETA(N,M)*T2)/USR
CONTINUE
FR(0) = FR(4) + (ALFA(N,M)*T1+BETA(N,M)*T2)/(USR)*P(N,M)
FR(4) = FR(1) - XR/USR*(ALFA(M,N)*T1+BETA(M,N)*T2)*P(N,M)
FR(3) = FR(3) - (X*ALFA(N,M)*T1+X*BETA(N,M)*T1)*P(N,M)/USR
FR(2) = FR(2) - (X*P(M,N)*T1+R(N,M+1))*ALFA(M,M)*T1+BETA(N,M)*T2)/USR
CALL L2
FR(0) = FR(1) + XL
FR(2) = FR(3) + CL
FR(4) = FR(4) + LL
DC M = 1,3
T4 = 1
DC M = 1,3
T4 = T4 + 1, N = N+1
E 3
A=T-(l)*CT-(l)*ST-T4(,-)*ST

RET(1)

END

SUBROUTINE FESSEL (XKAE*6) XKAE;TKAE,BEST0,BESI1,EMKAESQ

RETURN

END

EQUIVALENCE (BESI1, RES10(2))

DI.-P&51$ A(2), RES10(10), BESI1 $


XKAE:=(1(1)*R)/XKAE $

IF(XKAE=A,0)B*1.15

RTKAES=RT (XKAE)$

TEMP=XI:CON/XKAE$

DO 3 I=3,12$

TEP=TE$P+XI:CON(1)$

IF(I-1)3.2.2$

3TEP=TE$P/X:AE$

RES(1)=$(TEMP)/(RTKAES)$

TEP=XI:CON/XKAE$

DO 4 I=3,12$

TEP=TE$P+XI:CON(1)$

IF(I-1)5.6.6$

ETE=TE$P/X:AE$

CONTINUE$

RESI1(1)=(TEMP*R2PI)/RTKAES$

GO TO C$

EMKAE=EXP (-XKAE)$

XKAE=2*XKAE**2$

TEMP=XI:CONS*XKAE$

DO 10 I=3,15$

TEMP=TE$P+XI:CONS(I)$

IF(I-15)16,17$

10CONTINUE$

X1:CONS(1)=TE$P*EMKAESQ$

12BEST0(1)=TE$P*XKAE$

*NOTE THAT FESI=RESI1(-1) *

TEMP=XI:CONS*XKAE$

DO 13 I=3,15$

TEMP=TE$P+XI:CONS(I)$

IF(I-15)16,17

16TEMP=TE$P*XKAE$

CONTINUE$

17BEST1(I)=TE$P*EMKAESQ$ XKAE$

90(I)=0.0$

DO 18 I=1,8$

90(I)=90(I)-1.0$

1F RESI1(I+1)=RESI1(I)*2.0*Q(1)*XKAE+RESI1(I-1)$

RETURN

STOP TICA$"
SUBROUTINE COEFF(ARRAY, TRAP, XMERT)

END TAC

E-5
60 DO 11 I=1,13
57 TE=TER(I) / CCN
11 TE=TER(I)=TER(I) / CCN
CALC SETI(I-EX+1)S
TE=TER(I)=(COST-ARAY(1)+SINT*ARAY(2))/CCN
I=I+1
TE=TER(I)=(SINT-ARAY(1)+COST*ARAY(2))/CCN
I=I+1
TER=TER(I)/CCN
GO TO TSTORS

* RAMP-RATE OBSERVATION
COORD RHONT=U0.0
DO10 I=1,13
RHONT(I+1)=XDOT(I)+STO(I+7)
10 RHONT=ARAY(I) * RHONT(I+1) + RHODT
EXO=A*(E0SE+ESQ-1)
E0Y=A*RTES*ESINES
VDOT=VCOT/R
RS0R=R*R
RCUFE=5GR*RS
XMAX32=GR=A*(5RT(A(1)))
BARF=X-M32*AR/RCUBES
RC2=ROOT/2.0*UMU0*RTUS
RDTYNS=BARF*(SI:EO-AXNI*ESIN-EYNI)
RDTYNS=BARF*(-C0S0-Aryn*Esine+Axni)
UDULT=1.0*UMU32*EYOM/RCUBES
UDORTA=+VDT/2.0*UMU0*UDOTU
UDOTN=BARF*RTES*(C0S0-AXNI*BLECH)
UDOTN=BARF*RTES*(C0S0-AXNI*BLECH)
DO 11 I=1,13
21 RDOTU(I) = 0.0
DO 22 I=1,13
RDOTV=^RDOT(I+1)UX(I)+RDOTU
RDOTV=RDOT(V+1)*VX(I)+RDOTU
22 RDOTV = RDOT(I+1) *, VX(I) + RDOTU
I=I+1
CLOOP=PUPCRH*C(RDOT)(J)=VDT*USUBA(J)/RHDOT*RSUBA(J)
GLUR=RH*C*(UDOT)(J)/(RDOT*USUBA(J))/RHDOT*RSUBA(J)
TER=TER(I)=ADOTU+PUC+RECTU*RSUBA(J)+RDOTV*GLUR+RDOTV*USUBA(J)
I=I+1
DO 70 K=1,6
70 RDOTX(I)=AT.C*TW*(RHDOT*(HVDOT*C0S0-ADOTV*C0S0)-RH0FT*C0S0)
I=I+1
RESID = RESID * 7.0N5
DO 70 K=1,6
70 RDOTX(I)=AT.C*TW*(RHDOT*(HVDOT*C0S0-ADOTV*C0S0)-RH0FT*C0S0)
I=I+1
4  \( R = \arctan(C\Delta S/C\Delta A) \)
\( P = R + \pi \)
5  IF(G05) 7, 8, 9
6  \( R = R + \pi \)
7  \( \text{DEC} = \arctan F(S'/S'RTF(1-S'D'SD)) \)
8  RETURN

EMI:
SUN ROUTINE: PRESS(IXYR, X, TrG, XN, XY, VV, U1, U2, U3)
DI = FNSINL(x(3))
TABLEDEF SU'L(4), C14(4), C15(4), C16(4), C17(4)
C1 = .965472
P1 = 456 = 6
P2 = 1.0641764
P3 = 1.414592653
HR = 0.6
IF(IYR = 6) 10, 11, 12

10  I = 1
11  I = 2
12  IF(IYR = 7) 100, 101, 100
101  I = 3
13  SOL = SU'L(I) + C1*T + C15(I)*SINF(C1*T = C14(I))
RA = SOL - 16(I)*SINF(SOL + SOL)
DEC = C16(I)*SinF(RA)
CRA = COSF(RA)
CDEC = COSF(DEC)
SR = SINF(RA)
CSTEC = SINF(DEC)
U1 = CRA*CDEC + U2 = SRACDEC + U3 = CDEC
R1 = SRTT(1+X(1)*X(1)+X(2)*X(2)+X(3)*X(3))
V1 = X(1)/R1, V2 = X(2)/R1, V3 = X(3)/R1
TT = U1*V1 + U2*V2 + U3*V3
IF(TT) 1, 2
1  IF(ARSF(TT) - 500*TF(R1*R1-1), R1) 2, 3, 3
2  V = 1.0
3  V = 0.0
4  XSFCT = 1*0*PI/4
VV = XSFCT*X*PI*V*HRK
100  RETURN

START TAC
SU'L
F/4.371=48558
F/4.66542762
F/4.1621843
F/U, 0
F/U, 0
C14
F/3.5657282
F/3.33433592
F/0.652E14
C14 FOR 1964
F/0.0
F/U, 0
C15
F/3.334502
F/3.34314
F/3.3484
C15 FOR 1964
F/0.0
F/U, 0
C16
F/0.435E05
F/0.43
F/0.21
C16 FOR 1964
F/U, 0
F/U, 0
4 \begin{align*}
R &= \text{ATANF}(\text{CDSA/CCCA}) \\
&= R + \pi \\
&= \text{DEC} = \text{ATA} F(SF/S\text{RTF}(1.50 \cdot SD*SC)) \\
&= \text{RETURN }
\end{align*}

5 \begin{align*}
\text{EM: (P)} \\
&= \text{SFOUT}(\text{P}) \\
&= \text{PRESS}(\text{IXYR} \times \text{Tr}(\text{Tr} \times \text{VV} \times \text{U}1 \times \text{U}2 \times \text{U}3) \times \\
&= \text{TABLEDEF} \text{SU' L}(4), \text{C14(4)}, \text{C15(4)}, \text{C16(4)}, \text{C17(4)} \\
&= \text{C1} = 1.24 \times 10^{47} \\
&= \text{PI} = 4.56 \times 10^{-6} \\
&= \text{P2} = 1.0 \times 10^{14} \\
&= \text{PI} = 3.14 \times 9.2653 \\
&= \text{HRK} = 0.0 \\
&= \text{IF}(\text{IXYR} = 6) 10, 11, 12 \\
&= \text{I} = 1 \quad 10 \text{ TO} 13$ \\
&= \text{I} = 2 \quad 10 \text{ TO} 13$ \\
&= \text{IF}(\text{IXYR} = 7) 10, 11, 12 \\
&= \text{I} = 3 \quad 10 \text{ TO} 13$ \\
&= \text{SOL} = \text{SU' L}(I) + \text{C1T} + \text{C1F}(I) * \text{SINF}(\text{C1T} - \text{C14}(I)) \\
&= \text{RA} = \text{SOL} - 1.6(1) * \text{SINF}(\text{SOL} + \text{SOL}) \\
&= \text{DEC} = \text{ATANF}(\text{P} * \text{C17}(I) * \text{SINF}(\text{RA})) \\
&= \text{CRA} = \text{COSF}(\text{RA}) * \text{CDEC} = \text{COSF}(\text{DEC}) \\
&= \text{SRA} = \text{SINF}(\text{RA}) * \text{SDEC} = \text{SINF}(\text{DEC}) \\
&= \text{SRA} = \text{CDEC} = \text{U}2 = \text{SRA} * \text{CDECU3} = \text{CDEC} \\
&= \text{RI} = \text{SRTF}(\text{X}(1) * \text{X}(2) * \text{X}(3) * \text{X}(3)) \\
&= \text{V1} = \text{X}(1) / \text{RI} \times \text{V2} = \text{X}(2) / \text{RI} \times \text{V3} = \text{X}(3) / \text{RI} \\
&= \text{TT} = \text{U1} * \text{V1} + \text{U2} * \text{V2} + \text{U3} * \text{V3} \\
&= \text{IF}(\text{TT}) 1, 2 \\
&= \text{IF}(\text{ARSF}(\text{TT}) - \text{SOF}(\text{RI} * \text{RI} - 1, 1) / \text{RI} 2, 3, 3 \\
&= \text{V} = 1.0 \\
&= \text{GO TO} 4 \\
&= \text{V} = 0.0 \\
&= \text{GO TO} 10 \\
&= \text{XSFC/(U1 \times \text{PI} / 4.05) \\
&= \text{VV} = \text{XSECT} / \text{X} * \text{PI} * \text{V} * \text{HRK} \\
&= \text{RETURN }
\end{align*}

6 \begin{align*}
\text{SU' L} \\
&= \text{F} / 4, 57.48558 \\
&= \text{F} / 4, 66.542762 \\
&= \text{F} / 4, 629.0443 \\
&= \text{F} / 0.0 \\
&= \text{F} / 0.0 \\
&= \text{C1E} \\
&= \text{F} / 0.05567262 \\
&= \text{F} / 0.04433352 \\
&= \text{F} / 0.65214 \\
&= \text{C1 F} \\
&= \text{F} / 0.0334502 \\
&= \text{F} / 0.033414 \\
&= \text{F} / 0.0334484 \\
&= \text{C1 F} \\
&= \text{F} / 0.0 \\
&= \text{F} / 0.0 \\
&= \text{C1A} \\
&= \text{F} / 0.03436335 \\
&= \text{F} / 0.0343502 \\
&= \text{F} / 0.034314 \\
&= \text{F} / 0.0343484 \\
&= \text{C1 A} \\
&= \text{F} / 0.0 \\
&= \text{F} / 0.0 \\
&= \text{F} / 0.0
RFAD READ INPUT TAPE NOCR, ENDER, SATEL, ITYPE, STAI, IY, MONTH, DD, HH, XM, SI, HARAY $  
OCR FOR AT (A2, A3, I1, 4X, 4X, I1, I2, 3F2, 0, F6, 4, A3, 6A8) $  
  ALPHA = 0.0, DELTA = 0.0, RCTO = 0.0, RANGE = 0.0, $  
  DO 10 I = 1, 4$  
1:  ASIG1(I) = 0.0$  
  IF (I GT 4) E (HEHE) NCAP = 26 RETURN$  
NCAP = 1$  
  IF (ITY = 4) RCF, 3A, RCFD2A $ JUP IF FASE FREQ$  
RCFD2A DAYN = TMOTO(ONTH) + DD$  
  ST, T = C$  
  CH:CK FOR LEAP YEAR$  
  TW = HARAY$  
  SR = 00$  
  TA = HARAY$  
  INCTL IY$  
  TW = IY$
Yjr. J, I-

"ART

LFrP Y

\( \text{IF} ( \text{IN} \times \text{TH} + 1, \text{YNC}=\text{DAY}+0+1) \), \text{LEAP} \text{ YEAR}

\( \text{UT1} = \text{AN} \times \text{H} + \text{m} \times \text{N} + \text{SI/AN}, \text{S} \), \text{GET 0's TIME IN MINUTES}

\( \text{IF} ( \text{IT} \times -2) \), \text{CH1, RRD1, RRD4 S}

\( \text{STR T ICC} \), \text{APR = 40h}

P \times \text{AP} \times \text{E} \times \text{T} \times \text{I} \times \text{E} \times \text{H}

* \text{RCN=3 ARE IN Emitted FREQUENCY, JUMPS TO READ NEXT CARD}

\( \text{RRD3} \), \text{TM} \times \text{A} \times 6/1747 \times \text{S}

\( \text{ET} = \text{HARAY} + 7 \times \text{S}

\( \text{TM}_n \), \text{HARAY} + \text{S}

\( \text{JMP} \), \text{FLTFLT, FLTFLT}

\( \text{TA} = \text{EFREG1} \times \text{S}

\( \text{JMP} \), \text{REAL S}

\( \text{END TAC} \times \text{S}

* \text{OC=1 READS IN RANGE AND STD. DEV OF RANGE FOR RADAR OBSERVATION}

\( \text{CH=1} \), \text{IF} ( \text{IRD1} \times \text{HD1} \times \text{HD2} \times \text{S}

\( \text{WRITE OUTPUT TYPE 5, HD1, HD2} \times \text{S}

\( \text{Hi=2 FOR AT(2H2U,3HSTA,6X,4HTIME,5X,10HRANGE=E.R.,3X,5HSIGMA)} \times \text{S}

\( \text{IRD1} = 1 \times \text{S}

\( \text{I0H1=0)} \times \text{S}

\( \text{IDH1=0)} \times \text{S}

\( \text{Hi= CONTINUE} \times \text{S}

\( \text{START TAC} \times \text{S}

\( \text{TM} \times 36/1747 \times \text{S}

\( \text{ET} = \text{HARAY} + 7 \times \text{S}

\( \text{TA} = \text{HARAY} + 17 \times \text{S}

\( \text{TM}_n \), \text{HARAY} + \text{S}

\( \text{JMP} \), \text{FLTFLT, FLTFLT}

\( \text{FD} = \text{XMFS} \times \text{S}

\( \text{TO= RANGES} \), \text{RANGE IN EARTH RADIUS}

\( \text{JMP} \), \text{INLFX5, GET L(AS1G) TO IR4}

\( \text{CA} \times \text{S}

\( \text{TM} \times \text{HARAY} + \text{S}

\( \text{SLA} \times 6 \times \text{S}

\( \text{SLA} \times 6 \times \text{S}

\( \text{AV} \times 0/3747 \times \text{S}

\( \text{SRA} \times 36 \times \text{S}

\( \text{JMP} \), \text{FLTFLT, FLTFLT S}

\( \text{FA} \times \text{XMPER} \times \text{S}

\( \text{TA} \times 4 \times \text{S}

\( \text{END TAC} \times \text{S}

\( \text{WRITE OUTPUT TYPE 5, R0H1, STAID, UTILE, RANGE, AS1G1, (1)} \times \text{S}

\( \text{R=1 FOR AT(3H2U,4X,5X,1F,2,3X,1E12,6,3X,4F,2X)} \times \text{S}

\( \text{START TAC} \times \text{S}

\( \text{JMP} \), \text{RTI S}

\( \text{END EX} \times \text{S}

\( \text{TM} \times (P)+\text{FH} \times \text{S}

\( \text{CD4} \times \text{S}

\( \text{TXLC} \times 04 \times \text{S}

\( \text{TD} \times \text{SAV S}

\( \text{TM} \times \text{AS1-1 S}

\( \text{TOXLC} \times 04 \times \text{S}

\( \text{JMP} \), \text{2S}

\( \text{END TAC} \times \text{S}

\( \text{R=0 D} \times \text{2 IF} (10H1=HD1, HD2, HD4 S}

\( \text{WRITE OUTPUT TYPE 5, HD, 4 S}

\( \text{HCT4} \), \text{FOR AT(2H2U,3HSTA,6X,4HTIME,5X,9HAP=2,4X,19HDELTA,5EG,4X, 9S1G=ALPHA,3X,9S1G=DELTA,3X,9HDEL 1=AZ) S}

E-16
CA  \* CONVERT INS TO DEGS

JMP  FLTFLT.FXFLT
FM  \* D/6
TE  \* DELTA
TM  \* 11
CA  \* DELTA
JMP  FLTFLT.FXFLT
TA  \* D1 $
TM  \* FLTFLT.$SIGM $
AJ  \* (P)+4H $
TM  \* D1 $
FS  \* DELTA $
JMP  \* (P)+3H $
TM  \* D1 $
FA  \* DELTA $
TMA  \* HARAY+$
SLA  \* 12$ GET 0:59-62
SR  \* 24
SR  \* 12
SLA  \* 6
AM  \* 0/33T47
SR  \* 36
JMP  FLTFLT.FXFLT
CM  \* HARAY+$
TA  \* HARAY+$
TMA  \* HARAY+$
JMP  INDEX $
TAM  \* 2+4S
TM  \* 12/1T47S
ETA  \* HARAY+$
TMC  \* HARAY+$
SLA  \* 6
AM  \* 0/33T47
SR  \* 36
JMP  FLTFLT.FXFLT
TA  \* 3+4S
END TAC $

WRITE OUTPUT TYPE 5,0081,STAI,TIME,ALPHA,DELTA,ASIG1(3),ASIG1(4),\*UTH $
E: 1 FOR AT(2H2,4,3X,F10,6,3X,F11,6,5X,F5,2,8X,F5,2,  
R,X,11) $
OO(CU) i=3,4 $  
CV ASIG1(T)=ASIG1(I)*.000005 $ CONVERT SIGMA TO RADIANS
START TAC $
JMP  RTV $
RCPD4  IF(IDH().HD3,HD4,HD3 $)
H04 WRITE OUTPUT TAPE 5,HD03 $
H03 FOR AT(H2O,3HSTA,HY,4+TIME,EX,10HREF, = CPS,4X,5HSIGMA) $
IDH: =19 $,
IO: =0 $,
IRH: =0 $,
HI: =0 $,
CONTINUE $,
START TAC$, TAC: 6/1T47 $,
ETA: HAY+1 $,
TM: HAY+2 $,
JMP FLTFLT,FXFLT
TAK: 01
FAR: F/100.EP $,
TA: 01+1 $,
FDA: F/100. $,
TGI: 02 $,
TMA: 01 $,
FSW: EFREG1 $,
FD4: 01+1 $,
FMAP: F/37922.43
TAK: ROOT0
JMP INDEX $,
AIY: 1.5 $,
OCF12 CA $,
TM: HAY+2 $,
SLAC: 6,
SLA: 6,
AM: 0/33747
AM: 0/33747
JMP FLTFLT,FXFLT
TAK: 45 $,
END TAC $,
WRITE OUTPUT TAPE 5,DOB1,STATID,UTIME,D2,ASIG1(2) $,
DOF1 FORMAT(2H2O*W4,3X,F9.2*3X,F12.2*3X,F4.2) $,
START TAC$,
RTN: TMD SAV1 $,
TDXLC 0.4 $,
END AFEND
END TAC $,
RETURN $,
END $,
SURROUTINE RCTFY(X+PER,ESINE,ECOSE,A,WX,DRGC0,RKSTO,XN,XMZ,A/YNI,
UZ,$)
$,
$,
SURROUTINE RCTFY APPLIES THE CORRECTIONS FOR ATMOSPHERIC DRAG
* DURING THE INTEGRATION OF THE EPHEMERIS
* IT IS CALLED ONCE PER REVOLUTION BY CNTRL, INTEGRATION CONTROL
EQUVALENC (BES11, BES10(2) ) $,
DI+FANSION R(KST0(79),R(ES10(10),R(ESE1(1),wx(3),A(2),G(2) $,
START TAC $,
P PI F/3,141592653 $,
P XNE F/0.707458284
END TAC $,
ECCEN=TAN (ESINE/ECOSE) $,
IF(FCCF: 1,2$,$
1 ECCEN=F.ECCEN
2 XW=FANA=ECCF*ESINE*TYPI=X*FANA/WX $,
ESF=RKST-(N)*+R(KST0(7)+2*R(KST0(6)+2 $,
ESF=RT: S$.)$
CALL R-CFL(2K, 2AG, KAE, KAE, FSA, FESI, FESI, FESI, FESI) $ 
CALL A-RGG(ES*, EG, 0PC, 0PC, RAC, RAC, RAC, RAC, RAC, RAC, RAC) $ 
AP = AG = AG = AG = AG = AG = AG = AG = AG $ 
DO I = 1, 11 $ 
4 RKSTO(I) = 10(I-8) * PDFAG $ 
RETR-0$ 
WRITE OUT READER (STARC, ISTMNT, ISTMNT, IASM, IDBUF, XMPER) $ 
D1 ENSION STA-C(1000), IDBUF(10) $ 
TARLEDE = ATRG(4) $ 
* READ STATION CARDS FROM TAPE '10 $ 
* STORE ST TID'S INFO IN & WORD GROUPS IN STARC BUFFER $ 
* ASSIGN INTERNAL DATUM NUMBERS AND STORE EXTERNAL DATUM NUMBERS $ 
* IN TRAP TABLE $ 
ISTC T = 0$ REWIND 10 $ 
WRITE OUTPUT TAPE 5*SC1 $ 
SC1 FOR AT(1:000) INPUT DATA = STATION CARDS/ $ 
WRITE OUTPUT TAPE 5*SC2 $ 
SC2 FOR AT(1:200) 3HSTA*3X, FJ-LATITUDE, 4X, 9LONITUDE, 4X, 9HELEVATION, 
4X, 8DUTY, 12X, 19HOPSERVATION SIGMAS $ 
WRITE OUTPUT TAPE 5*SC3 $ 
SC3 FOR AT(1:200) 5X, 30HAPRANGE RATE RA-AZ DEC-EL $ 
KN. 1 J = ISTMNT + 9 + 1$ READ NEXT STATION CARD $ 
KE=+ $ 
READ INPUT TAPE 10, KN. (STARC(I), I = J K) $ 
KN. FOR AT(4, 8F, 5F, 9F, 6F, 5X F14, 1X, 14F, 83F) $ 
IF (STARC(J)) = (STARC(J)) = Hi; DO TO 2 $ 
WRITE OUTPUT TAPE 5*SC3 (STARC(I), I = J K) $ 
S3 FOR AT(1:200) 5X, 41X, 5X, 4X, 4X, 4X, 4X, 4X, 4X, 4X $ 
LIMIT $ 
M = 1$ REPLACE SIGMAS THAT 
DO ON I = L+K $ 
WERE NOT GIVE $ 
IF (STARC(J)) 20, 10, 20 $ WITH STANDARD VALUES $ 
10 STARC(I) = ATRG(M) $ 
M = M + 1 $ 
STARC(J+1) = STARC(J+1) * 1745329251 $ COV ERT LAT AND LONG TO 
STARC(J+2) = VR, (STARC(J+2) = 1745329251) $ 
RADIANS $ 
STARC(J+3) = STA-C(J+3) / XMPER $ 
STARC(J+4) = STA-C(J+4) / XMPER $ 
ISTMNT = ISTC T + 0$ FORM STATION COUNT IN ISTCNT $ 
GO TO 1 $ 
GO GET NEXT STATION CARD $ 
START TAK $ 
P = FRA 
WHIDOE 1 $ 
END TAK TX:LC * INC IRES THIS EXTERNAL DATUM NO. ALREADY IN TABLE $ 
TDA $ REPLACE STARC ENTRY & INTERNAL DATUM NO. $ 
SM IDBUF $ 
AFF. 72 $ 

E-20
TMA  INSTARC
JMP  NEXT

ASIG  F/10,0  $  KEYS - RANGE  SIGMA
      F/10,0  &  C/CL'S  PER  SECOND
      F/10,0,001  &  RATS
      F/0,0001  &  P.  RATS
      SA-F  INSTARC+3
      SA-F  INC  F,++

TYL  CD$.
      TXLC  ?
      TXFLC  ?
      TD:  SA-F
      TM:  ISTCNT
      SLA  X
      AM  ISTCINT
      TM:  STARC$.
      TDXLC  INSTARC
      AXN  4*INSTARC$.
      CD$.
      TXLC  0*INSTARC$
      AD$.
      AM  C/HLT,RC/JMP,TEST$.
      TAP  DONEKEYS  C/HLT,STARC+4+9*ISTCINTRC/JMP,TEST$.
      TM:  28/127298/1T47
      ETM  SEARCH
      TD:  SEARCH

TEST  TMA  #INSTARC
      JA?  NEXT$  IGNORE  STARC  ENTRY  IF  DATUM  NO.  ZERO
      TM:  IDLE$.
      TDXLC  0*INCURS0 = "ADDR  OF  DATUM  NO.  TABLE"
      RSEARCH  RPTAN  0$  IS  THIS  DATUM  NO.  ALREADY  IN  TABLE?
      TM:  1,INCURS
      JAEM  FOUND$  YES -
      NTFOUND$  INCURS$  SEARCH+$  NO.  -  FORM  NEW  INTERNAL  DATUM  NO.
      TM:  0/77777739
      ETM  SEARCH
      SC.$  24$  REPLACE  DATUM  NO.  IN  STARC  TABLE
      TDA  #INSTARC$  W.  INTERNAL  DATUM  NO.
      TAN  #INCURS  EXT.  DATUM  NO.  TO  DATUM  NO.  TABLE
      NFYT  TM:  DONEKEY
      AXN  4*STARC$.
      *  GO  TO  **TEST**  IF  MORE  DATA  IN  STARC  ARRAY
      FI:II  TAN  12/1239  END  OF  STARC  TABLE.
      ETM  SEARCH+$  STORE  SIZE  OF  DATUM  NO.  TABLE
      SC.$  24$  IN  IASIZE
      TDA  IASIZE.
      TDA
      SLA  1
      AD
      AM  F/6-15
      TAN  ISTCINT =  3  *  IASIZE  +  b
      TM:  SA-F
      TDXLC  ?
      TADFC  *
      TADFB  *
      E:  END
      EM:  TAC
      ATM  RETURN
      E:  =
      SI:  OUTNE  E=I(C.TAC,STARC,I-ED,CAFM)$
      DM  E=STARC (1-10)  :  C:TAC (27)  &
      RE:  I=LT  TAPE  10,10,10;T:14(2)$,  STARC(1),STARC(4),STARC(5)  =
FOR AT(4) $ 
IF (XLO) CCR5 $ CCR4 $ CCR3 $ CARD 4 $ 
OUT1(2)=XLO, OUT1(3)=AX(1), OUT1(4)=AX(2) $ 
OUT1(5)=HX(1) $ OUT1(6)=HX(2) $ OUT1(7)=HX(3) $ 
TEF= IN(T1), OUT(3)=AXN(1) **2) $ 
TF= P=(1+HX(2)+HX(3)) * 0.1745329 $ 
TF= 360*RA31RA53 $ 
CL2X IF (SXY(T)): GO TO CL1 $ 
XLO=TEMP $ 
GO TO CL21 $ 
CL1 TE= P=TF GE-TEM3 $ 
GO TO CL21 $ 
CL21 HX(2)= AX(2) * 0.1745329 $ 
HX(3)= AX(3) * 0.1745329 $ 
AXN(2)= AXN(2) * 0.1745329 $ 
CL2X TE= T= XN(1) * COS(HX(2)) $ 
TE= T= XN(1) * SIN(HX(2)) $ 
TF= TEM1 * SIN(HX(3)) * SIN(XN(2)) $ 
TF= COC(3) $ 
TF= T= AX(1) $ 
TE= T= IF (XLO) TF= IN(T1) $ 
TF= T= P= TF1 * COS(HX(2)) $ 
AX(1)= AX(2) = TEM4 $ 
HX(1)= TEM1 * XN(1) * TF 75 * X(2) = TF $ 
OUT(1) = XLO, CUTC(2) = AX(1), CUTC(3) = AXN(2) $ 
OUT(4) = HX(1) + CUTC(5) = HX(2) + OUT(6) = HX(3) $ 

HE = I = "UT TAP-19, CCER2, IP, TICL, GF, 6CA, C87NM, CT, TW (1), CNT (4),
EFL (6), STSG (1), REF (1), EFTa, IC, EN, IVY, ABSE, X1STSG (1), I = 2, 9,
AP
CUT 2
FOR AT (1) = F (1), = 0, 1, I = F1, (1), E20, F40, F90, = 1, I = FF, m,
HE = m, "1. %
OUT (11) = REF + / GET / 14, 0, 0
GREAT/ I = 10, TRIG F1 =
T/P/GF FOR AT (1) = 71, PR, 4, GET PREDICTIC AN-1 STATION LOCATE PROGRAM/
/
IF (CAT (1) = (1) = 6, GC TO T/PAGE7, %
WRITE OUTPUT T/P, = TRIG F1 =
T/PAGE7 = 10, T/PAGE8 = 10
T/PAGE8 WRITE OUTPUT T/P, T/PAGE E, %
T/P/GF FOR AT (1) = 71, 36, 27, DIFFERENTIAL CORRECTION RUN, %
T/PAGE8 WRITE OUTPUT T/P, T/PAGE E, %
T/PAGE E FOR AT (1) = 11, INPUT DATA, %
WRITE OUTPUT T/P, T/PAGE7, OUT (1, 1 = 12, Out(1), %
T/P/GF FOR AT (1) = 71, 36, 27, DIFFERENTIAL CORRECTION RUN, %
T/PAGE8 WRITE OUTPUT T/P, T/PAGE E, %
T/PAGE E FOR AT (1) = 71, 36, 27, DIFFERENTIAL CORRECTION RUN, %
RETURN
START TAC =

PLK K
W/1000000 =
END TAC =
EN =
FUNCTION CALH (13) = (12), XMPER =% G
COMPUTE HEIGHT IN T/P, AARC, OBIE, HERT
U2S = (2) =
CALH = XMPER = F = F2 = (2), 3S5Q = 2 = (F1 - 1) + P
RETURN
START TAC =

* EARTH FLATTEMI = CONST.

P F = F/168777364 = 3/2, * F**2
P F = F/336997364/2 F + 3/2, + F**2
PA =
EN TAC =
EN =
SUB: OUT WE TRIG T(I1, = SIGMA, XMP, X8K14, A10) =
TARGED = 60000E(132)
I =
IF ("KH" = F(13)) = 1, F =
100 = I = 139, 3
UE =
IF ("KH" = F()) = 3, 3 =
CO = "1 =
R = TIP =
L

LT

L

LT

L

LT

L

 LT

K

TF

LTP

IT

P

F. ru

I

I

F.

(14 10. ALT I: DE CF 124)

ST

T

C/LT,

ABCD

C/-LT

45

JMF

AF

RU

JT

JMF

AF

LA

CD

A/ALTIT DE TELU. Ru000 METERs $

ENNTAC

FH0-H1=HSGME(J)+HSGME(J-1)$

H2=HSGME(J)+hF

SIGMA=h-MH+HSGF(J-1)$

HMH1=H-MH+HSGF(J-3)$

SIGMA=SIGMA+(Hh1)*(HSGME(J+1))$

SIGMA=SIGMA/H2.H1S

XME=H2+HSGME(J-1)$

XMXGE=(MH1*HSGME(J+2)+XME)/H2.H1S

RATIO=EXP (SIGMA)$

IJ=1

RETURN

ST aN T TAC5

HSGME

F/50.0E™$

F/-7.0G40587

F/.13171F-02$

F/55.0E™$

F/-7.6022315$

F/.128756E-2$

F/40.0E™$

F/-A.1D3223$

F/.118625E-02$

F/.65.0E™$

F/-A.751657$

F/.108476E-02$

F/71.0E™$

F/-E.4134943$

F/.9318994-3$

F/75.0E™$

F/-10.13371$

F/.9135E-3$

F/80.0E™$

F/-10.54445$

F/.7795E-3$

F/55.0E™$

F/-11.49228$

F/.942E-3$

F/30.0E™$

F/-2.39875$

F/.7116E-3$

F/0C.0E™$

F/-14.97167$

F/.111E-3$

F/1O4.0E-3$

F/-15.357$

F/.7465E-3$

F/1.5E.3$

F/-1E.11O4$

F/.1O5H-2$

F/110.0E-3$

F/-16.3617$

F/.13635E-2$

E-24
F = 22, 23, 24, 25,
F = G, H
F = 3
F = \text{none}
F = \text{none}
F = 7
F = \text{none}
F = 0
F = \text{none}
F = 1
F = 2
F = \text{none}
F = 177
F = 45
F = 30
F = 100
F = 1
F = \text{none}
F = \text{none}
F = 23, 27, 28
F = 113
F = 16
F = 123
F = 100
F = 27
F = 100
F = 133
F = 100
F = 23
F = 100
F = 30
F = 23
F = 51
F = 21
F = \text{none}
END TAC
END
SUPPORT TAC
XEL(XEL1, X1, X2, X3, X4, X5, X6)
U1 = 1
XEL(XEL1)
A = XEL1
B = XEL1
C = XEL1
E = XEL1
F = XEL1
RAN = 0.0453, 0.252
P = 1.0 + E * E + F * F
ES = A * E + r * E + C * C
A = (1 - E) * ES
EX = \text{SORT} (ES)
X = (1 - F) * F
Y = (1 - T) * T
Z = (1 - F) * F
X1 = X1 + Z
X2 = X2 + X1
X3 = X3
X4 = X4
X5 = X5
X6 = X6
AX = A * X
AY = A * Y
X = X + X
X1 = X1 + 1
X2 = X2
X3 = X3
X4 = X4
X5 = X5
X6 = X6
AX = A * X
AY = A * Y
X = X + X
IF(A = 0) $\Rightarrow$ Go To 1

1: $X = X_1 + X_4 \times X_6 \times X_5$

2: $Y = Y_1 + Y_2 \times Y_3$

3: $Z = Z_1 + Z_2 \times Z_3$

4: $W = W_1 + W_2 \times W_3$

5: $V = V_1 + V_2 \times V_3$

6: $U = U_1 + U_2 \times U_3$

7: $T = T_1 + T_2 \times T_3$

8: $S = S_1 + S_2 \times S_3$

9: $R = R_1 + R_2 \times R_3$

10: $Q = Q_1 + Q_2 \times Q_3$

11: $P = P_1 + P_2 \times P_3$

12: $N = N_1 + N_2 \times N_3$

13: $M = M_1 + M_2 \times M_3$

14: $L = L_1 + L_2 \times L_3$

15: $K = K_1 + K_2 \times K_3$

16: $J = J_1 + J_2 \times J_3$

17: $I = I_1 + I_2 \times I_3$

18: $H = H_1 + H_2 \times H_3$

19: $G = G_1 + G_2 \times G_3$

20: $F = F_1 + F_2 \times F_3$

21: $E = E_1 + E_2 \times E_3$

GO TO 2

RETURN
AY = A + X*A + Y*A2 + X*A2*Y + A2*Y 2
IF(X = (X) + 3) GOTO 7
XNO = PI + ATN (XNY/XNX) GOTO 7

XNO' = PR + PI + XNOD(F(I))
GOTO 7

XNO' = AN (XNY/XNX) GOTO 7

U = RKSTO (5) - XNO' * SIG: F (1, 1.7) GOTO 7

IF (SE = SF LIGHT 1) 13, 12 $7

12U0(1) = 1

1 SENSE LIGHT 1 $7

U0(7) = U $7

! SOLVE KEPLERS EQUATION FOR E + OMEGA
IF((U0(2) - Tw CPI) 15, 15.14$7
U0(2) = (2) - TnP Pi$7
GOTO 15 $7

EO1 = U0(2)$7
DO 1 AI = 1, 3m

COS30 = COS (EO1)$7

SIN30 = SIN (EO1)$7

EO2 = AN * COSE0$7

ESINE = (SINE0 * AYNI) = EO2$7

EO2 = U0(2) + ESINE$7

IF (ABS (EO2 - EO1) > 0.000001) CNTRD2, CNTRD2, 17 $ TEST CNVR6NC

17EO1 = EO2$7

CONTINUE$7

START TAC $7

TMA C/HLT C/WRD C/HLT$5

JMP TAC$7


TRD? ECOSE = SINE0 * AYNI + COSE0 * AXNI$7

R = (1.0 - FCOS) * AR = X/Rg TESP = SGR (ESO)$7

XLGR = 1.0 + TESP - COSU = ESINE/XLGR$7

SINU = ((SINE0 = AYNI) - (AXN1 = COSU)) * AR$7

COSU = (COSE0 - AYNI + AYNI = COSE0) * AR$7

DO 20 I = 1, 13

UX(I) = SINU * XNX(I) + COSU * XNX(I)$7

VX(I) = CFSU * XNX(I) - SINU * XNX(I)$7

20 X(I) = UX(I) * R$7

COMPUTE POSITION VECTOR

RVNCT = (RTA * SQR U) X/R$7

RDOT = (RVDOT + ESINE) X/R$7

RVDOT = RVDOT + RTESQ$7

DO 21 I = 1, 13$7

1 XOUT(I) = VX(I) * RVDOT + UX(I) * RDOT$7

COMPUTE VELOCITY VECTOR

RFTUR$7

START TAC$7

RROA RUNOUT$7

JMP 3$7

1 IF(X1, 14) = 0.653$7

OPI F/6 = 2831RPS 6$7

IOV = F/6 = 796326$7

ARD A XKFPLES EQUATION NOT CONVERGING FOR F$7

END TAC$7

END$7

$7

SURFOUTNE SETI (IA, I)$7

JE: $7

GJ = J + 1$7

IF(IA = J) 55, 51, 50$7

E-29
OSL \cdot T(3), XL \cdot (3) \cdot GEL(3) \cdot RSUBA(4) \cdot USUBA(4) \cdot X \cdot XX(1) \cdot 78), PB \cdot (1) \cdot 4), RXSTO(79), LXI(3), H(\cdot (2), I \cdot 1G(4),

XX(\cdot T(1) \cdot T(2), \cdot EC(15), \cdot TA, A(1000), NLX(\cdot 3),

FT \cdot FT(1), AP \cdot AP(1), YTVE(4), YTVE(\cdot 6), YTVEC(6), YTVEC(6),

FT \cdot FT(4), UP \cdot UP(4), CHOT(4),

AXS(6), PY(6), RZSS(4), BCST(20), P \cdot B(3),

TH(4), F(26), CVE(10), AVEC(3), XVEC(\cdot 6),

UF(6), YVEC(6), YVEC(6), YVEC(6),

AX(25), SQ(25), SL(25), SCRF(25),

SQ (6), PB (625), SQC (625),

GSA(56), GSP(24), GSQ(24),

AM, (3), CCS(3), COEL (3), ABDEL (3), FCET(3),

HDECA(2), HDELB(2), HDEL(2), HDE(\cdot 3),

CAPX(3), AXC(3), DEL(3),

STAC(1000), CAPD(3),

DIENSTEM IDRF(10), DISENSTEM $CODE (3),$

TABLE \cdot T(12), T(15), TCHET(15), TCHET(15),

CHET(15), TCHET(15), TCHET(15), TCHET(15), TCHET(15),

TACDEF \cdot T(12), T(15), T(15), T(15), T(15),

READ ALL TAPES AHEAD

WRITE BPEQ(1, 2),

WRITE TAPES, WSTU(2),

WRITE TAPES, VSTU(2),

WRITE TAPES, WSTU(2),

WRITE TAPES, WSTU(2),

S START: TAC, 1

PI F / 3, 141592653

TAP \cdot F / 1, 410796626

GOTO F / 1, 576194182

TAP \cdot F / 1, 749251

DEGREES TO RADIANS

TOP \cdot F / 1, 5839536

TMP \cdot N / T32CH/BAT475REWINC TAPE 10

TML \,

JMP \cdot (P) \cdot 1H

TM \,

TA \,

TAM \,

TA \,

TAM \,

JMP \,

AFRNT \,

AR TR \,

AR LTI \,

AR RSR \,

AR RRR \,

1958

F / 0.0 \,

1959

F / 0.67 \,

1960

F / 0.42 \,

1961

F / 0.12 \,

1962

F / 0.43 \,

1963

F / 0.7 \,

1964

F / 0.0 \,

1965

F / 0.0 \,

1966

F / 0.0 \,

1967

F / 0.0 \,

1968

F / 0.0 \,

1969

F / 0.0 \,

1970

F / 0.0 \,

1971

F / 0.0 \,

1972

F / 0.0 \,

1973

F / 0.0 \,

1974

F / 0.0 \,

1975

F / 0.0 \,

1976

F / 0.0 \,

1977

F / 0.0 \,

1978

F / 0.0 \,

1979

F / 0.0 \,

1980

F / 0.0 \,

1981

F / 0.0 \,

1982

F / 0.0 \,
F/-0.91$ \text{ FC}25 1963$
F/-0.91$ \text{ FC}31 1963$
F/-N.91$ \text{ JAN} 1 1963$
F/-N.91$ \text{ JAN} 14 1963$
F/-N.851$ \text{ JAN} 13 1963$
F/-N.855$ \text{ JAN} 14 1963$
F/-N.853$ \text{ JAN} 14 1963$
F/-N.853$ \text{ JAN} 14 1963$
F/-N.861$ \text{ JAN} 14 1963$
F/-N.862$ \text{ JAN} 14 1963$
F/-N.862$ \text{ JAN} 14 1963$
F/-N.862$ \text{ JAN} 14 1963$
F/-N.862$ \text{ JAN} 14 1963$
F/-N.862$ \text{ JAN} 14 1963$
F/-N.862$ \text{ JAN} 14 1963$
F/-N.847$ \text{ JAN} 14 1963$
F/-N.847$ \text{ JAN} 14 1963$
F/-N.847$ \text{ JAN} 14 1963$
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F/-N.847$ \text{ JAN} 14 1963$
F/-N.847$ \text{ JAN} 14 1963$
F/-N.847$ \text{ JAN} 14 1963
F/-0.965 $ AUG26 1963
F/-0.967 $ AUG27 1963
F/-0.967 $
F/-0.966 $
F/-0.963 $
F/-0.961 $
F/-0.959 $
F/-0.959 $
F/-0.959 $
F/-0.959 $
F/-0.959 $
F/-0.959 $
F/-0.959 $
F/-0.959 $
F/-0.959 $ SEP17 1963
F/-1.000 $ SEP18 1963
F/-1.012 $
F/-1.021 $
F/-1.021 $
F/-1.034 $
F/-1.037 $
F/-1.039 $
F/-1.039 $
F/-1.037 $
F/-1.036 $
F/-1.036 $
F/-1.036 $
F/-1.036 $
F/-1.036 $
F/-1.036 $ SEP19 1963
F/-1.036 $
F/-1.036 $
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| F/-1.09 | $ |
| F/-1.08 | $ |
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$ NOV 11 1963

| F/-1.11 | $ |
| F/-1.10 | $ |
| F/-1.09 | $ |
| F/-1.08 | $ |
| F/-1.07 | $ |
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$ DEC 7 1963

| F/-1.06 | $ |
| F/-1.05 | $ |
| F/-1.04 | $ |
| F/-1.03 | $ |
| F/-1.02 | $ |
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$ DEC 8 1963

| F/-1.05 | $ |
| F/-1.04 | $ |
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**JULY 1 1964**

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**AUG 1 1964**

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</table>
DO (EDP, I = 1, 7)

CALL STARTER(HL, G, CNT, X, X1S, TO, CT, TF, D, XH, XLO, XN, HX, IPNTEL, AS, X, CODE, ORGA, ORGT; RFFCA, REFTH, AB, X2, EFLAG, IXYR, XAXS)

RHYN = 57.2957795

SET UP CONSTANTS
XH = 1.2504742610
R = 1.07944952215
PAKFK = 0.0

IF (IXY = -5) IS1, IS2, IS1
IF (IXY = -6) IS3, IS4, IS3
IF (IXY = -7) IS5, IS6, IS5

WRITE OUTPUT TAPE 5, IS6, IXY

FOR AT + 11, SHYEAR, I2, I6H GIVEN AS INPUT NOT IN EQUINOX TABLE

STRT C

RESULT =

EN. TAL =

IT = ORCH - 3,4
GO TO -17

IT = ORCH + 4,4
GO TO 17

CONTI =

RH, T = 0,0

EV =

ST. T = 1, APE = 72
THRH = ORCH (IXY)
FL = F2, 2, 42, 42, 2
VF = F2, 42, 2, 42, 2
SH = 72, 4
SN = 1, 4
XY = 1, 4
TH = T, 0, APE = 44
FE = F2, 2, 42, 42, 2
RH = 1, 4, 2
AX = 1, 7, 4, 2, 2
CNO = 4

END
X, MPRM = 1.67341E+3
* MPRM = 6.2E-6
* AMPRR = 3.19E-6
* JUAS = 0.2E-6
* XEPG = 6.972E-6
* OME = 1.17394
* CD = 2.0
* AE = 1.0

START 2: APR = 0.0
APRT71 = 0.0
APRN = 0.0
APRQ = 0.0
APRNT = 0.0
APRSH = APRS
NTAPE = 100

IF (AP = 1)
DRAE = DARK*(0.02/200)*(CD-R:00/2.0)*PI*2*(-1.0)
FRAC(1) = DARK/(MNPD)*FRAC(2) = SIORT*FRAC(1)
FRAC(2) = 0.0 + FRAC(1)+FRAC(2)
THGR = APRT71*(S0RT + FRAC(2) + THGR0)
THGRD = COSV*THGR

START TAC
TMA CNTWD
JAZ (P)+1:0
JMP SEC4
TM0 /0
TUM CNTWD
RMD TAC

SE CNTWD(10) = (REFDA-ORGDA)*MNNPD+REFTM-ORGTM - NEW-OLD EPOCH, INSEC
IF (CТHD(T(0)) = T7, T(0)) 60 TO SEC3S = 0 IF CANNOT BE REACHED
IF (CТHD(T(F)) = T8(BASIC TWD(10)), GO TO SEC3S IN SPECIFIED

SELECT ºFRP FILE TPE TAPF SEC3S INTEGRATI
SELECT FORMAT (IN2N0) START TIME //S
CHYD = 3.0

SELECT REMIND
REMIND
NTAPE = 0.0
GATE = 0.0
SE CNTWD(10) = (REFDA-ORGDA)*MNNPD+REFTM-ORGTM - NEW-OLD EPOCH, INSEC
THE FOLLOWING TRANSFER OF COLUMN HEADINGS MAY BE CHANGED
D1(I) = C.RD1(I) TIME-LATITUDE-LONGITUDE-ALTITUDE TO HEAD
BEGIN IF (G.THSG), TE(1) = X9THSG = 3.0

IF (CD9H, TE(1), X9THSG, = 3.0
UNI (12) = 0.94C, WD(13) = 0.0
ITI = 5: = THS
* = E.T**2+Y**2+Z**2
*UNP = UNP(P)*
X = X/A.R T = Y/A.RTP Z = Z/A.RTP
SIN = SIN(T**1)/H2**2)
SIN4 = X/SIN4COS4 = (-P1/Y/SIN1)
COS2 = 2.0
IF (E (1), XINCL = P10V2, GO TO 19
XINCL = ATAN2 (SIN, COS1) S
IF (XINCL) LT (0), XINCL = PI + XINCL
19 IF (CASO) E (0), XNODE = SIGNF(P10V2, SIN)60 TO 23 S
* COMPUTE PERTURBATION ACCELERATIONS
  * I*... I SAVE OUT PFR UNTIL RECTIFY ROUTINE IS CALLED, AND
  * CALL BUDGE PERTURBATION T.

```
SOLVE
VR5*R/PRM$ = UZSR*U/P*VR6*Z/RS$= XVR5*PZ(RSR)*VR6*Z/RS$= XVR5*PZ(RSR)

SAVE
VR5*VR6*Z/RS$= XVR5*PZ(RSR)*VR6*Z/RS$= XVR5*PZ(RSR)

EXIT
```

* RELATE PERTURBATION S TO ORITAL PARAMETERS

```
XNR = (DGP/SGPMU)*AXX(-1.5)GRBDGR=0.05
DO PG I=1,35
  RGR = XR*AX(I) + RPPGR
  SMRGR = SRMU*(I+1.0)*RTPS
  SMGR = SMGR*/SRMU/S*2GR*70
  E*YZ E0Y=AX*ZI.- -1Z*YI$ = EY=Z*XI.- -1Z*YI$ = E2=Z.*Y= Y*XI$ = E2=-Z.*Y= Y*XI$
  A*AV D0 = I1.5 = AX0*AX(I)*DG = (YGR*/ZXCT*Z+GR*DG) = ZPR
  XL*GR = XR*AX(I)*DG = (YGR*/ZC+GR*DG) = ZPR
  XL*GR = (ZC+GR*Z)*/SRMU
  HZGR = (YGR*/Z-GR*Z)/SRMU
  HZGR = (YGR*/Z-GR*Z)/SRMU
```

-1L1 = L. E+14
CALL P,k(T+1)+1*11 L T*XL*G+1$  
L1EF IF((RKSTO(TF) + T)GT(0.0), GO TO CSE$  
\* 71 IF(CNT D(11)) 7", HLL, 72$  
\* LOGIC TO STORE VALUES OF PARAMETERS. THEN RESTART TIME REACHED  
\* 7IF(CNT (11)) 74, IFNEE 741, IFNEE 7$  
\* 7IF(CNT (112)) 75, 76, 75$  
STU-T TAC $  
\* CALL JNP 4 RUNGE-ETURN$  
\* GO TO 78  
\* RESUME INTEGRATION  
\* 78 IF((RKSTO+KSTC(4)-CNTW(10))*DT)LT(0.0), GO TO CSE$  
\* RKSTO(TP) = RKSTO(T) - RKSTO(CW) - RKSTO(12)-RKSTO(T)  
\* GO TO 'HELL$  
\* 79 IF(CNT 0(11)) 80, 81, A0$  
\* RKSTO(13) = CT CW(11)$  
\* 80 GO TO $  
\* RKSTC(4) = RKSTC(4) + GCTW(12)=RKSTC(5)$  
\* 82 CNT D(11) = PR PR (RKSTO(5))  
\* 83 MUPR71=1.3$  
\* 87 CNT D(10+16) = HXI (1)$  
\* CNTD(10) = X * XN(1)+ CNTW(D16) = AYNI $  
\* GO TO 'HLL$  
\* 88 IFNEE IF(CNT 0(11)) F (0), RKSTC(4) = NT$  
\* GO TO 73$  
\* WRITE EPHE RUFFER ON TAPE 3, TURN ON SENSE LIGHT 4  
\* 0FLU WRITE TPE 3,(EPF-EM(1),I=1,IXX)$  
\* NTPE3= TAPE3+1  
\* SENSE LIGHT 46 CNTRL = 16 60 TO CNTRL2  
\* STA T TAC$  
\* 0AOF $  
\* CSEMD RECEIVES CONTROL AFTER INTEGRATION OF EPHEMERIS  
\* 0 IF REQUESTED, OUTPUT CODE < OR 3, PRINTS X, Y, Z EPHEMERIS  
\* WRITE OUT EPHE RUFFER ON TAPE 3  
\* SENDS CONTROL TO DIFFERENTIAL CORRECTION OR SIMULATION  
\* ENI TAC$  
\* CSFND IF(IPNL(I)LT2), GO TO 214$  
\* RE=XND $ YES - PRINT X, Y, Z EPHEMERIS, FROM DATA ON TAPE 6  
\* IPGCT = 18$  
\* DO MPS T = 1,15$  
\* 28 CHF(I) = CHF(I) + TIME X Y Z XGOT YGOT ZDOT = TO HEADING  
\* LI C=0$  
\* IT=P=TAPE$  
\* HIP TAP READ TAPE A, (OPT(I),I=1,7)$  
\* NTPE6= TAPE6+1$  
\* 28 IF(IGN =54) 227, 227, 22A  
\* 28 CALL Hc 0 (IPGCT)  
\* LI C=5*IPGCT T=IPGCT + 1$  
\* 27 LI C=LI C+1$  
\* WRITE OUTPUT TAPE 5, Z227,(OPT(I),I=1,7)$  
\* 227 IF (TAP =A) CT (0), GO TO 227, LOOP TILL ALL PRINTED  
\* NTPE6 == IT=P$  
\* 0 S1 IF(SENS> SWITCH 35) C36, C0$  
\* C4= CO TIN$  
\* RI = IN$ 1$  
\* IP=CITE$  
\* LI C=0$  
\* IT=P=TAPE=15$  
\* C36 READ TAPE 15,(OPT(I),I=1,7)$  
\* NTPE15= NTPE15+1$  
\* E-51
S
HI  AC  INT P2 $
TA  INT P2 $
TH  INT P2 $
ST  INT P2 $ 
TA  INT P3 $ 
S
HI  INT P3 $ 
TA  INT P3 $ 
TF  TA2 $ 
TF  P5=(TF P5-I*(P4)+0.000000000S $ 
TF  S=0.0000000000S $ 
TF  P3=P3*100.0000000000S $ 
TF  P4=P4*0.000000000S $ 
0001=901=13.3S $ 
X=15  XLSU"X(1)=XG"X(1)/R*C1$ 
TF  P5=1.0-XLSU"Z**2$ 
IF (TEMP5)*X914,X914,X915$ 
X=14  IF (XLSU"2)*X916,X917,X917S $ 
X=16  TEMP$=1.0*PI**2$ 
X=17  TF  TEMP$=PI**2$ 
GO TO ULTA2$ 
X=15  ODLTA=S.10RT(TEMP5)$ 
TF  TEMP$=ATAN(XLSU"Z/DELTA)$ 
ODLTA=TEMP5/CONV$ 
IF (XLSU"X(1))*C/LFA,Y901*C/LFA$ 
X=7  IF (XLSU"Y)*X908,ERROR,X909$ 
X=8  TEMP$=3,0*PI**2$ 
GO TO ALF2H$ 
X=9  TEMP$=PI**2$ 
GO TO ALF2H$ 
CALFA  ALFA=ATAN(XLSU"Y/XLSU"X)$ 
IF (XLSU"X(1))*X911,X911,X910$ 
X=10  IF (XLSU"Y)*X912,X913,X913$ 
X=11  TEMP5=ALFA+PI$ 
GO TO ALF2H$ 
X=12  TEMP$=ALFA+2.0*PI$ 
GO TO ALF2H$ 
X=13  TEMP$=PI**2$ 
ALF2H  ALFA=AT(TEMP5/CUMV*15.0)$ 
CPX=TSE-1.0*CAPIT*THDUTS$ 
CPY=TEC*PX*THDUTS$ 
RRATE=XLSU"X* (CPSCL+CPXCT)+XLSU"Y*(CBSCT (2)+CPYNT)$ 
RRATE=RRATE*XLSU"Z*CPSCT (3)$ 
10  IF (LINE)*119,119,120 $ 
17  CALL HED (TPGCNT )$ 
LINE=-5 IF (CAT=IPGCNT+1$ 
117  LINE=LINE+1 $ 
ALPHA=ALFA+15.0$ 
WRITE "OUTPUT TAPE 5",P1,CNTwC(P),TXZ(I),RHO1,RRATE,ALFA, 
ODLTA, C/P,TAPE $ 
P1  FOR A1 (HT=PA4,7X,7F15,R)$ $ 
*  
SE*SE > ITCH 3$  PLACE A2 AND EL CARDS 
*  
SE*SE > ITCH 3$  PLACE A3 AND DEC CARDS 
*  
SE*SE > ITCH 3$  PLACE RANGE CARDS 
*  
SE*SE > ITCH 3$  PLACE RANGE RATE CARDS 
IF (SE SE 5,ITCH 31) 7300.7301$ 
7.00  IN*4=ALPHA $ 
RT, ASCENSION TO FIXED POINT 
RARK=1 RAK $ HOURS TO FLOATING POINT 
RAK=4(C/P)*RFRK $ FRACTIONAL HOURS TO MINUTES 
IN*4=ALPHA $ TO FIXED POINT 
RARK=1 RAK $ BACK TO FLOATING
RAISEC = (AZ + FRK) * 60. / SECONDS/10
INH: = SEC $              CONVERT TO FIXED POINT
DF: = AZ: + LITA $      ASSUME DECLINATION TO
DELSZ = US $           PF POSITIVE ==
IF (FLT) 7302, 7303, 73:3 $ UNTIL PROVEN OTHERWISE --

7.2  UELZHA = INS $        CHANGE SIGN OF DECLINATION
7.3  INUCHS = DETA $      DECLINATION DEGREES TO FIXED POINT
DCF K = 1 DCD $           INTEGER TO FLOATING POINT
DCIN = (DEET - DCFRK) * 60. $ FRACTIONAL DEGREES TO MINUTES
INUCHS = INMIN $           MINUTES TO FIXED POINT
DCF K = 1 DCH $           PACK TO FLOATING POINT
DCSEC = (CHIN - DCFRK) * 60. $ SECONDS/10
INUCHS = DCSEC $           SECONDS TO FIXED POINT
START TAC S
TMA  = INRAH $             $ S
SRA  = 32 $                $  32 $
TAM  = INRAM $             $ S

S
BIM= RCL INRAM $         $ S
TM= INRAM $              $ S
SRA  = 32 $                $ S
TAM  = INRAM $             $ S

S
BIM= RCL INRAS $         $ S
TAM  = INRAS $             $ S
SRA  = 32 $                $ S
TAM  = INRAS $             $ S

S
BIM= RCL INDCS $          $ S
TAM  = INDCS $             $ S
SRA  = 32 $                $ S
TAM  = INDCS $              $ S

S
BIM= RCL INDCS $          $ S
TAM  = INDCS $             $ S
SRA  = 32 $                $ S
TAM  = INDCS $             $ S

S
BIM= RCL INDCS $          $ S
TAM  = INDCS $             $ S
END TAC S
PUSH ("BSC?"), X; YR, CNTM0(A), X; YR, ITMP1, ITMP2,
ITP3; ITMP4, INTMP2, INTMP3, INRAH, INRAM, INRAS, DELSN, INDCD, INDCM,
INDCS $  
C; SCR
FOR (AT (12, 3X1H2, 4X1A4, I1, 4I2, W2, W4, 1H2, 2W2, W4, W1, W3, W2, W3 ) $  
7.91 IF (SE; SF $; IUSK 30) 7400, 7401 $  
STA T TAC $  
PLU$ A $  
X; TNS A/ $ - $  
END TAC $  
7.70 INAR = CAPA $  
AZF = AZ $  
AZIN = (CAPA - AZFRK) * 60. $  
INAZV = INW1 $  
AZF = K = AZ $  
AZSEC = (AZV + AZFRK) * 6000. $  

E-55
7600 RRTT= *1*((-37922.43-100,RRATE)/(37922.43+RRATE))$ IS=10$ 
PU.CH ( SSCC),,IXY,R.CNTD(R),IXYR,ITEMP1,ITEMP2, 
ITEMP3,ITP4,1,TMP2,INTMP3,IS,RRJT $ 
GSSCR FOR:(AT(12;3X,1;3,4X,A1411,412;12;42;W4;8X;I2,F9,9) $ 
7701 GO TO 1 4$ 
START TAC$ 
PAGE$ 
* 
DIFFERENTIAL CORRECTION RUN$ 
END TAC$ 
0H:CO REWINDS $ 
IOH=2=IORACT $ 
IF (SENSE LIGHT 4)121,122$ 
121 SENSE Light4$ 
IF (EFLG)123,124$ 
123 REWIND 3 $ IF EPHEXERIS ON TAPE 3, REWIND 3 
122 NTAPE3 = NTAPE3 $ 
IF (SENSE LIGHT 3) 124, 124 $ TURN OFF SENSE LIGHT 3 
124 ISPCT = 1 $ SUM = 0.0$ SUM2 = 0.0$ 
IF (SENSE LIGHT 2) INITL,125$ IF FIRST PASS THRU OBS. RD FM CRD 
* READ STATION AND OBSERVATION CARDS 
125 IF (IRPT)GT (9)r IRPT=0$ SET NO. OF TIMES TO REPEAT CORR. 
RREC CALL READER(STARC,ISTCNT,LSTCNT,IASIZE,10BUF,1XMPER) 
START TAC$ 
TMA LSTCNT $ 
JMP CHGXXN $ SET UP LEAST SQUARES ROUTINE FOR MATRIX SIZE 
PAGE$ 
* READ OBSERVATION CARDS, STORE ON TAPE 9 
IALL=119, IORACT=0$ 
*ENTER RCARD AND READ 1 OBSV CARD STORING$ 
*UTIME, ALPHA, DELTA, RANGE, AND STAID = STA NO IN BCD$ 
*WHEN LAST CARD IS READ SET IALL=2$ 
X130 CALL RCARD(SATEL,STAID,ASIZE,1BMUTH, DAYNO, ALPHA, 
DELTA,RANGE,ROUTE,UTIME,NCARD,1XPER) 
GO TO (X132, 131), NCARD $ CHECK IF ALL OBS. CARDS READ 
131 REWIND 9 $ ALL OBS. CARDS READ - GO DO CORRECTION 
GO TO INITLS$ 
X132 I = 1 $ NO. OF STATION RECORD IN STARC 
START TAC$ 
TMA ISTCNT$ 
SLA 3$ 
AD $ 
AM C/HLT,STARC$ 
TDXLC 3$ 
TAM JXXY$ JXXY HAS ADDRESS OF END OF STARC TABLE 
* FIND STATION IN STARC BUFFER 
ZXXY TMA STAID$ 
TMD 3$ 
JAED H134$ SEARCH FOR STAID IN STARC TABLE 
TMA N/9T15$ 
AMS I $ 
TMD JXXY$ 
AIXOL 9$ 3 $ 
JNO ZXXYS 
TMD STAID$ STATION NOT FOUND - NOTE ON FLEXO 
TDM BLAB3+$ 
TMA C/HLT, BLAB3, C/HLT, 5$ 
JMPL 6$ AND ON OUTPUT TAPE 5 
END TAC$ 
WRITE OUTPUT TAPE 5, 705, STAID$ GO TO X130$ 

E-57
7.5 FORMAT(10H10STATION, 1A8, 10H NOT FOUND) $  
134 PHI(I) = STARC(I+1) $  GET LATITUDE, EAST LONGITUDE, HEIGHT  
XL, RA = STARC(I+2) & ALT = STARC(I+3) $  
ST/RK = STARC(I+4) $  GET IAXD  
GO TO R8 $  I = 1 $  
7.6 IF (SI=U(J)) E (0.), ASIG1(J) = STARC(I+J+4) $  
X=TS = UTIME -ORIGTA + XMPDA*(DAYNO-ORGDA) $  MINUTES SINCE EPC  
TEC $  134 $  IF(TECP=U(TL)) LT (0.), GO TO 706 $  FIND IF THIS TIME IN EPHEMERS  
IF(TECP $ (TEC-X), ORGDA)) GTE (0.), GO TO 707 $  
7.9 For AT (19=100$SERVATION FRMAg $8, 3H OR4, 11, 18H OUT OF TIME RAN  
UF $  
7.7 STPH = SIN (PHI(RD)) $  
TEC = (1.0-SINP+M2*EPSG) $  
CAPC = (1.0/SRT (TECP)) $  
CAP = CAPC*(1.0-EPSG) $  
CAP7 = (CAPS+ALT)*(-SINPH) $  
COSPH = COS (PHIND) $  
XOMCT = (ALT+CAPC)*(-COSPH) $  
XLPT = THGRA + XLAMBA $  
IDAY = DAYNO-ORGDA+IT $  
IITT = UTIME/144. $  
T = UTIME/144. = T $  
T = IITT $  
EQQ = (1.0-EQQ)/(IDAY+T)*EGE((IDAY+1) $  
EGE = EQQ*CON'/243. $  
THOA = XPSRIP+XMPTH+EGE $  
COSTH = COS (THOA) $  
CAPX = XLCT*COS(TIM) $  
SINH = SIN (THOA) $  
CLPH = COS (THOA-X) $  
SL = SIN (THOA-X) $  
CAPX = XLCT*SINH $  
183 CALL STOPS(IOTYPE)$  COMPUTE L PAR, ETC,  
185 IF (SENSE LIGHT 5) $  X130, 151$ STOPS TURNS THIS ON WHEN OBS DONE  
1.1 WRITE TAPE=89, SATEL=8, IOID=ITYPE, XMNT=3,  
(CAPY(I), (I=1,3), (ASIG1X(I), I=1,9), ASIG1, IAXD, SPHA, CPHA, SDEL,  
CC=EL, CLN, SLN, IMUTH, EGG $  
IO=CN=TOC+T+15 $  
IO=NT=IO=CN $  
IF (IOYPE=152, 152, X151$  
X151 IF (IOYPE=2) X152, X152, X130$  
X1=PALH=AM=1.0, DELTA=0.0 $  
GO TO 1-3 $  
133 RA=F=.3 $  
GO TO 1-3 $  
ST=T PACE $  
* OBSERVATION S ARE 0. TAPE 9 = MAKE PASS THRU THEY.  
EN$ TAG $  
I 1TL SF$SF LIGHT =2 $  
IF (SENSE LIGHT 4) 154, 155$  
141 RFA=TAPE=53, (CAPY(I), I=1, IXY) $  
SF$SF LIGHT =4 $  
T=TAPE+TAPE-1 $  
144 RC=T=E, RRC=T=0.0 $  
ACC=T=E $  
LST=T=1 FFC T=1.0 $  
IT=STRT $  
INC T= 1 0, T2=0. $  
E-58
* ENTER LEAST SQUARES HE FS
ST. TTA $ FS
- LSN $ F. TAC $ * PASS THRU OBSERVATIONS
FT. CT IF -(SNSL= LIGHT?) 178, 179 $ * JUST DIY RA CR ZI:UTH = TO DEC OR ELEVATION
17A ARS LE=FSI* DO (XI=1) I = 1, 3 $ X1=0 ARS(I) = ST. (I+I) $ CALL CLFF (ARAY, I, XPER) $ GO TO (180, ADF OX ST1, I) $ 1:0 IF (INST-2) A18O, A18O, R180 $ n=80 SUM = n=FISI**2 + SUM $ FORM SUM OF SQUARES OF RESIDUALS RCNT=RC T+1.0 $ IRC=IRCNT $ RC T2=RC T2+1.0 $ G0 TO FINEX $ RJ=0 SUM=RESID**2*SUM2 $ RC T2=RC NT+1.0 $ IRC T2=IRC T2+1.0 $ FIX FX GO TO LSAPS ADK THESE COEFFICIENTS TO LEAST SQUARES MATRIX 1/0 IF -(PCNT+RCNT2) AM 1, 181, PROBXX $ 1/3 DO IF 2 1=1.6 $ T=2 CHEC(I)=DRS=0(I) $ SUM. STA. TIME PHO RESID/KM RA RESID/KM ETC. 1/1 CALL HE I(I, PG6CT) $ IRCNT=IRCNT+1 $ LINE=6 $ GO TO TEOF $ PROBXX IF (INST - 1) 189, B189, F189 $ FI: S IF (INST') 18 (3), APRNT13 = RESID = GO TO PROBS APR T71 = RESID $ APR T56 = APR T56 $ PRINT ACCORDING TO PAGE 59 $ P, g5 IF (LINE = 54) PRO = SX, PROSX, PROSY $ P, aSY CALL HE I(D, PG6CT) $ IRCNT=IRCNT+1 $ LI=6 $ 3 $ wr I=1 TPUT TPE $ CVT0B J ST61, ST62, ST63, ST64, APRNT41, $ AP T56, APR T71, APR T8S, APRNT01, APR T13, APRNTS $ C, TUP AP = T41 = u, 0 $ AP = T56 = u, 0 $ AP = T71 = u, 0 $ AP = T8S = u, 0 $ AP = TO1 = u, 0 $ AP = T12 = u, 0 $ AP = TS = APR N T $ TEOF IF (IP PG6CT < 2) EFCHE, EFCHE, 565 $ 1 - I = T2 - 10 = T2 = 1 $ GO TO V01 $ T T1 CALL T = CMT +1 $ AP = TS = ST +5 $ IF (IE < LIGHT 3) T7A, PROXX $ 3 - AP = T41 = RESID $ GO TO FINEX $ AP = T56 = AP = T71 = AP = T8S = $ AP = TO1 = T12 = $ AP = TS = AP N T $ C, TUP IF (ST61 T1-CN T1-CN1-CN2) CTV1, CTV1, UNKERS $ ST. T 1 $..
IF (WE(E)) 722, 723, 722 $  
772 Go to lines $  
7.4 FOR AT*SC2*CORRECTION MADE TO ORBITAL ELEMENTS AND STATION POSITIONS $  
GO TO C.K.PK$  
GO TO C.WRAC$  
*  
7.3 J = LSTCN'T**2$  
DO 725 K = 1, $  
7.5 SQF(K) = SNA(K)$  
MATRIX A TO MATRIX A1  
DO 726 K = 1, LSTCN'T$  
7.6 SQF(K) = SBA(K)$  
MATRIX B TO MATRIX B1  
LEN$  
K = L * LSTCN'T$  
DO 727 = 1,$  
7.7 SQF(V) = 0. SET 1ST L ROWS OF MATRIX A1 = 0  
7.8 K = L * LSTCN'T + 1$  
M = K + 5$  
DO 729 = K,$  
7.9 SQF(V) = 0. SET 1ST L ELEMENTS OF REMAINING ROWS = 0.  
LST+15  
IF (L = LSTCN'T) 728, 730, 730 $  
7.3 K=LSTCN'T+1$  
LEN=LSTCN'T-3*INSIZE$  
DO 731 = 1, L*$  
7.1 SQF(V) = 1.0$  
SET FIRST L DIAGONAL ELEMENTS = 1.  
DO 732 = 1,$  
7.3 SQF(V) = 0.0$  
SET FIRST L ELEMENTS OF MATRIX B1 = 0.  
LM:5 = 2$  
IF (MC(E(2)) 733, 734, 735 $ SHALL WE CORRECT STATIONS ONLY $  
7.3 DO 735 = 1,$  
7.4 QLS8A(N) = SAM8N(M)$ YES-TRANSFER A1 AND B1 MATRICES TO  
IF(ISIZEE) E (U)$ WRITE OUTPUT TAPE 5, 773$ Go to CUMPAC$  
7.73 FOR AT*RH1: / 28H1NO STATION POSITIONS TO BE CORRECTED$  
DO 736 = 1, LSTCN'TS$ WORKING AREA USED BY LEAST SQUARES  
7.73 GO TO SQP(N) = SXPB(N)*  
SUBROUTINE  
GO TO SQS$ AND GO SOLVE EQUATIONS  
WHITE OUTPUT TAPE 5, 749$  
7.7 FOR AT*SC2*CORRECTION MADE TO STATION POSITION ONLY$  
GO TO C.K.PK$  
GO TO C.WRAC$  
*  
7.34 J = LSTCN'T**2$  
DO 739 = 1, $  
MATRIX A TO MATRIX A2 (SBC)$  
7.4 SQ(K) = SNA(K)$  
DO 739 = 1, LSTCN'T$  
MATRIX B TO MATRIX B2 (SBC)$  
7.4 SQ(K) = SBA(K)$  
IF ($.) 12134$,12134,12134$  
E-60
UI PER TMA  C/HLT: RCHC C/HLT,6$  
JMPL F$  
MVL T$  
EMU TAC$  
END READ$  
C-V1 GO TO LQS1$  "GO FILL IN A MATRIX"  
J = LSTCN T ++ 2$  
DO 720 = I, J$  
7. 0 S = A(I) = A (K)  SAVE A MATRIX IN SQMA  
DO 721 = 1, LSTCNT %  
7. 1 S = A(I) = A (K)  SAVE B MATRIX IN SAB  
7. 2 IF (LSTCN T) 722, 723, 722$  
7. 3 GO TO LQS$  
7. 4 WRITE OUTPUT TAPE 5,724$  
7. 5 FOR AT (-026) CORRECTION MADE TO ORBITAL ELEMENTS AND STATION POSI  
7. 6 TION  
7. 7 GO TO C FKT$  
7. 8 GO TO C WRAC$  
7. 9 $  
*  
7. 10 J = LSTCN T ++ 2$  
7. 11 DO 722 K = 1, J$  
7. 12 S = A(K) = S MK A(K)$  MATRIX A TO MATRIX A1  
7. 13 DO 722 K = 1, LSTCN T$  
7. 14 S = A(K) = S MK A(K)$  MATRIX B TO MATRIX B1  
7. 15 LSTCN T = L * LSTCN T$  
7. 16 DO 727 = I, J$  
7. 17 S = H(I) = 0.  SET 1ST L ROWS OF MATRIX A1 = 0  
7. 18 K = L * LSTCN T + 1$  
7. 19 M = K + 5$  
7. 20 DO 729 = K, M$  
7. 21 S = H(K) = 0.  SET 1ST L ELEMENTS OF REMAINING ROWS = 0.  
7. 22 LSTCN T = LSTCN T ) 728, 730, 730$  
7. 23 K = LSTCN T + 1$  
7. 24 LSTCN T = LSTCN T * INSIZE$  
7. 25 DO 731 = I, LSTCN T$  
7. 26 S = H(I) = 1.  SET FIRST L DIAGONAL ELEMENTS = 1.  
7. 27 DO 732 = I, LSTCN T$  
7. 28 S = H(I) = 0.  SET FIRST L ELEMENTS OF MATRIX B1 = 0.  
7. 29 LSTCN T = LSTCN T + 5$  
7. 30 IF (LSTCN T) 731, 732, 732$  
7. 31 IF (LSTCN T) 733, 734, 734$  
7. 32 S = H(I) = 1.  YES-TRANSFER A1 AND B1 MATRICES TO  
7. 33 IF (LSTCN T) 735, 735$  
7. 34 QLSA(A) = S MK H(M)$  YES-TRANSFER A1 AND B1 MATRICES TO  
7. 35 IF (LSTCN T) 736, 736$  
7. 36 FOR AT (281) / 281 NO STATION POSITIONS TO BE CORRECTED  
7. 37 DO 737 = I, LSTCN T$  
7. 38 SET WORKING AREA USED BY LEAST SQUARES  
7. 39 S = B(K) = S MK B(K)$  SUBROUTINE  
7. 40 GO TO SQS$  
7. 41 WRITE OUTPUT TAPE 5,723$  
7. 42 WRITE OUTPUT TAPE 5,724$  
7. 43 FOR AT (-026) CORRECTION MADE TO STATION POSITION ONLY  
7. 44 GO TO C FKT$  
7. 45 GO TO C WRAC$  
7. 46 $  
*  
7. 47 J = LSTCN T ++ 2$  
7. 48 DO 738 I = 1, J$  
7. 49 S = A(I) = S MK A(I)$  MATRIX A TO MATRIX A2 (50$C)  
7. 50 DO 739 = 1, LSTCN T$  
7. 51 S = B(I) = S MK B(I)$  MATRIX B TO MATRIX B2 (50$C)  
7. 52 IF (LSTCN T) 734, 734, 121, 124, 121$E$  
E-60
21 IF(J+4r-I ) 209,209,210 $ 
21 J=J+1 $ 
21 JJ=JM: $ 
20 I $ 
21 IF(J+4r-I ) 209,209,210 $ 
21 JJ = JJ + 8 $ 
* I TEPCLAT - TO GET PARAMETERS FROM HYPERBORBIS 
C1 LP DO 21 1 =1 $ 
C S I(I)=I*KK*KK*K$ 
DO 213 J=1,6 $ 
C T I I(KK)*TINTP(JJ)$ 
IF(TEPF) 214,213,214 $ 
216 C S I(I)=CSUR1(KK)*(WSTO(4)-TINTP(JJ)) 
/TE $ 
217 CO-TIMUS $ 
218 CO-TIMUS $ 
FL $ 
DO 215 =1,7 $ 
CSI=0,6KK=K+J $ 
DO 216 J=1,6 $ 
CSUJ=SURI1(KK)+SUBI(JJ)*EP-EM(KK)$ 
216 KK = K I + A$ $ 
FJUFT(I)=CSUJ $ 
215 R KSTO (+4) = SUM $ 
RKSTO(I)=WSTO(4) $ 
CALL X YZP $ GET X, Y, Z, RELATED PARAMETERS 
IF(TPF6) 1969,1969,1970 $ 
R1699 WRITE TYPE $, RKSTO(I), X(I), Y, Z, XDOT(1), YDOT, ZDOTS $ 
A1670 XNIZ=ZU $ 
A20=AP*AFSUBU=A20*ESINES $ 
UNI=I(-I0)*(-.0/2.0)$ $ 
RS=AF(UWOG*RSI)P+R$ $ 
ROVA=R/3$ $ 
RX=(AX-1 COSC)*A20R$ $ 
RY=(AY-1 SINE)*A20R$ $ 
USR=ARTEO*AR$ $ 
USR=USURU*UMC$ $ 
DEF=COL*XLGR*2*RTE$ $ 
TEP=(XGR+EC0S)*/(-1.0) - LS+(1.0) $ 
UYxc=TEP*/EIS  $ $ 
UX=UX*AR$ $ 
ROVA=1.0+ROVA $ 
UX=UX*ROVA+SINE $ 
UX=((-YNI/XLG)+UXN)*A20S$ $ 
UY=LY*A X=1-RUVA*C0S $ $ 
UY=AZO*(AXNI/XLG)+(HY) $ 
RHC=0.0 $ 
DO 227 J=1,3 $ 
RHOX(K)=ST. (4K+H) $ 
217 RHC = RHC + RHOX(K) $ $ 
RHC=S.5* (RHC)$ $ 
DO 218 I=1,3 $ 
XLX(K)=:-HOLX(K)/RHC $ 
218 NLTX(I) = KSTC(K+J3) - XLX(K) $ 
IF(TPF6) A44, A44, 219 $ 
* W R T E P A R A M E T E S FOR STD. DEVIATION DETERMINATION 
A=W WRITE TYPE 11, S KSTC(I),(RSURAI), IU-14),(USURAI), IU=1,4 $ 
, (X(I), I=1,7) $ 
(U(I), I=1,3) $ 
, RSSI, SUNI, SUNI, COSU $ 
,(X(I), I=1,3) $ 
,(X(I), I=1,3) $ $ 
* IN P R A P I T l O S E R V A T I O N TYPE AND CALL COEFF TO COMPUTE 
* CORREL T I O N COEFFICIENTS 
219 IF(I+ST) 220,221,220 $ 
E-62
CALL CFF(LX,I,XFER)$
GO TO (1A1,RA0B,GB1),I$
220 IF(I)IAI=2)Y221,Y227$2215$ Y220 SENSE LIGHT 3$
DO (222, I=1,3)$
X220 ARAY(I)=STC(741)$
CALL CFF(ARAY,I,PER)$
GO TO (1R0,RA0M,OMIT1),I$
START TAC$
C#KT TJK+P225$
END TAC$
DO 215 I = 1,7$
219 A1(I)=GL50X(I)$
IF(TPFG)X156+X157+X156$
X157 TPFG = 5.05 FIRST TIME HERE PUT END SENTINELS ON TAPE 6,11
WRITE TAPE 6, HEND, X(1), Y, Z, XDOT(1), YDOT, ZDOT$
REWIND 6$
WRITE TAPE 11 HEND, (STARC(I), I=1,25)$
REWIND 11$
X156 DO 156 I = 1,6$
156 DLTTA(I) = ALL(I)$
DO 156 I=1,18$
158 CHED(I) = CHED3(I)$
CALL HEAD (IPGCNT)$
IPGCNT=IPGCNT+15
LINE=6$
IF(RCNT) X161,X161,X160$
X160 SU(11) = SQRT(SUM/RCNT)$ COMPUTE ROOT MEAN SQUARES OF RESIDUALS
X161 IF(RCNT2) X163,X163,X162$
X162 SUM(21=SQRT(SUM/RCNT2)$
* OUTPUT CASE, SUM, DLTTAA, OUTAP, SEE PAGE 61$
*$
X163 WRITE OUTPUT TAPE 5,1011,ITIMES,IRPT,SUM(11),SUM(21),
(DLTTA(I),I=1,6)$
1011 FORMAT(2H10,I1,2X,I1,F12.2,F12.8,6F15.8,2H70)$
IF(IASIZE)XP1,P22,XP1$
XP1 WRITE OUTPUT TAPE 5,1004$
1004 FORMAT(2H10,SUGGESTED CHANGE IN )$
WRITE OUTPUT TAPE 5,1005$
1005 FORMAT(2H10,11X,25HCOORDINATES OF DATUM - METERS)$
L=LSTC(1)$
J=7$
DO 809 X = 1,IASIZE$
GLM(J)=GLSOX(J)*XMPFR$
GLM(J+1)=GLSOX(J+1)*XMPFR$
GLM(J+2)=GLSOX(J+2)*XMPFR$
WRITE OUTPUT TAPE 5, 752, IDBUF(K), GLM(J),GLM(J+1),GLM(J+2)$
752 FORMAT(2H10,26X,I3,4X,10HDELTA X = ,F13.4,4X,10HDELTA Y = ,
F13.4,4X,10HDELTA Z = ,F13.4)$
809 J = J+3$
START TAC$
P22 JMP (P)$
END TAC$
CUMBAC IF((ABS(SUM(11)-GATE1)+ABS(SUM(21)-GATE2))OMC(OMC-OMCT2))$
161 CLAC0 161$
161 OMC20.0*OMC(OMC-OMCT2)$
GATE1 = SUM(11) X15TS6 RESET GATES FOR ACCEPTANCE OF RESIDUALS
GATE2 = SUM(21) X15TS6$
IF(GATE1)A163,A163,A163$
A163 GATE1 = SUM(11)$
A163 IF(GATE2)162,A163,162$

GAT^2 = SUN \cdot 21$

IF (SE \cdot SE \cdot LIGHT \cdot 3 \cdot 164, 164) \cdot TUR \cdot OFF \cdot SE \cdot SE \cdot LIGHT \cdot 3$}

IF (ITI ES) CL \cdot CO, CLA \cdot CO, ORBCO $\Rightarrow$ SMALL \ WE \ DO \ ANOTHER \ PASS

GO TO I$\cdot 15$

IF (TFIP) 166, 167, 167$

IF (FIEL) 166, 167, 167$

TE = TE + PI$

GO TO 1$\cdot 5$

XINCL = TEMP$\ Honolulu (\ Temp)$

wz = COS\li

X0 = X0 + DLTND \cdot SIGNF (1.0, WZ)$

RKSTO (S) = XLO$\ Honolulu (\ Temp)$

SIJ = SIN \cdot (XINCL)$

COSC = COS \cdot (XNODE (1))$

SINN = SIN \cdot (XNODE (1))$

WX = SINI \cdot SINU$

WY = (-COSO \cdot SINI)$

ES = AXI \cdot 2 + AYN \cdot 2$

P = (1.0 - 50) \cdot A$

RTP = SQRT (P)$

DO 171 I = 1, 3$

HX (I) = WX (I) \cdot RTP$ \& \& HX (I) = WX (I)$

AXI = COS \cdot AYN \cdot SINO + COSO \cdot AXN$

AYI = SINI \cdot AYN \cdot COSO + COSI \cdot AYN \cdot COSO$

AZI = AY \cdot SINI$

* X1 = A \cdot X1$

X2 = COS \cdot (ES)$

X3 = XINCL \cdot RADY$

X4 = XNODE (1) \cdot RADYN$

X2 = ATAN (AYN / AXN (1))$

IF (XYN (1)) 1X \cdot X2, 2X, X2$

X1 X

X2 = X2 + PI$

X3 X

X2 = X2T \cdot TRPI$

X4 X

X2 = X2 \cdot RA \cdot RADY$

X1 = (XLO \cdot RADYN) \cdot X2B - X3B$ \& \& MEAN ANOMALY

X1C IF (X1C) \cdot 2C, X3C, X3C$

X2C X1 = X1 + 5A$

GO TO 1C

X3C WRITE \ UTPUT TAPE 5, X4C

X4C FOR AT (X1, 5, X2, X1AXIS, 9X, FHECCEN, 6X, SIGNL, AX, XHMEAN ANOM, 3X, 3X, X7X, PFRG, 5X, 7X, 1X)$

WRITE \ UTPUT TAPE 5, X5C, X1A, X2A, X3A, X1R, X2B, X3B$

X5C FOR AT (X10, 1X, F10.5, 3X, F9, P, 2X, 4F12.8, 1X)/)$

CALL XY7P

* PRINT \ UTPUT TAPE X (6)$

* PRINT \ CASE, L0, X, THRU X (6)$

E-64
C:10  OTPT=0.$
WRITE (ITPUT TAPE 5,9840.$
X.C FOR AT(2H10,4x,4HTGF,1X,11X,12X,13X,14X,5HX DOT,7X)
5Y DOT,7X*9HX DOT)$
WRITE OUTPUT TAPE 5,X9C,OTPT(1),(X(I,I=1,3),(XDOT(T),I=1,3)$
X4C FOR AT(2H10,7F12,8)$
*
T+THF DO 172 I=1,$
172  XISTSG(I) = XISTSG(I+1)$
IF(C0(I,<3))61U0,62YGT0$;
G2  IF(IASIZE)<2,G100+3$;
G3  REIND 9$;
REIND 14$;
WRITE OUTPUT TAPE 5,9300;
G31 FOR AT(2H70,4HNEP,POSITIONS FOR STATIONS IN NON-ZERO DATUM)$;
WRITE OUTPUT TAPE 5,9310;
G31 FOR AT(2H10,4H STA,6X,4H LATITUDE,9X,4HLONGITUDE,6X,8HELEV=+TS)$;
DO(94)I=1,IASIZE$
DO(94)J=1,3$
II=6+3*(I-1)+J$
G4 DELT(J,I)=GLSQX(II)$;
II=5$
DO(66)J=1,ISTC-J$
STARC=STARC(II)$;
J=IAXD$
IF(J)R5=06B55$
G5 PHRD=STARC(II=3)$;
XLABA=STARC(II-2)$;
OALT=STARC(II-1)$;
SINPH=SIN(PHRD)$;
TEMPS=1.0-SINPH*2*EPSQD$;
CAPC=1./SQRT(TEMP)$;
CAPS=CAPC*(1.0-EPSQD)$;
CAPZ=CAPS*(OALT+CAPC)*SINPH*DELT(3,J)$;
COSPH=COS(PHRD)$;
XOVT=(OALT+CAPC)*COSPH$;
COSTH=COS(XLABA)$;
SINTH=SIN(XLABA)$;
CAPX=XOVT*COSTH-DELT(1,J)$;
CAPY=XOVT*SINTH-DELT(2,J)$;
TEMP=CAPZ/TEMP$;
STAPC(II-3)=ATAN(TEMP*0.006814755)$;
STAPC(II-2)=ATAN(CAPY/CAPX)$;
IF(CAPZ(1)=001+002+002$;
G6.1 STARC(II-2)=STARC(II-2)+PI$
G6.2 CONTINUE$
TEMP=1.0/T((1.0+TEMP**2)$;
TEMP=SQRT(1.0+00676865650*TEMP)$;
STARC(II-1)=SQRT(CAPX**2+CAPY**2+CAPZ**2)-99600924/TEMP$
PHRD=STARC(II-3)/CONV$
XLABA=STARC(II-2)/CONV$
XLABA=STARC(II-2)/CONV$
OALT=STARC(II-1)*XPER$
WRITE OUTPUT TAPE 5,932,STARC(II=4),PHIRD,XLABA,OALT$;
G32 FOR AT(2H70,4X,24X,F13,8),4X,F22,,/
WRITE OUTPUT TAPE 5,9324,CAPX,CAPY,CAPZ$
G32A FOR AT(2H10,IOX,3HX=11.8+6X+3HY=11.8+6X+3HZ=11.8$
G6 II=11+9$
DO(C7) <-1,10B:CM 9
RE: A TPE 9: (STO(I),I=1,16),ASIG1,IAX,SPHA,
CP: .5,LCDEO,CLM,SL,IBMTH,EGG 9
IF(IAX, 7, 10, 7) 9 0
C7 WRITE TPE 9 : (STO(I),I=1,16),ASIG1,IAX,SPHA,
CP/.5,LCDEO,CLM,SL,IBMTH,EGG 9
RE:IND 9 9
RE:IND 14 9
DO(I,9) <-1,10B:CM 9
RE: A TPE 9: (STO(I),I=1,16),ASIG1,IAX,SPHA,
CP/.5,LCDEO,CLM,SL,IBMTH,EGG 9
OC WRITE TPE 9: (STO(I),I=1,16),ASIG1,IAX,SPHA,
CP/.5,LCDEO,CLM,SL,IBMTH,EGG 9
RE:IND 9 9
GO TO 6100 9
II=1 9
DO(I,10) <-STO(I),I=1,10) 9
IF(STU(II))艴ecute(E),GO TO 012 9
II=II+9 9
II = 1 9
WRITE OUTPUT TPE 5, 613 9
C3 FOR AT<PHI0+17=STATION NOT FOUND> 9
STA T T C 9
RUMOUT 9
JMPAL 5 9
ENCTAC 9
G12 PHI0=STARC(II+1) 9
XLA=PA=STARC(II+2) 9
OALT = SY:RC(II*2) 9
SINPH = SIN(PHII) 9
COSP H = COS(PHII) 9
TEM = 1.0 - SINPH**2*EPSG 9
CAPC = 1.0/SGT(TEMP) 9
CAPP = CAPC*(1.0- EPSG) 9
CAP-= (-CAPC+OALT)*SINP 9
XLT=UTS(STO(4)) 9
XWCT=-(OALT+C4PC)*COSPH 9
XLJI=TH=THMP+XLLAMBA 9
THTA=XT, UTS* RPTIM+XLPTH+EGG 9
COSTH=SC(THTA) 9
SINTH=SIN(THTA) 9
CAPX=XWCT*COSTH 9
CAPY=XWCT*SINTH 9
CLM = COS(THTA-XLLAMBA) 9
SLM = SI: (THTA-XLLAMBA) 9
WST(5) = CAPX1(1) 9
WST(6) = CAPY 9
WST(7) = CAPZ 9
STA[1:-STO(I)] 9
IF(IAAX-1) 9 12,15,14 9
WST (1) = -CAWY**2*EPSG4 9
WST (2) = CPX**2*EPSG4 9
GO TO 016 9
G16 IF(IAAX-2) 9 12,16,7,01F 9
G18 IF(IAAX-1) 9 17,017 9
ASU=P=SAX-SU=SFI-SPHA 9
XLT=7=SFDE:SLZT-CCDEO 9
XLS Y=US2ST*SYT*(-1.0) 9
XLT Y=UXTDULZT 9
ASU Z=E 9
DSI Z=ST*=SLZT 9
DSI Z=ST*AMPT 9
E-66
XS = -IK T, l! - Y CS L , 
(1 )

SS ... SL ... E+ RX Y
SS ... XZ ... FS ... Y
SS ... ZS ... -US 
ZSU ... Y = SUP ... ESU ... X
ZSU ... X = = SSU ... Z ... ESU ... Ys

DO (20) I = 1, 2
Ia = I + 7 ID = I + 10 IL = I + 13

KST(I) = XL ... Suy ... *ESU ... X(I) + XLS ... ZUH ... *ZSU ... X(I)
KST(I) = ASI ... X ... SSU ... X(I) + ASU ... T ... ZSUB ... X(I)

GO TO 73

EFLG = 0.5
IF (IRPT) R173 = E173, 174 $17$

IRPT = IRPT + 1
IF (SELE LIGHT 1) SEC3, SEC3 $60$ DO ANOTHER CORRECTION

*START A NEW PAGE AND PRINT SIGMA

WRITE OUTPUT TAPE 5, 1, 065$

1:06$
FOR ATT(?H1U ... 29 ... 10H SIGMA ... 3X ... 9 ... HDELTA UY ... 6X ... 9 ... HDELT A) UY ... 6X ... 9 ... HDELTA I)
WRITE OUTPUT TAPE 5, 1007, (DIAS(I), I = 1, 6) $

1:07$
FOR ATT(?H1U ... 29 ... 10H SIGMA ... 3X ... 9 ... HDELTA UY ... 6X ... 9 ... HDELTA I)
WRITE OUTPUT TAPE 5, 1008$

P11$
WRITE OUTPUT TAPE 5, 1008$

1:08$
FOR ATT (3H ... 10H SIGMA ... POSITION ERROR OF DATUM )$

LA = LETCAT $

J = 7$

DO 703 = 1, I SIZE
BIAS(J) = RCIAS(J) * XPER $'
BIAS(J+1) = DIAS(J+1) * XPER$
BIAS(J+2) = DIAS(J+2) * XPER $

WRITE OUTPUT TAPE 5, 1009, IDUF(K) = DIAS(J), BDIAS(J), BDIAS(J+1), BDIAS(J+2)

1:09$
FOR ATT (?H10 ... 26X ... 13 ... 4X ... 10H SIGMA ... X ...) 3X ... 9 ... F13 ... 2 ... 4X ... 10H SIGMA ... Y (...) 3X
XVEC(1) = AVEF(1) , YVEC(1) = AVEF(2) ... ZVEC(1) = AVEF(3)$

7:3$
J = J + 3$
R = IPG... CNT = IPG ... CAT + 1$
REM ... 11 $
XFLG *, 1$

S:2$
REM. $TA = 11 , R = ST(1) ... (RSUBA(I), I = 1, 4) ... (USUBA(I), I = 1, 4) ... (UX(I), I = 1, 4) ... (Y(I), I = 1, 4) ... (X(I), I = 1, 3 ... UT(I + 1); I = 1, 3)$

IF (KST(1) = 0) $HE$ $C(1)$, GO TO 173$

*FOR ... THE 6 VECTORS FOR $X Y Z$

DO 759 = 1, 3$

7:5$
AVEC(I) = UX(I) ... RSUBU + VX(I) ... USUBU$
XVEC(1) = AVEC(1) ... YVEC(1) = AVEC(2) ... ZVEC(1) = AVEC(3) $

DO 760 = 1, 3$

7$

AVEC(I) = UX(I) ... RSUBA + VX(I) ... USUBA$
XVEC(2) = AVEC(1) ... YVEC(2) = AVEC(2) ... ZVEC(2) = AVEC(3)$

DO 761 = 1, 3$

7:1$
XVEF(1) = UX(I) ... RX ... VX(I) ... UY $XVEF(3) = AVEC(1) ... YVEC(3) = AVEC(2) ... ZVEC(3) = AVEC(3)$

DO 762 = 1, 3$

7:2$
AVEF(I) = UX(I) ... RX ... VX(I) ... UY$
XVEC(4) = AVEC(1) ... YVEC(4) = AVEC(2) ... ZVEC(4) = AVEC(3)$

DO 763 = 1, 3$

7:3$
AVEF(1) = UX(I) ... RX ... VX(I) ... COSU ... USIN $XVEF(5) = AVEC(1) ... YVEC(5) = AVEC(2) ... ZVEC(5) = AVEC(3)$

E-67
DO 744  I=1,3

XVEC(1) = X(I) * X(I) * SINU  $  
XVEC(2) = AVEC(1) * XVEC(6) = AVEC(2) * XVEC(6) = AVEC(3)  $  

*TRNSP*  
SF = ATCFS X1 YZ  
ST = T C S  
SA = FMAU = FMAN = FMAN +1 $  
TM = ADRC $  
TM = ADRC $  
JMP TRP TRP $  
TM = ADRC $  
TM = ADRC $  
JMP TRP TRP $  

*TRNSP MULPLY 3 ATICES  
A FMAU = ADRC = TRXG ADR3 = ADR4 $  
A FMAU = ADRC = ADR1 T ADR2 $  
A FMAU = ADRC = ADR3 T ADR4 $  
A FMAU = ADRC = ADR1 T ADR2 $  

JMP GO0 $  

ATC C/HLT = C/HLT +1 $  
ATX C/HLT = AVEC = C/HLT XTVEC $  
AY C/HLT YVEC = C/HLT YVEC $  
AZ C/HLT ZVEC = C/HLT ZVEC $  
AC C/HLT = XVEC = C/HLT = XVEC $  
AX C/HLT = MTC = C/HLT = MTC $  
AY C/HLT = CYC = C/HLT = CYC $  
AZ C/HLT = CZC = C/HLT = CZC $  
AV X C/HLT = XVEC = C/HLT = XVEC $  
AY Y C/HLT = YVEC = C/HLT = YVEC $  
AZ Y C/HLT = YCY = C/HLT = YCY $  
AV Y C/HLT = ZVEC = C/HLT = ZVEC $  
AY Z C/HLT = ZCY = C/HLT = ZCY $  
AZ Z C/HLT = ZCZ = C/HLT = ZCZ $  

EN: TAC  

*FOLLOWING THE FMAMU ROUTINES  
G(CN) AXSIG = RT(XCY) XMPER $  
AYSIG = RT(YCY) XMPER $  
AZSIG = RT(ZCY) XMPER $  
OO TEMP I = 1,18 $  

745 CHT(I) = CHEL5(I) $  
   IF("FLA") 766 $ 747 7XFLA = I:  
   LINC=56 $  
748 IF(LINC=54) 769 $ 768 749  
745 = CALL HEAO(I = GC T) $  
   LINC=55 $ IPGC T = IPGC T +1  
745 = CALL C=1 $  

*PRINT SATELLIT V POSITIONS SIGN $S  
AXAM WRITE 0; TPUTAPE 5; 227 = RKSTO(I), (X(I), I=1,3) AXSIG, AYSIG, AZSIG $  
1010 FOR A(TH10, 7F15, 8):  
GO TO 5,2:  
173 IF(CNT = (10)) 175, START 175 $  
175 TE = P = 2 = (10) * ( = 2 = 0, 48) = THGF = 360, 0 $  
X176 IF(TE=?) 176, 177 $  

E-68
*LEAST SQUARES SUBROUTINE*

* GETS UP THE LEAST SQUARES ROUTINE FOR MATRIX SIZE N *
* ENTERS WITH N15 IN A *
* SETS UP THE FOLLOWING PARAMETERS

---

* COUNTL NT15 *
* COUNTR NT39 *
* LSQP1 C/H TL*TERMS+NC/JMP,LSQMULT *
* LSQP2 C/H TL*GLSGA+N*(N+1)/C/JMP,LSQLOC2 *
* LSQP3 C/H TL*GLSQG+N* C/H TL*GLSGA+N *
* LSQP4 NT15 *
* LSQP5 (N+1)T15 *
* LSQP6 NT15NT39 *
* LSQDM C/TN+12GC/AIXL,N+2 ------- PROGRAM INSTRUCTION
* LSQP6 (N+1)T150 (N+1)T39

CHGXXN

TJX

CHGXXN

TA

COU.TL$ *

SRD

24$ *

TDX

COUNTR$ *

AD

$ *

TA

COUNTR$ *

TMA

C/H TL*TERMSGC/JMP,LSQMULT$ *

AM

COUNTL$ *

TA

LSQP1$ *

TMA

COUNTR$ *

SRG

$ *

TMG

COUNTL$ *

TGA

$ *

AM

COUNTR$ *

TMA

C/H TL*GLSGA/GC/JMP,LSQLOC2$ *

TAX

LSQP2$ *

TMA

C/H TL*GLSQG/GC/JMP,LSQLOC$ *

AM

COUNTL$ *

TA

LSQP3$ *

TMA

C/H TL*GLSQG/GC/H TL,GLSQA$ *

AM

COUNTR$ *

TAX

LSQP4$ *

TMA

COUNTR$ *

TDX

LSQP1$ *

SM

C/H TL,1$ *

TAM

LSQP5$ *

TMA

COU TR$, *

TDM

LSQP3$ *

TMA

C/TN+2GC/AIXL,0,2$ *

AM

COUNTR$ *

TAM

LSQGN$ *

TMA

C/H TL,10C/H TL,1$ *

AM

COUNTR$ *

TA

LSQP6$ *

CHGXXN XJMP

0$ *

LS

TDM

C/H TL,1GC/H TL,GLSCAS *

TDX:C

15$ *

TM$ F/05 *

L

HPT

6005
BUILD A

BUILD B

FILL IN A MATRIX

END TAC

*DIAGONAL ELEMENTS AND ROOTS

IF(LM mode)E(3), IBG = 6 $  
IB = IB + 1 $  
I = I + 1 $  
DO 774 K = 1, IB(1) IB(2) $  
E-71
IF (I = 6) 774, 774, 770

770 BDIAG(I) = QLSQA(K) $  
BDIAG(I) = SORT(QLSQA(K))$  
SORT(DIAG ELEM OF INVERSE MATRIX A)

774 CONTINUE $  
IF (LANCE) E (P), GO TO MATM $

*REF-LOCATE THE FX6 MATRIX I: CVERT$

I = 1 $

DO 772 = 1, 6 $  
J = (M-1) * LSTCNT + 1 $  
FORM CVERT;  
K = J + 5 $  
DO 771 L = J, K $  
CVERT(I) = QLSQA(L) $  
771 I = I + 1 $
772 CONTINUE $  

START TAC$

A *MATM FMAMU LSQSP3,LSQSP4,LSQSP5 $
LSQSPX JMP 05$  
LSQSP1 C/HLTL,TERMSGC/HLTL,0$  
LSQSP2 C/HLTL,TERMSGC/HLTL,1$  
LSQSP3 C/HLTL,TERMSGC/JMP,LSQBP$  
LSQSP4 C/HLTL,TERMSGC/HLTL,0$  
LSQSP5 C/HLTL,TERMSGC/HLTL,1$  
LSQBUF SET (P)+50 $  

PAGE$

AFEND 40 $  
AFEND 40$  
NAME BCD2BIN$

EXIT JMP (P)  
RCD2BIN TJM EXIT  
TMA 0/77  
TAA BCD,WOR$  
ETA BCD,WOR$  
JG0 EXIT$

TAG1 SRAQ 2  
AD SRAQ 3  
EA BCD,WOR$  
JGF TAD1  
JMP EXIT$

PAGE$

*CONVRT EXP,DEC, TO FLT, BINARY$

AFEND 40$  
NAME FLTFLT$

FLTFLT TJM FLTFLTX  
JMP INDEX  
TJM DCNTR $  
CM MSIGN  
CM CSIGN  
CM DIGITS  
CM CNTDIG  
CM ADIG  
TM1 K8  
TDV AF  
TMD K9  
TDM AD  
TGV SAV$  
SRAQ 1R  
TQV SAV1  
TAG$

E-72
<table>
<thead>
<tr>
<th>Function</th>
<th>Operation</th>
<th>Flags</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDXLC</td>
<td>Store C to X, C to XM, X to XM</td>
<td>5</td>
</tr>
<tr>
<td>TDXXC</td>
<td>Store C to X, C to XM, X to XM</td>
<td>6</td>
</tr>
<tr>
<td>IM EXT JMP</td>
<td>Jump to memory location</td>
<td>(P)</td>
</tr>
<tr>
<td>BLANK</td>
<td>Store 0 to memory location</td>
<td></td>
</tr>
<tr>
<td>K1</td>
<td>Jump to memory location</td>
<td></td>
</tr>
<tr>
<td>K2</td>
<td>Jump to memory location</td>
<td></td>
</tr>
<tr>
<td>K3</td>
<td>Jump to memory location</td>
<td></td>
</tr>
<tr>
<td>K4</td>
<td>Jump to memory location</td>
<td></td>
</tr>
<tr>
<td>K5</td>
<td>Jump to memory location</td>
<td></td>
</tr>
<tr>
<td>K6</td>
<td>Jump to memory location</td>
<td></td>
</tr>
<tr>
<td>PLUS</td>
<td>Add memory location</td>
<td></td>
</tr>
<tr>
<td>MINUS</td>
<td>Subtract memory location</td>
<td></td>
</tr>
<tr>
<td>K7</td>
<td>Multiply memory location</td>
<td></td>
</tr>
<tr>
<td>K8</td>
<td>Multiply memory location</td>
<td></td>
</tr>
<tr>
<td>DEC</td>
<td>Subtract memory location</td>
<td></td>
</tr>
<tr>
<td>ENE</td>
<td>Write memory location</td>
<td></td>
</tr>
<tr>
<td>DIC</td>
<td>Write memory location</td>
<td></td>
</tr>
</tbody>
</table>

* Fixed point dec. to floating binary

**FIXED POINT DEC. TO FLOATING BINARY**

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FXFLT</td>
<td>Float X to memory location</td>
</tr>
<tr>
<td>JMP</td>
<td>Jump to memory location</td>
</tr>
<tr>
<td>CM</td>
<td>Memory sign</td>
</tr>
<tr>
<td>CM</td>
<td>Memory digits</td>
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<tr>
<td>CM</td>
<td>Memory digits</td>
</tr>
<tr>
<td>TMD</td>
<td>Memory</td>
</tr>
<tr>
<td>TDTK</td>
<td>Tag register</td>
</tr>
<tr>
<td>TQ9</td>
<td>Tag register</td>
</tr>
<tr>
<td>TAG</td>
<td>Tag register</td>
</tr>
<tr>
<td>TIXZ</td>
<td>Double word memory location</td>
</tr>
<tr>
<td>BB</td>
<td>Double word memory location</td>
</tr>
<tr>
<td>BA</td>
<td>Double word memory location</td>
</tr>
<tr>
<td>CA</td>
<td>Double word memory location</td>
</tr>
<tr>
<td>SLA9</td>
<td>Shift left</td>
</tr>
<tr>
<td>TMD</td>
<td>Memory</td>
</tr>
<tr>
<td>JAED</td>
<td>Register</td>
</tr>
<tr>
<td>TMD</td>
<td>Memory</td>
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<tr>
<td>JAED</td>
<td>Register</td>
</tr>
<tr>
<td>TMD</td>
<td>Memory</td>
</tr>
<tr>
<td>JAED</td>
<td>Register</td>
</tr>
<tr>
<td>LBD</td>
<td>Long word memory location</td>
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<tr>
<td>TMD</td>
<td>Memory</td>
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<tr>
<td>JAED</td>
<td>Register</td>
</tr>
<tr>
<td>TAK</td>
<td>Tag register</td>
</tr>
<tr>
<td>TMA</td>
<td>Tag register</td>
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<tr>
<td>SLA</td>
<td>Shift left</td>
</tr>
<tr>
<td>AM</td>
<td>Memory digits</td>
</tr>
<tr>
<td>SLA</td>
<td>Shift left</td>
</tr>
<tr>
<td>AM</td>
<td>Memory digits</td>
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<tr>
<td>BC</td>
<td>Shift left</td>
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<tr>
<td>TMD</td>
<td>Memory</td>
</tr>
<tr>
<td>AIXJ</td>
<td>Memory register</td>
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<td>Memory register</td>
</tr>
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<td>TMD</td>
<td>Memory</td>
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<tr>
<td>TAK</td>
<td>Tag register</td>
</tr>
<tr>
<td>SLA9N</td>
<td>Shift right</td>
</tr>
<tr>
<td>SLA9</td>
<td>Shift right</td>
</tr>
<tr>
<td>AM</td>
<td>Memory digits</td>
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<tr>
<td>TAM</td>
<td>Memory register</td>
</tr>
<tr>
<td>FCAMS</td>
<td>Write memory location</td>
</tr>
<tr>
<td>TQA</td>
<td>Write memory location</td>
</tr>
</tbody>
</table>

E-75
AM D/35
FANS SAV1
TMA ADIG
JAZ BR
TDX<C +1
TMA F/10
TMC F/10
RA FMAP
TMD X5
SIXJ 1 +1
TAA SAV
TMA SAV1
FDAS SAV
BR1 TMA MSIGN
JAZ (P)+2H
FCMS SAV
TMA SAV
JMP INDEXE
FXFLTX JMP (P)
*
BR TMD SAV1
TD< SAV
JMP BR1
LX1 TMD DEC
JAED BDEC
X2 C/NOP+UTC/INCAR;ADIG
X3 C/HLT+UGC/JMP;BA
X4 C/HLT+GC/JMP;BB
X5 C/HLT+UGC/JMP;BN
BMIN TJM MSIGN
JMP BC
BDFC TMD X2
TDM BD
JMP AC
PAGE $ AFEND 80 $
NAME TRP$
LRESET HLT$
HLT$
LTRP TAO$
NOP TRAN$S
TDXLC +1X$
TDXRC +2X$
TJM EXIT$
TIU +1X$
TIU TRANS$S
TIU +2X$
TJM TRANS+1H$
TGM RESET$
ADXL +2X$
TIU +2X$
TDXLC +1X$
TDXRC +2X$
TJM TRPS
RTRANS RPTAA$
TMD 0 1X$
TDM +1 2X$
INCA RESET$
TDX +1X$
TMD TRPS$
AIU +0 1X$

E-76
EXIT
JMP (P)$
ENDSUB
*
RUNGE KUTTA INTEGRATION ROUTINE
NAME RUNGE$
LEXIT
JMP (P)$
ERROR
JMP (P)$
RUNGE
TJM ERRORS$ SET ERROR EXIT
TXDLC *3X5$ SAVE 3X THRU 0X
TXORC *4X5$
TDM X5X4S$
TXDLC *5X5$
TXORC *6X5$
TDM X5X5S$
TXDLC *7X5$
TXORC *0X5$
TDM X7X0S$
*
SET UP INPUT PARAMETERS
LXSET
TAD SET A PARAMETER
TDXFC *1X5$
TDXLC *2X5$
TXORC *1X5$
TJM CTLS SET CONTROL ENTRY
TXDLC *2X5$
TJM DER1S SET DERIV ENTRIES
TJM DER2S$
TJM DER3S$
TJM DER4S$
TJM DER5S$
TQD SET Q PARAMETER$
TXDLC *1X5$
TXDLC *1X5$
TJM TESTMS SET MODE ADDRESS
TCXSC *1X5$
TXDL *1X5$
TJM CX5$ X FL
TJM EX$ TCM X1S
TJM BXS$ X FX
TJM IX5$
AIXCR 1,1X5S
TXDL *1X5$
TJM ADXPS PREV DELTA-X FX
TJM BDXPS$
AIXCR 1,1X5S
TXDL *1X5$
TJM AXZS X-ZERO FX
TJM IXZS$
TJM BXZ5$
TJM IX5$
TCXSC *1X5$
TXDL *1X5$
TJM HDX1S DELTA-X FL
TJM HDX2S$
TJM HDX3S$
TCXZ *1X5$
TXDL *1X5$
TJM ADX5 DELTA-X FX
TJM HDX5$
AIXCR 1,1X5S
TXDL *1X5$
TJM XSETS Y FX
TJX F6NS
TCXZ $1X5
TXDL $1X5
TJXR CENV5
TQD $1X5
ADXR $1X5
TCXZ $1X5
TXDL $1X5
TJMH HLOOP5
TQO $1X5
ADXR $1X5
TXDL $1X5
TJMM B9NS
TJMR I9NS
TCXS $1X5
TXML $1X5
TJXR F9NS
TJMH H9NS
TMD JUMP5 SET NO DECREASE
J0E (P)+1S TEST FOR DECREASE LOOP
TMD RETURN5 SET DECREASE
TDXRC $1X5
TXDRC $1X5
TJM OPTJS SET OPTIONAL JUMP
TMA EXIT5
AM FBITS
TAD
TXDRC $1X5
TXDRC $1X5
TJM EXIT5 SET NORMAL EXIT

* ACTUAL RUNGE-KUTTA INTEGRATION STARTS HERE
RESTARTTOM DONE5 SET SWITCH PLUS
TOM SWITCH5
TMD XSETS SET REGIONS TO ZERO
TOXLCC $1X5 FOR INITIAL PRINT
TMG F/O5 GET F.P. ZERO
ALOOP TOM $1X5 CLEAR Y-HALF
A2N TOM $1X5 Y-ZERO
A4N TOM $1X5 D-HALF
A5N TOM $1X5 D-ZERO
TMD TEST05
AIXJ $1X5 LOOP TIL DONE
AXZ TOM $ CLEAR X-ZERO
AXZ TOM $ MOVE DELTA-X TO
ACPX TOM $ PREVIOUS DELTA-X
DER1 JMP (P)+S ENTER DERIV
LCTNU TOM CTLS SET INDEX FOR
LDXF $7X5 VARIABLE RETURN
CTL JMP (P)+S ENTER CONTROL
JMP RETURN5 DUMMY ADDRESS
Bx TOM $ MOVE X TO X-ZERO
BXZ TOM $ MOVE Y TO Y-ZERO
<table>
<thead>
<tr>
<th>B2N</th>
<th>TDm</th>
<th>*1X$</th>
<th>D TO D-ZERO</th>
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<td>B3N</td>
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<tr>
<td>BSN</td>
<td>TDA</td>
<td>*1X$</td>
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</tr>
<tr>
<td>BSN</td>
<td>TMG</td>
<td>*1X$</td>
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<td>JAP:</td>
<td>XERROR$</td>
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<td>0+1X$</td>
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<td>JAP:</td>
<td>(P)$</td>
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<td>TMD</td>
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CLEAN DELTA-Y ACCUMULATOR

LOOP TIL DONE

MAKE ERROR EXIT

MOVE DELTA-X TO PREVIOUS DX

FORM DX/2

FORM DX/4

SET LOOP FOR STEP 1

GET DX/4

D*DX/4 TO CUMULATIVE

MOVE Y TO Y-HALF

Y + D*DX/4 TO Y

ENTER DERIV

SET LOOP FOR STEP 2

GET DX/4

D*DX/4 TO D

D*DX/4 + Y-HALF TO Y

D*DX/2 + CUMULATIVE TO CUMULATIVE

LOOP TIL DONE

ENTER DERIV

GET DX/2

SET LOOP FOR STEP 3

D*DX/2 TO D

D*DX/2 + Y-HALF TO Y

D*DX/2 + CUMULATIVE TO CUMULATIVE

LOOP TIL DONE

X + DX/4 TO X

ENTER DERIV

SET LOOP FOR STEP 4

GET DX/4

(D*DX/4 + CUMUL.)/3

+ Y-HALF TO Y
ADD HALF-STEP INCREMENT TO DELTA-Y ACCUMULATOR

LOOP TIL DONE

ENTER DERIV

FLIP SWITCH

IF FULL STEP, TO MORE TEST

SET LOOP FOR D MOVE

MOVE D TO D-HALF

LOOP TIL DONE

TO 2ND HALF-STEP

GET MODE

VARIABLE-TO FIND MAX

FIXED-TO CONTROL ENTRY

F.P. ZERO TO MAX

SET MAX ERROR LOOP

GET REL ERR CONTROL

R*Y-ABS

ADD ABS ERR CONTROL

SAVE ERR CONTROL TERM

IF ZERO

MAKE ERROR EXIT

FORM SIMPSONS RULE DY

(4*D-HALF)

+D

+D-ZERO)/3

*DX/2

SUBTRACT RK DELTA-Y

FORM ERROR TERM

ABS VALUE TO A

TEST MAX

TO SET NEW MAX

TO LOOP TEST

STORE NEW MAX

LOOP TIL DONE

GET MAX ERROR TERM

TEST 1.0

TO DECREASE AND CONTINUE

TO DECR. AND BACKUP

TEST 0.75

TO CONT.

TO DECR. AND CONT.

TEST 0.075

TO CONT.

INCREASE AND CONT.

DECREASE AND BACKUP

OPTIONAL DECREASE LOOP

MAX/10 TO MAX

TO DECREASE AGAIN
CJmp BAKUPS

OK
DECREASE AND CONT.

In TW4 RPT10%

CONT.

HrX3 FM s

JMP CTIUS

BAKUP TMD XSETS

SET LOOP

TDXL & F/05

GET F.P. ZERO

TMD 1X5

MOVE D-ZERO TO D

TMD 1X5

Y-ZERO TO Y

TMD 1X5

CLEAR DELTA-Y

TMD TEST85

LOOP TIL DONE

TMD 1X5

MOVE X-ZERO TO X

TMD

TO REPEAT STEP

TMD

ADDRESS DUMMY

TMD

NORMAL CONTINUE

RFILL HLTK TEST05

LRETURN JMP BX5

JMP OPTJ+1HS

LJUMP JMP BAKUPS

JMP BAKUPS

LFBIT JMP RESTARTS

HLTP 05

LDONE JMP RESETS

JMP EXITS

XERROR CSM DONE5

JMP RESETS

JMP ERRORS

DERERROR CAM DONE5

JMP SET A-SIGN PLUS

RESET TJM XERROR+1HS

ERR CONTROL TERM=O

RESET A-SIGN MINUS

RM XERROR+1HS

RESTORE X-REGS

BACK JMP (P)5

LOOP CONTROLS

-TEST0 HLT 05

JMP ALOOPS

TFST1 HLT 05

JMP BLOOPS

TEST2 HLT 05

JMP CLOOPS

TEST3 HLT 05

JMP DLOOPS

TEST4 HLT 05

JMP ELOOPS

TEST5 HLT 05

JMP FLOOPS

TEST6 HLT 05

JMP GLOOPS

TEST7 HLT 05

JMP HLOOPS

TEST8 HLT 05

JMP ILOOPS

RT10 F/1.584#931935
NAME 0001PRC $ END TAC $ END $
REFERENCES

1. Research In Geodesy and Gravity, Computer Programs for Orbit Correction and Station Location; AFCRL 62-892, C.G. Hilton, J.E. Evans, L. Nicola (1962)


4. An Introduction to Astrodynamics; Academic Press; Baker and Makemson (1960)

The analysis and programming associated with performing a differential correction to orbital elements and/or station positions from weighted observations of range, range rate, azimuth-elevation and/or right ascension-declination on close earth satellites are described. The ephemeris computation considers perturbations due to the earth's gravitational potential as described by a spherical harmonic representation through $n = m = 5$, the lunar gravitational potential, air drag, and radiation pressure. All observations may be simulated in punched card form for the purpose of conducting geometric studies.
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