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SCOUT TRAJECTORY ERROR PROPAGATION
COMPUTER PROGRAM

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SCOUT TRAJECTORY ERROR PROPAGATION
COMPUTER PROGRAM

by T. R. Myler
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SUMMARY

This report describes a FORTRAN coded computer program which calculates trajectory error covariance matrices and statistics from a data base of flight experience. The data base consists of trajectory errors resulting from past flights. A covariance matrix is calculated and may be propagated in time and added to a boost covariance matrix of a spin-stabilized stage. A sensitivity matrix is developed from the eigenvalues and eigenvectors of the final propagated covariance matrix. This sensitivity matrix is provided for use by another computer program to randomly sample the matrix using a Monte Carlo technique to yield sample errors which will produce the same covariance matrix.

The theory and methods presented in this report for calculating error statistics and propagating an error covariance matrix are of general interest since they have applications other than those contained herein.

Included in this report are program theory, user instructions, output descriptions, subroutine descriptions and detailed FORTRAN coding information.
1.0 INTRODUCTION

Since 1969, flight experience has been used as the basis for predicting Scout orbital accuracy. The data base used for calculating the accuracy consists of errors in the trajectory parameters (altitude, velocity, etc.) at stage burnout as observed on Scout flights. Approximately 50 sets of errors are used in a Monte Carlo analysis to generate error statistics in the trajectory parameters. A covariance matrix is formed which may be propagated in time. The mechanization of this process resulted in computer program Scout Trajectory Error Propagation (acronym STEP) and is described herein.

Computer program STEP may be used in conjunction with the Statistical Orbital Analysis Routine (Reference 1) to generate accuracy in the orbit parameters (apogee, perigee, inclination, etc.) based upon flight experience.
2.0 **DEFINITIONS**

2.1 **Notation**

Symbols used in this report are listed below with their definition and units.

**English Alphabet**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{E}_{\text{el}}$</td>
<td>East component of position error, ft</td>
</tr>
<tr>
<td>$\mathcal{E}_{\text{N}}$</td>
<td>North component of position error, ft</td>
</tr>
<tr>
<td>$\mathcal{C}_{\text{R}}$</td>
<td>Crossrange, n.mi.</td>
</tr>
<tr>
<td>$\mathcal{N}$</td>
<td>Altitude, n.mi.</td>
</tr>
<tr>
<td>$\mathcal{N}$</td>
<td>Number of samples</td>
</tr>
<tr>
<td>$r_e$</td>
<td>Earth radius, ft</td>
</tr>
<tr>
<td>$R$</td>
<td>Range, n.mi.</td>
</tr>
<tr>
<td>$V$</td>
<td>Velocity, fps</td>
</tr>
</tbody>
</table>

**Greek Alphabet**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>Flight path angle, deg</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>Deviation from nominal</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>Random number, unitless</td>
</tr>
<tr>
<td>$\xi$</td>
<td>Velocity azimuth, deg</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Latitude, deg</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Longitude, deg</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Statistical mean</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Correlation coefficient</td>
</tr>
<tr>
<td>$\Sigma$</td>
<td>Summation</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Standard deviation</td>
</tr>
</tbody>
</table>

**Others**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{\partial x}{\partial y}$</td>
<td>Partial derivative of $x$ to $y$</td>
</tr>
</tbody>
</table>
2.2 Flowchart Conventions

Flowchart conventions used in this report are as follows:

- Process
- Input/Output
- Subroutine
- Decision
- Subroutine Call
3.0 PROGRAM DESCRIPTION

This section describes the utilization of the Scout data base, program theory, user instructions and output definitions.

3.1 General

The purpose of computer program STEP is to calculate trajectory error statistics from a data base of errors resulting from actual flights. This data base consists of stage burnout errors in the trajectory parameters - altitude, velocity, flight path angle, flight azimuth, latitude and longitude.

The Scout data base at orbit insertion is shown in Table 3.1. These errors represent flights at various launch azimuths and insertion altitudes. Since errors in latitude and longitude are dependent upon launch azimuth and since errors in altitude, velocity and flight path angle may be dependent upon insertion altitude, adjustments are made to the flight errors in order to provide a consistent data base from which to generate the error statistics. These adjustments are discussed in the following paragraphs.

The Scout data base includes flights with launch azimuths ranging from easterly to southerly to slightly west of south. Latitude and longitude errors, which may produce inclination errors, result from crossrange errors on easterly flights and range errors on southerly flights. Therefore, latitude and longitude errors of the flight history data base are not a consistent set of sample errors for a given launch azimuth. Since it is necessary to have a consistent set of sample errors, the data base latitude and longitude errors are adjusted to the launch azimuth of interest. From the nominal flight azimuth, latitude, longitude and their errors on each flight of the data base, range and crossrange errors are calculated. Since range and crossrange errors are independent of the flight azimuth, these
errors can be converted to new latitude and longitude errors for the flight azimuth of interest by the following transformation.

\[
\begin{align*}
C_N &= r_e \Delta \lambda \\
C_E &= r_e \Delta \mu \cos \lambda \\
\Delta R &= C_N \cos \xi + C_E \sin \xi \\
\Delta CR &= C_N \sin \xi - C_E \cos \xi
\end{align*}
\]

The above relationships are evaluated for each flight sample of the data base, resulting in range and crossrange errors for each flight. Note that latitude and longitude errors are needed to calculate range and crossrange errors. The range and crossrange errors are then converted to latitude and longitude errors applicable to the flight azimuth of interest as shown below.

\[
\begin{align*}
C_N' &= \Delta R \cos \xi' + \Delta CR \sin \xi' \\
C_E' &= \Delta R \sin \xi' - \Delta CR \cos \xi' \\
\Delta \lambda' &= C_N'/r_e \\
\Delta \mu' &= C_E'/r_e \cos \lambda
\end{align*}
\]

where the primed values pertain to the conditions at which the error statistics are desired.

The above process yields latitude and longitude errors which are used in the flight data base for calculating trajectory error statistics.

The second adjustment made to the flight data base is to "normalize" the errors in altitude, velocity and flight path angle to the insertion altitude of interest. The purpose of this adjustment is to obtain the flight errors which would have resulted if all the flights had had the same insertion altitude. This adjustment is accomplished for each flight sample as follows:

\[
\Delta V' = \frac{\sigma V'}{\sigma V} \Delta V
\]

- 6 -
where $\Delta V'$ = adjusted velocity error at the insertion altitude of interest

$\Delta V$ = flight sample velocity error

$\sigma_{V'}$ = standard deviation of velocity at the insertion altitude of interest

$\sigma_{V}$ = standard deviation of velocity at the flight sample insertion altitude

Similar expressions are used for altitude and flight path angle errors. Azimuth, latitude and longitude errors are not adjusted for insertion altitude because they are independent of insertion altitude.

The "normalized" deviations in altitude, velocity and flight path angle - the adjusted deviations in latitude and longitude - and the azimuth deviations from the flight samples - are combined to be the flight data base from which error statistics are calculated. This flight data base is applicable only to a trajectory with the insertion altitude and launch azimuth to which the flight errors were adjusted.

The "normalizing" process should be used only when altitude, velocity and flight path angle errors input in the flight data base, are a function of insertion altitude. This relationship is true for Scout because there is a long coast time (300-400 seconds) prior to the last stage boost, which allows the errors to grow. Thus, the error magnitudes at last stage ignition are a function of time and altitude. If the input flight data base corresponds to the stage burnout prior to the long coast time, the errors should not be normalized.

The normalizing equation involves a ratio of standard deviations of the trajectory parameter. These deviations can be obtained by inputting a flight data base at stage burnout prior to the long coast time and propagating the covariance matrix to various insertion altitudes.
3.2 Program Theory

The primary function of STEP is to calculate and/or propagate a covariance matrix of trajectory state parameters - altitude, velocity, flight path angle, azimuth, latitude and longitude. The initial covariance matrix is either input directly or is calculated from input samples of actual flight errors (flight experience). Covariance propagation is optional and is controlled by inputs to the program. If selected, a boost covariance matrix of a spin-stabilized stage is calculated and added to the propagated covariance matrix. The resulting matrix - or the covariance matrix at the input epoch if it is not propagated - provides statistics in the trajectory parameter errors. Also, sensitivity coefficients calculated from the covariance matrix can be used by another computer program to provide a sampling of trajectory errors which can be converted to orbital parameter error statistics. Such a program is the Statistical Orbital Analysis Routine, Reference (1).

The calculation of a covariance matrix from flight results and the calculation of the sensitivity coefficients are discussed below.

Each of the six parameters of the flight data base, as described in Section 3.1, are combined in the manner shown below to yield mean values, standard deviations and correlation coefficients.

\[
\bar{x} = \frac{\sum_{i=1}^{n} \Delta x_i}{n} \quad \text{mean value}
\]

\[
\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} \Delta x_i^2}{n-1} - \bar{x}^2} \quad \text{standard deviation}
\]

\[
\rho_{xy} = \frac{\sum_{i=1}^{n} \Delta x_i \Delta y_i - n\bar{x}\bar{y}}{n\sigma_x\sigma_y} \quad \text{correlation coefficient}
\]

where \( x \) and \( y \) are any two parameters.
The error covariance matrix is obtained from the error statistics calculated as shown on the preceding page and has the following form:

\[
\begin{bmatrix}
\sigma_n^2 & \rho_{n,v} \sigma_n \sigma_v & \rho_{n,\delta} \sigma_n \sigma_{\delta} & \ldots & & \\
\rho_{n,v} \sigma_n \sigma_v & \sigma_v^2 & \rho_{v,\delta} \sigma_v \sigma_{\delta} & \ldots & & \\
\rho_{n,\delta} \sigma_n \sigma_{\delta} & \rho_{v,\delta} \sigma_v \sigma_{\delta} & \sigma_{\delta}^2 & \ldots & & \\
\ldots & \ldots & \ldots & \ldots & \ddots & \\
\end{bmatrix}
\]

Symmetric

The error covariance matrix is a real, symmetric matrix and can be diagonalized to obtain the eigenvectors and eigenvalues. A matrix using the eigenvalues is formed as follows:

\[
[A] = [\sqrt{EV_1} \ \sqrt{EV_2} \ \sqrt{EV_3} \ \sqrt{EV_4} \ \sqrt{EV_5} \ \sqrt{EV_6}]
\]

where \( EV_i \) = eigenvalues

The sensitivity matrix is formed from the A matrix and the eigenvector matrix as follows:

\[
[S] = [A][ET]^T
\]

where \([ET]^T\) is the transpose of the eigenvector matrix.

The S matrix represents a sensitivity matrix of the six trajectory parameters to six independent and uncorrelated error sources and has the following form:

\[
[S] = \begin{bmatrix}
\frac{\partial h}{\partial E_1} & \frac{\partial V}{\partial E_1} & \frac{\partial \gamma}{\partial E_1} & \frac{\partial \xi}{\partial E_1} & \frac{\partial \lambda}{\partial E_1} & \frac{\partial \mu}{\partial E_1} \\
\frac{\partial h}{\partial E_2} & \frac{\partial V}{\partial E_2} & \frac{\partial \gamma}{\partial E_2} & \frac{\partial \xi}{\partial E_2} & \frac{\partial \lambda}{\partial E_2} & \frac{\partial \mu}{\partial E_2} \\
\frac{\partial h}{\partial E_3} & \frac{\partial V}{\partial E_3} & \frac{\partial \gamma}{\partial E_3} & \frac{\partial \xi}{\partial E_3} & \frac{\partial \lambda}{\partial E_3} & \frac{\partial \mu}{\partial E_3} \\
\frac{\partial h}{\partial E_4} & \frac{\partial V}{\partial E_4} & \frac{\partial \gamma}{\partial E_4} & \frac{\partial \xi}{\partial E_4} & \frac{\partial \lambda}{\partial E_4} & \frac{\partial \mu}{\partial E_4} \\
\frac{\partial h}{\partial E_5} & \frac{\partial V}{\partial E_5} & \frac{\partial \gamma}{\partial E_5} & \frac{\partial \xi}{\partial E_5} & \frac{\partial \lambda}{\partial E_5} & \frac{\partial \mu}{\partial E_5} \\
\frac{\partial h}{\partial E_6} & \frac{\partial V}{\partial E_6} & \frac{\partial \gamma}{\partial E_6} & \frac{\partial \xi}{\partial E_6} & \frac{\partial \lambda}{\partial E_6} & \frac{\partial \mu}{\partial E_6}
\end{bmatrix}
\]
where $E_i$ = independent, uncorrelated error sources

The sensitivity matrix is used to calculate random errors in the trajectory parameters as follows:

$$
\begin{bmatrix}
\Delta h \\
\Delta v \\
\Delta \gamma \\
\Delta \delta \\
\Delta \lambda \\
\Delta \mu
\end{bmatrix} =
\begin{bmatrix}
\epsilon_1 \\
\epsilon_2 \\
\epsilon_3 \\
\epsilon_4 \\
\epsilon_5 \\
\epsilon_5
\end{bmatrix}

$$

where $\epsilon_i$ are random numbers from a normal distribution with a mean value of zero and a standard deviation of one.

A covariance matrix is propagated by using a Monte Carlo analysis to: (1) sample the trajectory errors from the sensitivity matrix, (2) add the errors to the nominal values, (3) propagate the state parameters along a conic by a time increment, and (4) subtract the new state parameters from the nominal values at the new epoch. The resulting trajectory errors are combined as described on the preceding pages to yield the mean values, standard deviations and correlation coefficients and, thus, the covariance matrix.

The spin-stabilized stage boost covariance matrix is also formed using a Monte Carlo analysis. The boost error sources are sampled as shown below and combined as shown previously in this section.
where \( E_i \) = boost error sources
\[
\frac{\partial X}{\partial E_i} = \text{partial derivative of respective trajectory parameter to a one sigma magnitude of the error source}
\]
\( \epsilon_i \) = a random number defined as follows
For motor performance error source
\( \epsilon_1 = X_{n_1} \)
For pitch tipoff error source
\( \epsilon_2 = |X_{n_2}| \cos (X_u *360^\circ) \)
\( \epsilon_3 = |X_{n_2}| \sin (X_u *360^\circ) \)
\( \epsilon_4 = X_{n_3} \)
\( X_{n_i} \) = a normally distributed random number with a mean value of 0 and a standard deviation of 1.
\( X_u \) = a uniformly distributed random number from 0 to 1.

3.3 User Instructions

STEP utilizes both fixed field and a modified FORTRAN NAMELIST for data input. The flight experience data base is input via fixed field format since the data base normally does not change. The remaining data, which normally changes with each program execution, is input via NAMELIST in order to utilize a flexible input format.

3.3.1 Fixed Field Format - The flight data base is input via fixed field format. For each flight the following parameters are input at an epoch.

- flight identification
- option specifying usage of latitude, longitude and azimuth errors.
- nominal altitude
- nominal latitude
- nominal flight azimuth
- observed errors in altitude, velocity, flight path angle, flight azimuth, latitude, longitude.
Fixed field data must either be right justified in the field or contain a decimal point.

The flight experience data base is input in the order shown below for each flight. Data may be input for up to 100 flights. Preceding the flight data, one title card is used for identification purposes only. Following the flight data, an END card beginning in column 1 is used to specify the end of the flight data.

### Fixed Field Input Definition

<table>
<thead>
<tr>
<th>Column Range</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>Flight Number</td>
</tr>
<tr>
<td>6-9</td>
<td>Flag</td>
</tr>
<tr>
<td></td>
<td>= 1 if flight is to be used for latitude and longitude statistics only.</td>
</tr>
<tr>
<td></td>
<td>= 2 if flight is to be used for all statistics.</td>
</tr>
<tr>
<td></td>
<td>= 3 if flight is to be used for azimuth statistics only.</td>
</tr>
<tr>
<td></td>
<td>= 4 is flight is not to be used for statistics.</td>
</tr>
<tr>
<td>10-16</td>
<td>Nominal altitude, n.mi.</td>
</tr>
<tr>
<td>17-23</td>
<td>Altitude error, n.mi.</td>
</tr>
<tr>
<td>24-30</td>
<td>Velocity error, fps</td>
</tr>
<tr>
<td>31-37</td>
<td>Path angle error, deg</td>
</tr>
<tr>
<td>38-44</td>
<td>Azimuth error, deg</td>
</tr>
<tr>
<td>45-52</td>
<td>Latitude error, deg</td>
</tr>
<tr>
<td>53-60</td>
<td>Longitude error, deg</td>
</tr>
<tr>
<td>61-70</td>
<td>Nominal latitude, deg</td>
</tr>
<tr>
<td>71-80</td>
<td>Nominal azimuth, deg</td>
</tr>
</tbody>
</table>
3.3.2 NAMELIST Format - A modified FORTRAN NAMELIST is used for inputting data to STEP. NAMELIST is used because of its readability and simplicity of inputting data. The following rules apply to NAMELIST input to STEP.

1. First card of a data group or case is $INPUTD$ beginning in column 2. Blanks are not allowed.

2. Last card of a data group or case is $END$ beginning in column 2. Blanks are not allowed.

3. Blanks may not be used within names but may be used elsewhere.

4. Variable names are followed by an equal sign, followed by a value, followed by a comma, e.g., NSAMP=1000,

5. Only columns 2-72, inclusive, are used.

6. Titling information may be input by the appropriate title names, e.g., TITLE1= LOW ALTITUDE TRAJECTORY ERROR STATISTICS TITLE1 must begin in column 2.

7. Any number of names and values may be on a single card or line.

8. Complete data arrays are input in the following form:
   name = value, value, value, ..., Data values may be continued on the next line, but the last character on every line must be a comma, excluding title cards.

9. Repeated data values may be input by using a repetition factor and an asterisk, e.g., DATAG = 0.4, 4*0.45, 0.5, 0.65,

10. One or more specific elements of an array may be input, e.g., EMAG(2)= 1.2, 1.6,

Subsequent data cases are allowed by providing additional sets of NAMELIST data. All input data is retained for subsequent cases but can be changed by inputting new values.

A sample data case is included as Appendix A to exemplify data case setup.

Definitions of specific NAMELIST inputs to STEP are shown below. Default values are shown when they are set by the program prior to reading input data. Data units are feet, degrees and seconds unless otherwise noted.
NAMELIST Input Definitions

COV
Covariance matrix of altitude, velocity, flight path angle, azimuth, latitude and longitude.
Input when IERROR = 4

DATAG
Standard deviation in flight path angle, used to normalize flight errors. Array of 7 values.
Independent variable is HINJ.
(0.428, 0.428, 0.428, 0.430, 0.434, 0.442, 0.453 built-in)

DATAH
Standard deviation in altitude, used to normalize flight errors. Array of 7 values. Independent variable is HINJ.
(3.35, 4.85, 5.80, 6.45, 6.90, 7.20, 7.30 built-in)

DATAV
Standard deviation in velocity, used to normalize flight errors. Array of 7 values. Independent variable is HINJ.
(75.6, 84.6, 88.8, 91.3, 92.5, 93.0, 93.0 built-in)

EMAG
Values for error sources used to calculate covariance matrix of a spin stabilized stage. Array of 4 values. Input when propagation is used.
(1) = ratio of standard deviation desired to the standard deviation used to determine SEN1 for the motor performance error source.
(2) = same as above except for determining SEN2 for the pitch tipoff error source.
(3) = same as above except for determining SEN3 for the yaw tipoff error source.
(4) = same as above except for determining SEN4 for the timer error source.

HINJ
Altitude used to normalize flight errors. Array of 7 values. Dependent variables are DATAG, DATAH, DATAV.
(100., 200., 300., 400., 500., 600., 700. built-in)

IERROR
Option for inputting data errors
= 1 Input flight results of altitude, velocity and path angle errors, 100 samples or less. Errors are input in fixed field format prior to NAMELIST data.
= 2 Input flight results of altitude, velocity path angle, azimuth, latitude and longitude, 100 samples or less. Errors are input in fixed field format prior to NAMELIST data.
(2 built-in)
### NAMELIST Input Definitions (Continued)

- **NERROR**
  Number of error sources of the spin stabilized stage. (3 built-in)

- **NORM**
  Non-zero value normalizes altitude, velocity and path angle errors of the flight data base to the altitude of $S_1$. (1 built-in)

- **NSAMP**
  Number of samples used in Monte Carlo analyses. (5000 built-in)

- **RHO**
  Correlation coefficients in order of altitude velocity, path angle, azimuth, latitude and longitude. Array of 15 values. Input when IERROR = 3.

- **SEN1**
  Sensitivity of spin stabilized stage burnout state parameters to one sigma motor performance error source. Units are state parameter units/sigma. Array of 6 values. Order of state parameters are altitude, velocity, path angle, azimuth, latitude and longitude.

- **SEN2**
  Same as SEN1 except error source is pitch tipoff. Units are state parameter units/deg.

- **SEN3**
  Same as SEN1 except error source is yaw tipoff. Units are state parameter units/deg.

- **SEN4**
  Same as SEN1 except error source is stage ignition time. Units are state parameter units/sec.

- **SIG**
  Standard deviation of altitude, velocity, path angle, azimuth, latitude and longitude. Array of 6 values. Input when IERROR = 3.

- **S1**
  Nominal state parameters at last stage burnout if covariance matrix propagation is not selected. If propagation is selected, S1 is state at burnout of next to last stage. Array of 6 values. Order is altitude, velocity, path angle, azimuth, latitude and longitude.

- **S2**
  Nominal state parameters at last stage burnout. Input if TCOAST is non-zero. Array of 6 values. Order is altitude, velocity, path angle, azimuth, latitude and longitude.
3.4 Output Description

Both the fixed field and NAMELIST input data are listed verbatim on the output listing. These lists provide a quick check of the input data for format correctness and validity.

Following the input data lists, the flight experience data are provided in a labeled format. The next page provides the flight experience data after the altitude, velocity, path angle errors have been normalized and the latitude, longitude errors have been adjusted.

The following page provides error statistics for only those flights with latitude and longitude errors. The next page provides error statistics based upon all flight samples provided. The altitude, velocity, path angle and azimuth error statistics are obtained from those flight samples identified for that purpose. The latitude and longitude error statistics are derived from only those flights available for latitude and longitude statistics. Unless the covariance matrix is propagated, the final error covariance matrix is included on this page. Following the covariance matrix, the sensitivity matrix is provided, which when properly sampled will produce the covariance matrix.

If the covariance matrix is propagated, additional matrices are shown on the next two pages. The sensitivity matrix obtained from the final error covariance matrix is also included.
<table>
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<th>VEHICLE</th>
<th>INSERTION PATH</th>
<th>ALTITUDE DEG</th>
<th>VELOCITY FPS</th>
<th>PATH ANGLE DEG</th>
<th>AZIMUTH DEG</th>
<th>LATITUDE DEG</th>
<th>LONGITUDE DEG</th>
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</table>

**NOTE:** LATITUDE, LONGITUDE ERRORS NOT SHOWN ARE NOT AVAILABLE
4.0 SUBROUTINE DESCRIPTIONS

This section provides a brief description of each subroutine of STEP.

4.1 STEP (Main Program)

The main program initializes the input data defaults; calls the two input subroutines; normalizes the errors in altitude, velocity and flight path angle; adjusts the errors in latitude and longitude; calculates the error covariance matrix at the input epoch; calculates the sensitivity matrix; calculates the boost covariance matrix; propagates the covariance matrix; and outputs the results.

4.2 CARDS

Subroutine CARDS reads the fixed field data in alphanumeric format; writes the data as read on the output file in alphanumeric format; and writes the data as read on Unit 8 for subsequent reading by the main program in floating point format. CARDS counts the number of samples read and writes error messages if there are no samples or if they exceed the maximum of 100.

4.3 CONIC

Subroutine CONIC initializes a conic path from an input trajectory state (altitude, velocity, flight path angle, azimuth, latitude and longitude) for subsequent propagation of the state along the conic path by an input time increment. CONIC verifies that the conic path is elliptical and, if so, calculates the orbital elements and coordinate transformations from the spherical state to inertial cartesian components. CONIC is called one time per conic path.
4.4 CORCO

Subroutine CORCO calculates mean values, standard deviations and the correlation coefficient of two independent variables from random samples of each. On option, the mean values may be set to zero.

4.5 COVR

Subroutine COVR generates a symmetric error covariance matrix of six parameters. COVR is called as each set of error samples is generated. COVR1 (an entry point) is called after all sets of samples have been generated and a covariance matrix is desired.

4.6 EIGEN

Subroutine EIGEN calculates the eigenvalues and eigenvectors of a real symmetric matrix. These values are used in STEP to generate a sensitivity matrix of six pseudo, independent, uncorrelated error sources to the six trajectory parameters.

4.7 INIT

Subroutine INIT initializes constants used by several of the subroutines, which are available to the subroutines via labeled common DIG. Entry point INIT1 initializes the parameters used to obtain random numbers. These parameters are available to the subroutines via labeled common BLK4.

4.8 INPUT

Subroutine INPUT reads input data cards in a modified NAMELIST format. Titling information on title cards is placed in appropriate arrays for use by the main program. Non-title cards are written on unit 8 for a NAMELIST read
by the main program.

4.9 INTER

Subroutine INTER is a second-order interpolater of two variables. It selects the four closest data points to the desired value of the independent variable and interpolates or extrapolates for the value of the dependent variable.

4.10 NEWTON

Subroutine NEWTON iterates for the eccentric anomaly corresponding to a value of time along a conic. If the iteration fails, a diagnostic is written. If the iteration is successful, the radius and true anomaly are calculated.

4.11 NORRAN

Subroutine NORRAN generates a normally distributed random number from the set of numbers which have a mean value and standard deviation as supplied to the subroutine.

4.12 TSTEP

Subroutine TSTEP propagates a trajectory state along a conic by a given time increment. Subroutine CONIC is used to initialize the conic from the initial state parameters. Subroutine NEWTON is used to iterate on eccentric anomaly. TSTEP updates the trajectory state parameters at the new time. TSTEP is called each time the trajectory state is to be propagated.
4.13 UNIRAN

Subroutine UNIRAN generates a uniformly distributed random number between zero and one. This random number is used when analyzing tipoff error sources.
5.0 PROGRAM CODING

This section presents details about the program coding. Included are flowcharts of each subroutine, FORTRAN listings of each subroutine and definitions of the FORTRAN variables. The information presented in this section is intended to be helpful in developing a thorough understanding of STEP and in making modifications to the program.

5.1 Subroutine Flowcharts

Flowcharts are presented in Figures 5.1 through 5.9. The flowchart conventions used are defined in Section 2.0 of this report.

5.2 FORTRAN Listings

STEP is coded in FORTRAN IV, Reference (2), on the CDC CYBER 175 computer with the NOS/BE 1.4 operating system. Listings of the FORTRAN coding are presented in Appendix B.

5.3 FORTRAN Variable Definition

Definitions of the FORTRAN variables are presented below. This information is normally used only when making modifications to the program.

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<th>Description</th>
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<td>Error covariance matrix after propagation</td>
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<td>Description</td>
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<td>-------------</td>
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</tr>
<tr>
<td>CP3</td>
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</table>
Figure 5.1
FLOWCHART OF MAIN PROGRAM STEP

1. Start
2. Initialize input data defaults
3. Call CARDS for fixed field data
4. Normalize the altitude, velocity, path angle errors to the nominal altitude
5. Propagate the nominal state 51 by TCOAST seconds
6. Adjust the latitude, longitude errors to the nominal azimuth
7. Calculate mean values and standard deviations at the input epoch
8. Calculate the error covariance matrix at the input epoch
9. Calculate sensitivity matrix
10. Calculate eigenvectors and eigenvalues
11. Generate boost covariance matrix
12. Sample trajectory errors at input epoch
13. Propagate perturbed state by TCOAST
14. Calculate sensitivity matrix
15. Add boost covariance matrix to propagated covariance matrix
16. Accumulate errors at end of propagation. Form covariance matrix
17. Write output data
Figure 5.2
FLOWCHART OF SUBROUTINE CARDS

Enter CARDS

Read title card and write on unit 6

Read data card, write on unit 6, write on unit 8. Accumulate counter.

If card read is "END"

YES

Set number of samples read

Rewind unit 8

Return

NO
Figure 5.3
FLOWCHART OF SUBROUTINE CONIC

Enter CONIC

Establish rotational matrix to inertial coordinate system at initial conditions
Calculate semi-major axis

Is eccentricity zero?

Calculate eccentricity

Is semi-major axis greater than zero?

Conic is circular

Calculate orbital elements for elliptical orbit

Return

Conic is non-elliptical
Figure 5.4
FLOWCHART OF SUBROUTINE CORCO

- Enter CORCO
- Calculate summation of: x error, y error, square of x error, square of y error, x error times y error
- Are zero mean values to be used?
  - YES: Set mean values to zero
  - NO: Calculate mean values
- Calculate standard deviation and correlation coefficient
- Return
Figure 5.5
FLOWCHART OF SUBROUTINE COVR

Enter COVR

Accumulate summations of errors and errors squared

Accumulate summations of products of errors

Return

Enter COVR

Calculate standard deviations and correlation coefficients

Calculate covariance matrix

Return
Figure 5.6
FLOWCHART OF SUBROUTINE INPUT

Enter INPUT

Read data card.

If end-of-file read?

Write data card on unit 6

YES

Stop

NO

Place title information in appropriate array

YES

If card is a title card

NO

Blank columns 73 thru 80

If card read is "$END"

Rewind 8

Write card on unit 8

Write date and time on unit 6

Return
Figure 5.7
FLOWCHART OF SUBROUTINE INTER

Enter INTER

If number of elements = 4
YES
Set index to 1

Interpolate for dependent variable according to index selected

Return

NO

If number of elements in data array < 4
YES
Write diagnostic

Select interpolator index to the 4 closest values to the desired independent variable

NO

Stop
Figure 5.8
FLOWCHART OF SUBROUTINE NEWTON

Enter
NEWTON

Iterate for eccentric anomaly at new time along conic

Did iteration converge?

YES

Calculate true anomaly and radius

Return

NO

Return
Figure 5.9
FLOWCHART OF SUBROUTINE TSTEP

Is orbit non-elliptical?

Enter TSTEP

YES

Return

Calculate true and eccentric anomaly according to time step

Did iteration converge on eccentric anomaly?

NO

Newton

Calculate true and eccentric anomaly according to time step

YES

Update time by time step

Calculate direction cosines for obtaining the north and east components of velocity

Calculate inertial position and velocity components

Calculate altitude, velocity azimuth, latitude and longitude

Update the STATE array of the new spherical state parameters

Return
REFERENCES


### APPENDIX A

#### SAMPLE DATA CASES

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TRAJECTORY TO 200 NM ALTITUDE
WITH PROPAGATION 500 SAMPLES

FLIGHTS FOR SCOUT FLIGHT EXPERIENCE ACCURACY

STANDARD DEVIATIONS
ALT-VEL-GAM-ZET-LAT-LONG (FT,FPS,DEG)

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CORRELATION COEFFICIENTS
ALT-VEL-GAM-ZET-LAT-LONG

| .43278 | .43300 | .11934 | .40168 | .14018 |
| -.32800 | -.10618 | -.33622 | -.20859 | .16758 |
| -.16758 | -.21837 | -.11681 | .07191 | -.47921 |
| -.07191 | -.07939 |

COVARIANCE MATRIX (A MATRIX)

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EIGENVALUES

| .85830E+09 | .11315E+03 | .13160E+00 |
| .52973E+04 |

EIGENVECTORS

| .10000E+01 | .11841E+00 | .21916E+00 | .39473E+00 | .11341E+00 | .31095E+00 |
| .11841E+00 | .54569E+00 | .61192E+00 | .39731E+00 | .80723E+00 | .59516E+00 |
| .21916E+00 | .61192E+00 | .95227E+00 | .40492E+00 | .25918E+00 | .88833E+00 |
| .39473E+00 | .39731E+00 | .95227E+00 | .40492E+00 | .25918E+00 | .88833E+00 |
| .11341E+00 | .80723E+00 | .25918E+00 | .88833E+00 | .37319E+00 | .37319E+00 |
| .31095E+00 | .59516E+00 | .88833E+00 | .37319E+00 | .37319E+00 |

SENSITIVITY COEFFICIENTS
ALT-VEL-GAM-ZET-LAT-LONG (TOP TO BOTTOM)

| .29297E+05 | .86180E+01 | .11795E+05 | .14319E+05 | .21294E+07 | .32780E+06 |
| .34816E+02 | .75254E+02 | .23990E+03 | .22198E+03 | .74598E+04 | .85096E+04 |
| .17423E+00 | .62761E+01 | .86785E+01 | .34545E+00 | .76026E+03 | .27322E+01 |
| .62651E+01 | .32968E+01 | .51429E+00 | .64912E+01 | .42622E+01 | .62740E+02 |
| .59333E+01 | .29929E+01 | .39073E+00 | .86710E+01 | .73394E+01 | .93698E+01 |
| .31391E+01 | .36744E+01 | .13299E+00 | .23047E+01 | .16748E+00 | .39340E+01 |
**TRAJECTORY TO 200 NM ALTITUDE**

**WITH PROPAGATION 500 SAMPLES**

---

**COVARIANCE MATRIX OF LAST STAGE BOOST**

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**SAMPLED COVARIANCE MATRIX AT INPUT EPOCH**

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**COVARIANCE MATRIX AFTER PROPAGATION**

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ROUTINE STEP
DTD MAR 1981
PROB. NO. 1
TRAJECTORY TO 200 NM ALTITUDE  
NO PROPAGATION  500 SAMPLES  

NORMALIZED DEVIATIONS AND ADJUSTED LATITUDE, LONGITUDE DEVIATIONS  
ALTITUDE=  90.0 N MI  
AZIMUTH=  178.900 DEG  
LATITUDE=  30.6500 DEG  

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TRAJECTORY TO 200 FT ALTITUDE
NO PROPAGATION 500 SAMPLES

FLIGHTS WITH LATITUDE/LONGITUDE DEVIATIONS
33 FLIGHT SAMPLES

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ALT-VEL-GAM-ZET-LAT-LONG (FT, FPS, DEG)

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CORRELATION COEFFICIENTS
ALT-VEL-GAM-ZET-LAT-LONG

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TRAJECTORY TO 200 NM ALTITUDE
WITH PROPAGATION 500 SAMPLES

FLIGHTS WITH LATITUDE/LONGITUDE DEVIATIONS
33 FLIGHT SAMPLES

STANDARD DEVIATIONS
ALT-VEL-GAM-ZET-LAT-LONG (FT,FPS,DEG)

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MEAN VALUES
ALT-VEL-GAM-ZET-LAT-LONG

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CORRELATION COEFFICIENTS
ALT-VEL-GAM-ZET-LAT-LONG

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 ROUTINE STEP
 DTD MAR 1981
 PROB. NO. 1
### Trajectory to 200 NM Altitude

**With Propagation 500 Samples**

### Covariance Matrix at Last Stage Burnout

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ALT-VEL-GAM-ZET-LAT-LONG (Top To Bottom)

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**TRAJECTORY TO 200 NM ALTITUDE**

**WITH PROPAGATION 500 SAMPLES**

**FLIGHT RESULTS AT INPUT TIME**

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**Routines Step**

**DTD Mar 1981**

**Prob. No. 1**

---

-9-
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TITLE2=WITH PROPAGATION 500 SAMPLES
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SEN3= 1, -3.0, 0, .35, .002, .001,
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DATE IS 06/30/81
TIME IS 13.27.34
TRAJECTORY TO 200 NM ALTITUDE
NO PROPAGATION 500 SAMPLES

FLIGHTS FOR SCOUT FLIGHT EXPERIENCE ACCURACY

STANDARD DEVIATIONS
ALT-VEL-GAM-ZET-LAT-LONG (FT, FPS, DEG)

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4.822 NM

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ALT-VEL-GAM-ZET-LAT-LONG

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CORRELATION COEFFICIENTS
ALT-VEL-GAM-ZET-LAT-LONG

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COVARIANCE MATRIX (A MATRIX)

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EIGENVALUES

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EIGENVECTORS

SENSITIVITY COEFFICIENTS
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---A13---
APPENDIX B

FORTRAN CODE LISTINGS

PROGRAM STEP (INPUT, OUTPUT, TAPE1, TAPE8, TAPE5, INPUT, TAPE6 = OUTPUT)
SCOUGHTRAJECTORYERRORPROPAGATIONPROGRAM
C
COV = COVARIANCE MATRIX OF ALT, VEL, GAM, ZET, LAT, LONG.
C
INPUT IF IERROR = 4.
C
DATAG = TABLE OF STANDARD DEVIATIONS OF PATH ANGLE FOR NORMALIZING.
C (1.428, 4.28, 4.28, 4.30, 4.34, 4.42, 4.53 BN)
C
DATAH = TABLE OF STANDARD DEVIATIONS OF ALTITUDE FOR NORMALIZING.
C (3.35, 4.05, 5.80, 6.45, 6.90, 7.20, 7.30 BN)
C
DATAV = TABLE OF STANDARD DEVIATIONS OF VELOCITY FOR NORMALIZING.
C (75.5, 84.6, 88.8, 89.1, 92.5, 93.0, 93.0 BN)
C
EMAG = VALUES FOR ERROR SOURCES USED TO CALCULATE COVARIANCE
C MATRIX OF A SPIN STABILIZED STAGE. ARRAY OF 4. INPUT
C
WHEN PROPAGATION IS USED. VALUES ARE THE RATIO OF
C STANDARD DEVIATION DESIRED TO THE STANDARD DEVIATION
C USED TO CALCULATE THE SEN1-SEN4 DATA.
C
HINJ = TABLE OF ALTITUDES FOR NORMALIZING.
C (100, 200, 300, 400, 500, 600, 700 BN)
C
IERROR = OPTION FOR INPUTTING DATA ERRORS IN FLIGHT DATA BASE.
C = 1 INPUT FLIGHT RESULTS OF ALT, VEL, GAM.
C = 2 INPUT FLIGHT RESULTS OF ALT, VEL, GAM, ZET, LAT, LONG.
C = 3 INPUT STANDARD DEVIATIONS (SIG) AND CORRELATION COEFFICIENTS (PHO)
C OF ALT, VEL, GAM, ZET, LAT, LONG.
C = 4 INPUT COVARIANCE MATRIX (COV) OF ALT, VEL, GAM, ZET, LAT, LONG.
C
NEROR = NUMBER OF ERROR SOURCES OF THE SPIN STABILIZED STAGE.
C MAXIMUM OF 4. (3 BN)
C
NORM = NON-ZERO VALUE-normalizes ALT, VEL, GAM ERRORS OF THE
C FLIGHT DATA BASE TO THE ALTITUDE OF S1. (1 BN)
C
NSAMP = NUMBER OF SAMPLES USED IN THE MONTE CARLO ANALYSES.
C (5000 BN)
C
RHO = CORRELATION COEFFICIENTS IN ORDER OF ALT, VEL, GAM, ZET,
C LAT, LONG. ARRAY OF 15. INPUT WHEN IERROR = 3.
C
SEN1 = SENSITIVITY OF SPIN STABILIZED STAGE BURNOUT STATE
C PARAMETERS TO ONE SIGMA MOTOR PERFORMANCE ERROR SOURCE.
C UNITS ARE STATE PARAMETER UNITS PER SIGMA. ARRAY OF 6.
C ORDER IS ALT, VEL, GAM, ZET, LAT, LONG.
C
SEN2 = SAME AS SEN1 EXCEPT ERROR SOURCE IS PITCH TIPOFF.
C UNITS ARE STATE PARAMETER UNITS PER DEGREE.
C
SEN3 = SAME AS SEN1 EXCEPT ERROR SOURCE IS YAW TIPOFF.
C UNITS ARE STATE PARAMETER UNITS PER DEGREE.
C
SEN4 = SAME AS SEN1 EXCEPT ERROR SOURCE IS TIME OF SPIN
C STABILIZED STAGE IGNITION. UNITS ARE STATE PARAMETER
C UNITS PER SECOND.
C
SIG = STANDARD DEVIATION OF ALT, VEL, GAM, ZET, LAT, LONG.
C INPUT WHEN IERROR = 3.
C
S1 = NOMINAL STATE PARAMETERS AT STAGE BURNOUT. IF
C PROPAGATION IS SELECTED, S1 IS STATE AT BURNOUT OF
C NEXT TO LAST STAGE. ARRAY OF 6. ORDER IS ALT, VEL,
C GAM, ZET, LAT, LONG.
C
S2 = NOMINAL STATE PARAMETERS AT LAST STAGE BURNOUT.
C INPUT IF TCOAST IS NON-ZERO. ARRAY OF 6. ORDER IS
C ALT, VEL, GAM, ZET, LAT, LONG.
C
TCOAST = NOMINAL COAST TIME TO PROPAGATE COVARIANCE MATRIX.
C INPUT ZERO IF PROPAGATION IS NOT DESIRED. (0. BN)
C
TITLE1 = TITLE INFORMATION PRINTED AT TOP OF EACH PAGE OF
C
TITLE2 = OUTPUT. 72 CHARACTERS MAXIMUM.
REAL 'MEANH,MEANV,MEANG,MEANZ,MEANL,MEANLG
COMMON /BLK4/ XMUS,GAMMA,GAUSS,GN(16),XK, ZRAN, ICNT
COMMON /CONIC/ STATE(6), TCALL, KERR, DELT, T, TZERO
COMMON /DIG/ ZERONE,TWO,RAO,PI,TWOPI,GM,FT,RE,CON,ROTATE
DIMENSION SIG(6), X(6),DX(6),RHO(15),R(36),RR(6,6),W(6)
DIMENSION INORD(100), WORD(11,100)
DIMENSION TITLE(8), TITLE2(8), BEST(6,4)
DIMENSION SEN(6), SEN2(6), SEN3(6), SEN4(6)
DIMENSION HINJ(7), DATAH(7), DATAG(7), DATAV(7)
DIMENSION EPAR(6), EXIC(6), S1(6), S2(6), SS(6), EMAG(4)
DIMENSION SUMS(6), SUM2(6), SUM3(6)
DIMENSION SUMS0(6), SUMS01(6), SUMS03(6)
DIMENSION CP1(15), CP2(15), CP3(15)
DIMENSION CMAT1(21), CMAT2(21)
DIMENSION DH1(100), DL1(100), DLG1(100), DV1(100), DG1(100)
DIMENSION DZ1(100), DH2(100), DV2(100), DG2(100), DZ2(100)
DIMENSION SC(6,6), COV(21)
EQUIVALENCE (BEST(1,1), SEN1(1)),
           (BEST(1,2), SEN2(1)),
           (BEST(1,3), SEN3(1)),
           (BEST(1,4), SEN4(1))
EQUIVALENCE (R(1),RR(1,1))
EQUIVALENCE (SIGH ,SIG( l)), (SIGV ,SIG( 2)), (SIGG ,SIG( 3))
       , (SIGZ ,SIG( 4)), (SIGL ,SIG( 5)), (SIGLG ,SIG( 6))
       , (RHOHV ,RHO( 1)), (RHOHG ,RHO( 2)), (RHOHZ ,RHO( 3))
       , (RHOHL ,RHO( 4)), (RHOHLG,RHO( 5)), (RHOVL ,RHO( 6))
       , (RHOQZ ,RHO( 7)), (RHOQL ,RHO( 8)), (RHOQLG,RHO( 9))
       , (RHOQZ ,RHO(10)), (RHOQL ,RHO(11)), (RHOQLG,RHO(12))
       , (RHOQZ ,RHO(13)), (RHOQLG,RHO(14)), (RHOQLLG,RHO(15))
DATA TITLE1,TITLE2/16*10H
DATA HINJ/1Uc,200.,300.,400.,500.,600.,700.1,
           DATAH/3.35,4.55,5.80,6.45,6.90,7.20,7.30/,
       DATAV/75.68,6.88,6.91,3.92,5.93,0.93,0./,
       DATAQ/4.26,4.26,4.26,4.30,4.34,4.42,4.53/,
NAMELIST /INPUT/ NSAMP,NERROR,SIG,RHO,CQV,TCOAST,IERROH,S1,S2,
         SEN1,SEN2,SEN3,SEN4,EMAG,HINJ,DATAH,DATAG,
         DATAV,NORM
REWRIND 1
REWIND 8
CALL INIT
NDATA=7
NFLAG=1
NSAMP=5000
IPRINT=2
NORM=1
TCOAST=0.
MEAN=1
NERROR=3
NPORB=0
WRITE(6,330)
READ FIXED FIELD INPUT DATA
CALL CARD$(IN,100)
READ(8,320) (1WORD(J),(WORD(I,J),I=2,11),J=1,N)
10 CONTINUE

- B2 -
C READ NAMELIST DATA
CALL INPUT(TITLE1,TITLE2)
READ(8,INPUTD)
NPROB=NPROB+1
WRITE(6,340) NPROB,TITLE1,TITLE2
INITIALIZE

CALL INITI
DO 20 I=1,6
SUM1(I)=0.
SUM2(I)=0.
SUM3(I)=0.
SUMSQ1(I)=0.
SUMSQ2(I)=0.
SUMSQ3(I)=0.
20 CONTINUE

DO 30 I=1,15
CP1(I)=0.
CP2(I)=0.
CP3(I)=0.
30 CONTINUE

DO 40 I=1,6
STATE(I)=S1(I)
40 CONTINUE
CALL CONIC
DELT=AAMAX(TCOAST,1,E-3)
CALL TSTEP
DO 50 I=1,6
SS(I)=STATE(I)
50 CONTINUE

ALT=S1(1)/FT
ZET=S1(4)
XLAT=S1(5)

C SET-UP OF INPUT DATA ACCORDING TO IERROR
GOTO (60,60,160,170), IERROR

C

60 CONTINUE
SZET=SIN(ZET/RAD)
CZET=COS(ZET/RAD)
CLAT=COS(XLAT/RAD)
WRITE(6,350)
WRITE(6,360) (J,J,WORD(J),J,WORD(I),I=3,9),J=1,N)
WRITE(6,340) NPROB,TITLE1,TITLE2
WRITE(6,370) ALT,ZET,XLAT
WRITE(6,380)
CALL INTER (ALT,DEVH1,NDATA,DATAH,HINJ)
CALL INTER (ALT,DEVV1,NDATA,DATAV,HINJ)
CALL INTER (ALT,DEVG1,NDATA,DATAG,HINJ)
N1=0
N2=0
N3=0

C

DO 120 I=1,N
X4=WORD(4,I)*FT
X5=WORD(5,I)

- B3 -
XG = WORD(6, I)
XZ = WORD(7, I)
XL = WORD(8, I)
XG = WORD(9, I)
IF (NORM.EQ.0) GOTO 70.
NORMALIZE FLIGHT ERRORS
XALT = WORD(3, I)
CALL INTER (XALT, DEVH2, NODATA, DATAH, HINJ)
CALL INTER (XALT, DEVV2, NODATA, DATAV, HINJ)
CALL INTER (XALT, DEVG2, NODATA, DATAG, HINJ)
XH = DEVH1/DEVH2*XH
XV = DEVV1/DEVV2*XV
XG = DEVG1/DEVG2*XG
70 ICODE = WORD(2, I)
GOTO (80, 80, 90, 120), ICODE

CONVERT LAT, LONG DEVIATIONS TO RANGE, CROSSRANGE DEVIATIONS
80 SZ = SIN(WORD(11, I)/RAD)
CZ = COS(WORD(11, I)/RAD)
CN = RE*XL/RAD
CE = RE*XLG*COS(WORD(10, I)/RAD)/RAD
DR = (CN*SZ+CE*SZ)/FT
DCR = (CN*SZ-CE*CZ)/FT

CONVERT RANGE, CROSSRANGE DEV TO LAT, LONG DEV FOR INPUT
AZIMUTH AND LATITUDE
CN = DR*SZET+DCR*SZET
CE = DR*SZET-DCP*CZET
XL = CN/RE*FT/PAD
XG = CE/RE*FT/CLAT*PAD
90 CONTINUE
N3 = N3+1
WRITE (6, 390) N3, XH, XV, XG, XZ, XL, XLG, ICODE
GOTO (100, 100, 110, 120), ICODE
100 N1 = N1+1
DH1(N1) = XH
DV1(N1) = XV
dg1(N1) = XG
dz1(N1) = XZ
dl1(N1) = XL
dlG1(N1) = XLG
GOTO (120, 110, 110, 120), ICODE
110 N2 = N2+1
DH2(N2) = XH
DV2(N2) = XV
dg2(N2) = XG
dz2(N2) = XZ
120 CONTINUE
WRITE (6, 340) NPROB, TITLE1, TITLE2
IF (ERRORP.EQ.1) GOTO 140
IF (ERROR.GT.1) GOTO 150
130 CALL CIRCQ (DH2, DZ2, N2, SIGH, SIGZ, RHOHZ, MEANH, MEANZ, MEAN)
CALL CIRCQ (DV2, DZ2, N2, SITY, SIGZ, RHOVZ, MEANY, MEANZ, MEAN)
CALL CIRCQ (DG2, DZ2, N2, SIGG, SIGZ, RHOGZ, MEANG, MEANZ, MEAN)
NFLAG = 0
WRITE (6, 340) NPROB, TITLE1, TITLE2

- B4 -
140 WRITE(6,400) CALL CORCO (DH2, DV2, N2, SIGH, SIGV, RHOHV, MEANH, MEANV, MEAN)
    CALL CORCO (DH2, DG2, N2, SIGH, SIGG, RHOG, MEANH, MEANG, MEAN)
    CALL CORCO (DV2, DG2, N2, SIGV, SIGG, RHOGV, MEANV, MEANG, MEAN)
    GOTO 160
150 CALL CORCO (DH1, DV1, N1, SIGH, SIGV, RHOHV, MEANH, MEANV, MEAN)
    CALL CORCO (DH1, DG1, N1, SIGH, SIGG, RHOG, MEANH, MEANG, MEAN)
    CALL CORCO (DV1, DZ1, N1, SIGH, SIGG, RHOGV, MEANV, MEANG, MEAN)
    CALL CORCO (DV1, DG1, N1, SIGV, SIGZ, RHOGZ, MEANZ, MEAN)
    CALL CORCO (DV1, DZ1, N1, SIGV, SIGL, RHOL, MEANL, MEAN)
    CALL CORCO (DZ1, DG1, N1, SIGV, SIGZ, RHLG, MEANL, MEAN)
    CALL CORCO (DZ1, DZ1, N1, SIGV, SIGL, RHLG, MEANL, MEAN)
    WRITE(6,410)
    WRITE(6,420) N1
160 D(1)=SIGH*SIGH
    D(2)=RHOHV*SIGH*SIGV
    D(3)=SIGV*SIGV
    D(4)=RHOG*SIGH*SIGG
    D(5)=RHOGV*SIGV*SIGG
    D(6)=SIGG*SIGG
    D(7)=RHOHV*SIGH*SIGZ
    D(8)=RHOHZ*SIGG*SIGZ
    D(9)=RHOZG*SIGG*SIGZ
    D(10)=SIGZ*SIGZ
    D(11)=RHOHL*SIGH*SIGL
    D(12)=RHOVL*SIGV*SIGL
    D(13)=RHOGL*SIGG*SIGL
    D(14)=RHOZL*SIGZ*SIGL
    D(15)=SIGL*SIGL
    D(16)=RHOHLG*SIGH*SIGLG
    D(17)=RHOVLG*SIGV*SIGLG
    D(18)=RHOGLG*SIGG*SIGLG
    D(19)=RHOZLG*SIGZ*SIGLG
    D(20)=RHOLOGYG*SIGL*SIGLG
    D(21)=SIGL*SIGLG
    WRITE(6,430) SIGH, SIGV, SIGG, SIGZ, SIGL, SIGLG
    SIGALT=SIGH/6076.11549
    WRITE(6,440) SIGALT
    WRITE(6,450) MEANH, MEANV, MEANG, MEANZ, MEANL, MEANLG
    WRITE(6,460) RHOHV, RHOOG, RHOHZ, RHOHL, RHOHLG,
    RHOOG, RHOOG, RHOVL, RHOVLG,
    RHOZG, RHOGL, RHOGLG,
    RHOZL, RHOZLG,
    RHOLOGYG
    GOTO 190
170 DO 180 I=1,21
180 D(I)=COV(I)
190 WRITE(6,470)
WRITE(6,480) 0
IF (NFLAG.EQ.1) GOTO 130
CALL EIGEN(D,R,6,0)
WRITE(6,490)
C D ARRAY IS NOW THE EIGENVALUES
C RR ARRAY IS THE EIGENVECTORS
WRITE(6,500) D(1),D(3),D(6),D(10),D(15),D(21)
WRITE(6,510)
WRITE(6,500) ((RR(I,J),J=1,6),I=1,6)
W(1)=SORT(D(1))
W(2)=SORT(D(3))
W(3)=SORT(D(6))
W(4)=SORT(D(10))
W(5)=SORT(D(15))
W(6)=SORT(D(21))
DO 200 J=1,6
DO 200 K=1,6
SC(J,K)=W(K)*RR(J,K)
200 CONTINUE
WRITE(6,520)
WRITE(6,500) ((SC(I,J),J=1,6),I=1,6)
C IF (TCOAST.EQ.3.) GOTO 310
C WRITE(5,340) NPROB,TITLE1,TITLE2
C COMPUTE LAST STAGE BOOST COVARIANCE MATRIX CMAT1
DO 230 NTIMES=1,NSAMP
CALL NORRAN
X(1)=GAUSS
CALL NORRAN
THET=ZRAN*TWOPI
X(2)=THET
CALL UNIPAN
X(3)=THET
IF (NERROR.LT.4) GOTO 210
CALL NORRAN
X(4)=GAUSS
210 CONTINUE
DX IS LAST STAGE BOOST STATE ERRORS
DO 220 I=1,6
DX(I)=0.
DO 220 J=1,NERROR
220 DX(I)=BEST(I,J)*X(J)*EMAG(J)+DX(I)
CALL COVR(CMAT1,DX,NTIMES,SUM1,SUMSQ1,CP1)
230 CONTINUE
C CALL COVR1(CMAT1,DX,NSAMP,SUM1,SUMSQ1,CP1)
WRITE(6,560)
WRITE(6,530)
WRITE(6,480) CMAT1
C
C COMPUTE COVARIANCE MATRIX AFTER PROPAGATION
DO 280 NTIMES=1,NSAMP
C SAMPLE Input EPOCH ERRORS
- B6 -
CALL NORRAN
EPAR(I) = GAUSS
DO 250 J = 1, 6
EXIC(J) = ZERO
DO 250 I = 1, 6
CALL ICOR(J)
DO 250 J = 1, 6
EXIC(J) = EXIC(J) * SC(J, I) * EPAR(I)
DO 260 I = 1, 6

STATE IS AT INPUT EPOCH
STATE(I) = SI(I) + EXIC(I)
CALL COVR (D, EXIC, NTIMES, SUM2, SUMSQ2, CP2)
INITIALIZE ORBIT PARAMETERS FOR STATE
CALL CONIC
DELT = TCOAST
ADVANCE STATE
CALL TSTEP
DX IS STATE ERRORS AFTER PROPAGATION
DO 270 I = 1, 6
STATE(I) = STATE(I) - SS(I)
CALL COVR (CMAT2, DX, NTIMES, SUM3, SUMSQ3, CP3)
CONTINUE

WRITE (6, 540)
WRITE (6, 530)
CALL COVR1 (D, DX, NSAMP, SUM2, SUMSQ2, CP2)
WRITE (6, 480) D
WRITE (6, 550)
WRITE (6, 530)
CALL COVR1 (CMAT2, DX, NSAMP, SUM3, SUMSQ3, CP3)
WRITE (6, 480) CMAT2

COMPONE COVARIANCE MATRIX AT LAST STAGE BURNOUT
DO 290 I = 1, 21
CMAT1(I) = CMAT1(I) + CMAT2(I)
WRITE (6, 340) NPROB, TITLE1, TITLE2
WRITE (6, 570)
WRITE (6, 530)
WRITE (6, 480) D

COMPONE SENSITIVITIES
CALL EIGEN (D, R, 6, 0)
WRITE (6, 490)
WRITE (6, 500) D(1), D(3), D(6), D(10), D(15), D(21)
WRITE (6, 510)
WRITE (6, 500) ((RR(I, J), J = 1, 6), I = 1, 6)
W(I) = SORT(D(I))
W(2) = SORT(D(3))
W(3) = SORT(D(6))
W(4) = SORT(D(10))
W(5) = SORT(D(15))
W(6) = SORT(D(21))
DO 300 J = 1, 6
DO 300 K = 1, 6
300 SC(J,K)=W(K)*RR(J,K)
      WRITE(6,520)
      WRITE(6,500) ((SC(I,J),J=1,6),I=1,6)
C
310 CONTINUE
C
      WRITE SENSITIVITIES ON UNIT 1 FOR READING BY SOAR
      WRITE (1) ((SC(I,J),J=1,6),I=1,6)
      GOTO 10
C
320 FORMAT (1X,A4,F4.0,5F7.0,2F8.0,2F10.0)
330 FORMAT (1H*)
340 FORMAT (*1T72,P23U0003000* ROUTINE STEP*/T72,*DOA MAR 1981*/
      * T72,*PR0709. NO.*13/ 10X,8A10/ 10X,8A1C//)
350 FORMAT (28X,*FLIGHT RESULTS AT INPUT TIME*/#6X,*SAMPLE VEHICLE P
      *REDALT*, 5X,*DELA DELTA DELTA DELTA DELTA DELTA DELTA DELTA DELTA DELTA* /6X,*NUM
      *BER NUMBER*, 15X,*ALT VEL GAM AZ LAT LONG*/2
      *4X,N.MI.,6X,N.M*.
      * FPS*, 5X,*DEG*, 5X,*DEG*, 5X,*DEG*, 5X,*DEG*, 5X,*DEG*/)
360 FORMAT (6X,10X,*55*, 5F9.1,F11.3,F8.1,2F8.3,2F8.4)
370 FORMAT (12X,*NORMALIZED DEVIATIONS AND ADJUSTED LATITUDE, LONGITUDE
      * DEVIATIONS*/28X,*ALTITUDE==T38,F9.1,* N MI*/28X,*AZIMUTH==T38,F
      *9.3,* DEG*/28X,*LATITUDE==T38,F9.4,* DEG//)
380 FORMAT (7X,*SAMPLE ALT VEL GAMMA ZET-LAT
      *LONG CODE*/7X,*NUMBER FT FPS DEG D
      *FG DEG*/)
390 FORMAT(I11,F12.0,F10.1,2F10.3,2F9.4,18)
400 FORMAT (20X,*FLIG0S FOR SCOUT FLIGHT EXPERIENCE ACCURACIY*/)
410 FORMAT (20X,*FLIGHTS WITH LATITUDE/LONGITUDE DEVIATIONS*)
420 FORMAT (30X,12X,*FLIGHT SAMPLES*)
430 FORMAT (10X,*STANDARD DEVIATIONS*/10X,*ALT-VEL-GAM-ZET-LAT-LONG (FT
      *FPS,DEG*/10X,F10.0,F10.1,2F10.3,2F10.4)
440 FORMAT (10X,F10.3,* NM*)
450 FORMAT (10X,*MEAS VALUES*/10X,*ALT-VEL-GAM-ZET-LAT-LONG*/
      *10X,F10.0,F10.1,2F10.3,2F10.4//)
460 FORMAT (10X,*CORRELATION COEFFICIENTS*/10X,*ALT-VEL-GAM-ZET-LAT-LONG
      *10X,F10.5/20X,F10.5/30X,F10.5/40X,F10.5/50X,F10.5//)
470 FORMAT (25X,*COVARIANCE MATRIX (A MATRIX)*/12X,*ALT*,9X,*VEL*,9X,*GA
      *MN*, 9X,*ZET.*, 6X,*LAT*, 9X,*LONG*/)
      *5//)
490 FORMAT (75X,*EIGENVALUES*)
500 FORMAT (6X,6E13.5)
510 FORMAT ((13X,*SCLN)*10X,*ALT,*10X,*GAM*10X,*ZET*10X,*LAT,9X,*LONG//)
520 FORMAT ((13X,*SCLN)*10X,*ALT-VEL-GAM-ZET-LAT-LONG*/
      *G (TOP TO BOTTOM)*/)
530 FORMAT (10X,*COVARIANCE MATRIX AFTER PROPAGATION//)
540 FORMAT ((10X,*SAMPLES COVARIANCE MATRIX AT INPUT EPOCH//)
550 FORMAT ((10X,*COVARIANCE MATRIX AT LAST STAGE BURNOUT//)
560 FORMAT ((10X,*COVARIANCE MATRIX OF LAST STAGE BURNOUT//)
570 FORMAT ((10X,*COVARIANCE MATRIX AT LAST STAGE BURNOUT//)
END
SUBROUTINE CARDS(NSAMP,NMAX)
C
THIS SUBROUTINE READS FIXED FIELD DATA CARDS IN (A) FORMAT, WRITES ON UNIT 6 FOR PRINTOUT AND WRITES ON UNIT 8 FOR SUBSEQUENT READING IN (F) FORMAT.
C
IMPLICIT INTEGER(A-Z)
DIMENSION CARDS(8)
C
NSAMP=0
MAX=NMAX+1
READ(5,50) CARD
IF (EOF(5) .NE.0) GOTO 30
WRITE(6,60) CARD
DO 10 I=1,MAX
READ(5,50) CARD
WRITE(6,60) CARD
WRITE(8,50) CARD
IF (CARD(1) .EQ. 'HEND') GOTO 20
10 CONTINUE
WRITE(6,70) NMAX
GOTO 40
20 CONTINUE
NSAMP=I-1
IF (NSAMP.LE.0) WRITE(6,80)
IF (NSAMP.LE.0) GOTO 40
REWIND 8
RETURN
30 CONTINUE
WRITE(6,90)
40 STOP
C
50 FORMAT (8A10)
60 FORMAT (5X,8A10)
70 FORMAT (//15X,*SUBROUTINE CARDS - SAMPLES EXCEEDS MAX OF * I4)
80 FORMAT (//15X,*SUBROUTINE CARDS - NO DATA PROVIDED*)
90 FORMAT (//15X,*SUBROUTINE CARDS - NO SAMPLES INPUT*)
END
SUBROUTINE CONIC
INITIALIZES A CONIC FROM A SPHERICAL STATE VECTOR (STATE)
FOR SUBSEQUENT PROPAGATION OF THE STATE VECTOR ALONG THE
CONIC, WHICH IS ACCOMPLISHED BY SUB. TSTEP.

COMMON /CENT/ CETA, SETA, CG, SG, R, V, SEA
COMMON /CONIC/ STATE(6), TCALL, KERR, STEP, T, TZERO
COMMON /CORD/ Q(3,3)
COMMON /DIG/ ZERO, ONE, TWO, RAD, PI, TWOP, GM, FT, RE, CON, ROTATE
COMMON /MAN/ A, A1EE, AVG, E, DOG, EAREF, ETA, ICIRCL, LOUSY, P,
\^PGME, RREF, TANOM, TRUE, TREF, XNA, PERIOD, EP
DATA SMALL/1.E-6/

T = TZERO
ICIRCL = 0
LOUSY = 0

SG = SIN( STATE(3)) * CON
CG = COS( STATE(3)) * CON
SZ = SIN( STATE(4)) * CON
CZ = COS( STATE(4)) * CON
SL = SIN( STATE(5)) * CON
CL = COS( STATE(5)) * CON
TEMP = STATE(6) * CON
SO = SIN(TEMP)
CO = COS(TEMP)
P = STATE(1) + RE
V = STATE(2)

Q(1,1) = CO * CL
Q(1,2) = - SO * SZ - CO * SL * CZ
Q(1,3) = - SO * CZ - CO * SL * SZ
Q(2,1) = SO * CL
Q(2,2) = CO * SZ - SO * SL * CZ
Q(2,3) = - CO * CZ - SO * SL * SZ
Q(3,1) = SL
Q(3,2) = CL * CZ
Q(3,3) = CL * SZ

TP = ZERO
TA = ZERD

A = R * GM / ( TWO * GM - R * V * V )
IF (A.GT.0.) GOTO 30
10 LOUSY = 1
COMPUTED A NON-ELLIPATIC, OR LOUSY, CONIC.
IT WILL BE IGNORED.
WRITE (6,20)
20 FORMAT (/ 6X 20H LOUSY CONIC FOR BODY )
RETURN
30 DOG = R * V * CG
P = DOG ** 2 / GM
E = SQRT( ONE - P / A )
IF (E-SMALL.GT.0.) GOTO 40
E = ZERO
ICIRCL = 1
CIRCULAR ORBIT ENCOUNTERED. SET ICIRCL TO UNITY.

- B10 -
GOTO 50
40 IF (ABS(F-ONE)-SMALL .LE. C.) GOTO 10
PGME = SORT( P / GM ) / E
50 AVG = SQRT( GM / A**3 )
   PERIOD = TWOPI / AVG
   XNA = AVG * A
   A1EE = A * SORT( ONE - E**2 )
   IF (ICIRCL.GT.0) GOTO 60
   STA = PGME * V * SG
   CTA = ( P - R ) / ( R * E )
   TA = ATAN2( STA, CTA )
   SEA = R * STA / A1EE
   CEA = E + R * CTA / A
   EA = ATAN2( SEA, CEA )
   IF (EA.LT.ZERO) EA = EA + TWOPI
   TP = ( EA - E * SEA ) / AVG
60 TANOM = TA
   TRUE = TA
   PREF = R
   EAREF = EA
   TPEF = TP
   ETA = ZERO
   RETURN
END
SUBROUTINE COPCO(X,Y,NSAMP,SIGX,SIGY,RHOXY,YMEAN,YMEAN,MEAN)
CALCULATES STANDARD DEVIATIONS, MEAN VALUES AND THE
CORRELATION COEFFICIENT OF TWO VARIABLES OF (NSAMP)
random samples each.
DIMENSION X(1),Y(1).

YSUM=0.
YSUP=0.
XSOSUM=0.
YSOSUM=0.
YSUM=C.
SAMPLES NSAMP
DO 10 I=1,NSAMP
XSUM=XSUM+X(I)
YSUM=YSUM+Y(I)
XSOSUM=XSOSUM+X(I)*X(I)
YSOSUM=YSOSUM+Y(I)*Y(I)
10 XYSUM=XSUM*Y(I)*Y(I)
XMEAN=YSUM/SAMP
YMEAN=YSUM/SAMP
IF (MEAN.EQ.C) XMEAN=0.
IF (MEAN.EQ.C) YMEAN=0.
SIGX=SQRT(XSOSUM/(SAMPN-1.0)-XMEAN*XMEAN)
SIGY=SQRT(YSOSUM/(SAMPN-1.0)-YMEAN*YMEAN)
RHOXY=(XYSUM-SAMPN*XMEAN*YMEAN)/SAMPN/SIGX/SIGY
RETURN
END
SUBROUTINE COVR(COV, DX, NTIMES, SUMX, SUMSOX, CP)

    GENERATES A SYMMETRIC COVARIANCE MATRIX OF SIX PARAMETERS.
    COVR IS CALLED EACH SAMPLE.
    COVR1 IS CALLED AFTER ALL SAMPLES ARE CALCULATED.
    COVARIANCE MATRIX IS GENERATED.

    DIMENSION DX(6), SUMX(6), SUMSOX(6), CP(15), XHOM2(6),
            RHO(15), SIG(6), SVAR(6), COV(21)

    CALL WHEN EACH SAMPLE SET IS GENERATED.

    XN = FLOAT(NTIMES)
    XNP = (XN - 1.0) / XN
    DO 10 I = 1, 6
        DX(I) = DX(I)*DX(I)
        SUMX(I) = XNP*SUMX(I) + DX(I)/XN
        SUMSOX(I) = XNP*SUMSOX(I) + DX(I)/XN
    10 CONTINUE
    DO 20 I = 1, 5
        LB = I + 1
        DO 20 J = LB, 6
            PROD = DX(I)*DX(J)
            IND = I + (J(J - 3*J + 1) + 2)/2
            CP(IND) = XNP*CP(IND) + PROD/XN
        20 CONTINUE
    CALL

    ENTRY COVR1
    XN = FLOAT(NTIMES)
    XNP = XN/(XN - 1.0)
    DO 30 I = 1, 6
        XM2 = SUMX(I)*SUMX(I)
        XHOM2(I) = SUMSOX(I) - XM2
        SVAR(I) = XNP*XMOM(I)
    30 CONTINUE
    DO 40 I = 1, 5
        LB = I + 1
        DO 40 J = LB, 6
            IND = I + (J(J - 3*J + 1) + 2)/2
            DENOM = SORT(XHOM2(I)*XHOM2(J))
            RHO(IND) = (CP(IND) - SUMX(I)*SUMX(J))/DENOM
            IF (DENOM.EQ.0.) RHO(IND) = 0.
        40 CONTINUE
    DO 50 I = 1, 6
        50 SIG(I) = SORT(SVAR(I))
        COV(1) = SVAR(1)
        COV(2) = RHO(1)*SIG(1)*SIG(2)
        COV(3) = SVAR(2)
        COV(4) = RHO(2)*SIG(1)*SIG(3)
        COV(5) = RHO(3)*SIG(2)*SIG(3)
        COV(6) = SVAR(3)
        COV(7) = RHO(4)*SIG(1)*SIG(4)
        COV(8) = RHO(5)*SIG(2)*SIG(4)
        COV(9) = RHO(6)*SIG(3)*SIG(4)
        COV(10) = SVAR(4)
        COV(11) = RHO(7)*SIG(1)*SIG(5)
\begin{align*}
\text{COV}(12) &= \text{RHO}(8) \cdot \text{SIG}(2) \cdot \text{SIG}(5) \\
\text{COV}(13) &= \text{RHO}(9) \cdot \text{SIG}(3) \cdot \text{SIG}(5) \\
\text{COV}(14) &= \text{RHO}(10) \cdot \text{SIG}(4) \cdot \text{SIG}(5) \\
\text{COV}(15) &= \text{SVAR}(5) \\
\text{COV}(16) &= \text{RHO}(11) \cdot \text{SIG}(1) \cdot \text{SIG}(6) \\
\text{COV}(17) &= \text{RHO}(12) \cdot \text{SIG}(2) \cdot \text{SIG}(6) \\
\text{COV}(18) &= \text{RHO}(13) \cdot \text{SIG}(3) \cdot \text{SIG}(6) \\
\text{COV}(19) &= \text{RHO}(14) \cdot \text{SIG}(4) \cdot \text{SIG}(6) \\
\text{COV}(20) &= \text{RHO}(15) \cdot \text{SIG}(5) \cdot \text{SIG}(6) \\
\text{COV}(21) &= \text{SVAR}(6) \\
\text{RETURN} \\
\text{ENO}
\end{align*}
SUBROUTINE EIGEN(A,R,N,MV)
DIMENSION A(I),R(I)

DESCRIPTION OF PARAMETERS
A - ORIGINAL SYMMETRIC MATRIX, DESTROYED IN COMPUTATION.
RESULTANT EIGENVALUES ARE DEVELOPED IN DIAGONAL OF MATRIX
A IN DESCENDING ORDER.
R - RESULTANT MATRIX OF EIGENVECTORS STORED COLUMNWISE IN
SAME SEQUENCE AS EIGENVALUES.
N - ORDER OF MATRICES A AND R
MV - INPUT CODE
0 COMPUTE EIGENVALUES AND EIGENVECTORS
1 COMPUTE ONLY EIGENVALUES

METHOD - DIAGONALIZATION METHOD ORIGINATED BY JACOBI AND ADAPTED
BY VON NEUMANN FOR LARGE COMPUTERS AS FOUND IN MATHEMATICAL
METHODS FOR DIGITAL COMPUTERS, EDITED BY A. RALSTON AND H. S.
WILF, JOHN WILEY AND SONS, NEW YORK, 1962, CHAPTER 7.

GENERATE IDENTITY MATRIX

5 RANGE=1.0E-12
IF (MV=1) 10,25,10
10 IO=-N
20 DD 20 J=1,N
30 IO=IO+N
40 DO 20 I=1,N
50 IJ=IO+I
60 R(IJ) = 0.0
70 IF (I-J) 20,15,20
15 R(IJ) = 1.0
20 CONTINUE

COMPUTE INITIAL AND FINAL NORMS (ANORM AND ANORMX)

25 ANORM=0.0
30 DO 35 I=1,N
40 DO 35 J=1,N
50 IF (I-J) 30,35,30
60 IA=I+(J*J-J+J)/2
70 ANORM=ANORM+ABS(A(IA)*A(IA))
80 CONTINUE
90 IF (ANORM) 165,165,46
46 ANORM=1.414*SQRT (ANORM)
50 ANORMX = ANORM*RANGE/ FLOAT(N)

INITIALIZE INDICATORS AND COMPUTE THRESHOLD, THR

IND=0
70 THR=ANORM
80 L=1
90 M=L+1

COMPUTE SIN AND COS

60 MO=(M+M-M)/2
70 LO=(L+L-L)/2
IM=L+MQ
62 IF (ABS (A(LM))-THR) 130, 65, 65
65 INO=1
LL=L+LQ
MM=M+MQ
Y=0.5*(A(LL)-A(MM))
69 Y=-A(LM)/SORT (A(LM)*A(LM)+X*X)
IF (X) 70, 75, 75
70 Y=-Y
75 SINX=Y/SORT (2.0*(1.0+(SORT (1.0-Y*Y))))
SINX2=SINX*SINX
78 COSX=SORT (1.0-SINX2)
COSX2=COSX*COSX
SINCS=SINX*COSX

ROTATE L AND M COLUMNS
ILQ=N*(L-I)
IMQ=N*(M-I)
DO 125 I=1, N
IQ=(I*I-I-I)/2
IF (I-L) 80, 115, 80
80 IF (I-M) 95, 115, 90
85 IM=I+IQ
GOTO 95
90 IM=M+IQ
95 IF (I-L) 100, 105, 105
100 IL=I+LQ
GOTO 110
110 X=A(IL)*COSX-A(IM)*SINX
A(IM)=A(IL)*SINX+A(IM)*COSX
A(IL)=X
115 IF (MV-1) 120, 125, 125
120 ILR=ILQ+I
IMR=IMQ+I
X=R(ILR)*COSX-R(IMR)*SINX
R(IMP)=R(ILR)*SINX+R(IMR)*COSX
R(ILR)=X
125 CONTINUE
X=2.0*A(LM)*SINCS
Y=A(LL)*COSX2+A(MM)*SINX2-X
X=A(LL)*SINX2+A(MM)*COSX2+X
A(LP)=A(LL)-A(MM)*SINCS+A(LM)*(COSX2-SINX2)
A(LL)=Y
A(MM)=X

TESTS FOR COMPLETION
TEST FOR M = LAST COLUMN
130 IF (M-N) 135, 140, 135
135 M=M+1
GOTO 60
140 IF (L-(N-1)) 145, 150, 145
145 L=L+1
GOTO 55
150 IF (IND-1) 166, 155, 160

- B16 -
155 IND=0
    GOTO 50

C                      COMPARE THRESHOLD WITH FINAL NORM
C
160 IF (THR-ANRMX) 165,165,45
    SORT EIGEN VALUES AND EIGENVECTORS

165 IQ=-N
    DO 185 I=1,N
    IQ=IQ+M
    LL=I+(I*I-I)/2
    JO=H*(I-2)
    DO 185 J=1,N
    JO=JO+M
    MM=J+(J*J-J)/2
    IF (A(LL)-A(MM)) 170,185,185
    X=A(LL)
    A(LL)=A(MM)
    A(MM)=X
    IF (MV=1) 175,185,175
    DO 180 K=1,N
    ILR=IQ+K
    IMR=JO+K
    X=R(ILR)
    R(ILR)=R(IMR)
    R(IMR)=X
180 CONTINUE
185 CONTINUE
    RETURN
    END
SUBROUTINE INIT

INITIALIZES CONSTANTS

COMMON /DIG/ ZERO, ONE, TWO, RAO, PI, TW0PI, GM, FT, RE, CON, ROTATE
COMMON /BLK4/ XMU, SIGMA, GAUSS, GM(16), XK, ZRAN, ICNT

31.*67. /

C
C ZERO=0.0
ONE=1.0
TWO=2.0
RAD=57.2957795
CON=1./RAD
PI=3.1415926536
TW0PI=2*PI
GML=1.4076576E16
FT=6076.11549
RE=20925741.
ROTATE=7.29211E-5

C
ENTRY INIT1
ICNT=1
SIGMA=1.
XK=12345678.
XMU=0.
RETURN
END
SUBROUTINE INPUT (TITLE1, TITLE2)
C THIS SUBROUTINE READS MODIFIED NAMELIST FORMATTED DATA.
C IT READS A CARD ON UNIT 5, WRITES THE CARD ON UNIT 6,
C WRITES THE CARD ON UNIT 8 (FIRST 72 CHARACTERS ONLY).
C THE TITLE1 AND TITLE2 CARDS ARE NOT WRITTEN ON UNIT 8
C BUT THE DATA IS PLACED IN THE TITLE1 AND TITLE2 ARRAYS
C FOR TRANSFER BACK TO THE CALLING PROGRAM. TITLE1= AND
C TITLE2= CARDS MUST BEGIN IN COLUMN 2 WITH NO SPACES.
C THE CALLING PROGRAM MUST BLANK THE TITLE ARRAYS,
C CALL INPUT(ARG1, ARG2), AND READ(IO, INPUTO). NAMELIST
C DATA MUST BEGIN WITH $INPUTO AND END WITH $END, BOTH
C BEGINNING IN COLUMN 2.
C IMPLICIT INTEGER(A-Z)
DIMENSION TITLE1(IO), TITLE2(IO), CARD(IO)
DATA BLANK/10H /
C REWIND 8
WRITE(6,40)
10 CONTINUE
READ(5,50) CARD
IF (EOF(5).NE.0) STOP
WRITE(6,60) CARD
C BLANK COLUMNS 9 AND 10
ENCODE (10,70, WORD) CARD(1), BLANK
IF (WORD.NE.10H TITLE1= ) GOTO 20
C CARD READ IS A TITLE CARD
ENCODE (72, 80, TITLE1) CARD
GOTO 10
C 20 CONTINUE
IF (WORD.NE.10H TITLE2= ) GOTO 30
C CARD READ IS A TITLE CARD
ENCODE (72, 80, TITLE2) CARD
GOTO 10
C 30 CONTINUE
C CARD READ IS NOT A TITLE CARD
BLANK COLUMNS 73-80 OF DATA CARD
ENCODE (1G, 90, CARD(IO)) CARD(IO), BLANK
WRITE(IO,50) CARD
IF (CARD(IO).NE.10H $END ) GOTO 10
C REWIND 8
CALL DATE(DAT)
CALL TIME(TIM)
WRITE(6,140) DAT,TIM
RETURN
C 40 FORMAT (1H1)
50 FORMAT (8A10)
60 FORMAT (10X,8A10)
70 FORMAT (A8, A2)
80 FORMAT (R2,7A10)
90 FORMAT (A2, A8)
100 FORMAT (10X,*DATE IS *A9/10X,*TIME IS *A9)
END
SUBROUTINE INTER (X,Y,NUM,B,A)
SELECT FOUR DATA POINTS CLOSEST TO X TO INTERPOLATE FOR Y.
Y=INDEPENDENT VARIABLE VALUE
Y=RESULTING DEPENDENT VARIABLE VALUE
LMT=NUMBER OF ELEMENTS IN A AND B
B=ARRAY OF DEPENDENT VARIABLES
A=ARRAY OF INDEPENDENT VARIABLES
DIMENSION A(15),B(15)
C
I=1
IF (NUM.EQ.4) GOTO 30
IF (NUM.LT.4) WRITE (6,40) NUM
IF (NUM.LT.4) STOP
C
IF (X.LT.A(3)) I=1
IF (X.GT.A(NUM-2)) I=NUM-3
IF (X.LT.A(3) .OR. X .GT. A(NUM-2)) GOTO 30
C
LMT=NUM-2
DO 10 K=4,LMT
IF (X.LT.A(K)) GOTO 20
10 CONTINUE
20 CONTINUE
I=K-2
C
30 CONTINUE
X0=A(I)
X1=A(I+1)
X2=A(I+2)
X3=A(I+3)
Y11=((X1-X)*B(I)-(X3-X)*B(I+1))/(X1-XC)
Y12=((X2-X)*B(I)-(X0-X)*B(I+2))/(X2-XC)
Y13=((X3-X)*B(I)-(X2-X)*B(I+3))/(X3-XC)
Y22=((X2-X)*Y11-(X1-X)*Y21)/(X2-X1)
Y32=((X3-X)*Y11-(X1-X)*Y31)/(X3-X1)
Y=((X3-X)*Y22-(X2-X)*Y32)/(X3-X2)
RETURN
C
40 FORMAT (//10x,6SUBROUTINE INTER - VALUES IN INTERPOLATION TABLE =*
I3* MUST BE GE. 4*)
END
SUBROUTINE NEWTON

ITERATES ON ECCENTRIC ANOMALY GIVEN A TIME (TCALL)

COMMON /CENT/ CETA, SETA, CG, SG, R, V, SEA
COMMON /CONIC/ STATE(6), TCALL, KERR, STEP, T, TZERO
COMMON /MAN/ A, A1EE, AVG, E, DOG, EAREF, ETA, ICIRCL, LOUSY, P,
           PGME, RREF, TANOM, TRUE, TREF, XNA, PERIOD, EP

KERR = 0
K = -30
OM = TCALL - TREF
EA = EAREF + XNA * OM / RREF
VALUE = AVG * TCALL

10 FCN = ( EA - E*SIN(EA) - VALUE )/(1. - E*COS(EA) )
EA = EA - FCN
K = K + 1
IF (X.GE.0) GOTO 30
IF (ABS(FCN)-1.E-9 .LE. 0.) GOTO 50
GOTO 10

30 WRITE (6,40)
40 FORMAT( '/ 6X 22H30 ITERATIONS FOR BODY // ')
KERR=1
GOTO 60

50 EAREF = EA
SEA = SIN( EA )
CEA = COS( EA )
RREF = A * ( 1. - E * CEA )
TREF = TCALL
STA = SEA * A1EE / RREF
CTA = ( CEA - E ) * A / RREF
ETA = ATAN2( STA, CTA ) - TANOM
TRUE = STA
TRUE STORES STA FOR SIGN ON GAMMA

60 CONTINUE
RETURN
END
SUBROUTINE NORRAN
C
GENERATES A NORMALLY DISTRIBUTED RANDOM NUMBER.
REAL NG, MU
COMMON /BLK4/ MU, SIGMA, GAUSS, NG(16), KX, ZRAN, ICNT
C
TEMP = 0.
DO 100 I=1,12
KX = NG(ICNT)*KX
KTEMP = INT(KX/1000000000.00)
KX = ABS(KX - FLOAT(KTEMP)*1000000001.00)
ZRAN = KX*0.000000001CC
ICNT = ICNT + 1
IF (ICNT.GT.16) ICNT = 1
100 TEMP = TEMP + ZRAN
GAUSS = SIGMA*(TEMP - 6.0) + MU
RETURN
END
SUBROUTINE TSTEP
PROPORT S ALONG A CONIC BY TIME INCREMENT (STEP)
SUBROUTINE CONIC MUST BE CALLED TO INITIALIZE

COMMON /CENT/ CETA, SETA, CG, SG, R, V, SEA
COMMON /CONIC/ STATE(6), TCALL, KERR, STEP, T, TZERO
COMMON /CORD/ Q(3,3)
COMMON /DIG/ ZER0, ONE, TWO, RAD, PI, TWOP1, GM, FT, RE, CON, ROTATE
COMMON /MAN/ A, ALE, AVG, E, DOG, EAREF, ETA, ICIRCL, LOUSY, P,
& PGME, RREF, TANOM, TRUE, TREF, XNA, PERIOD, EP
DIMENSION XU(3), XV(3), ZN(3), DN(3), DA(3)
DATA ZN / 0., 0., 1. /

IF (LOUSY.GT.0) GO TO 80
IF (ICIRCL.LT.0) GO TO 10

CIRCULAR ORBIT REQUIRES SPECIAL CARE.

ETA = AVG * STEP + ETA
TRUE = ZERO
EAREF=ETA
GOTO 20

10 TCALL = TREF + STEP
CALL NEWTON
IF (KERR.NE.0) GO TO 90

20 T = T + STEP

CALCULATE POSITION AND INERTIAL VELOCITY COMPONENTS.

SETA = SIN( ETA )
CETA = COS( ETA )
R = RREF
V = SQRT( GM*(TWO/P - ONE/A) )
CG = DOG / ( R * V )
SG = SQRT( ARS( ONE - CG * CG ) )
IF (TRUE.LE.Z.) SG = -SG
RCOMP = V * ( CETA * SG - SETA * CG )
HCOMP = V * ( SETA * SG + CETA * CG )

CONVERT INTO INERTIAL X-Y-Z AXES.

X = R * ( CETA * Q(1,1) + SETA * Q(1,2) )
Y = R * ( CETA * Q(2,1) + SETA * Q(2,2) )
Z = R * ( CETA * Q(3,1) + SETA * Q(3,2) )
DXDT = RCOMP * Q(1,1) + HCOMP * Q(1,2)
DYDT = RCOMP * Q(2,1) + HCOMP * Q(2,2)
DZDT = RCOMP * Q(3,1) + HCOMP * Q(3,2)

XU(1) = X / R
XU(2) = Y / R
XU(3) = Z / R
XV(1) = DXDT
XV(2) = DYDT
XV(3) = DZDT
DA(1) = XU(2) * ZN(3) - XU(3) * ZN(2)
DA(2) = XU(3) * ZN(1) - XU(1) * ZN(3)
DA(3) = XU(1) * ZN(2) - XU(2) * ZN(1)
AA = DA(1) + DA(2) + DA(3)

IF (AA .GT. 1.E-6) GOTO 40
DA(1) = 1.
DA(2) = 0.
DA(3) = 3.
GOTO 50

40 AA = SORT(AA)
DA(1) = DA(1) / AA
DA(2) = DA(2) / AA
DA(3) = DA(3) / AA

50 CONTINUE
DN(1) = DA(2) * XU(3) - DA(1) * XU(2)
DN(2) = DA(3) * XU(1) - DA(1) * XU(3)
DN(3) = DA(1) * XU(2) - DA(2) * XU(1)
AA = DN(1) + DN(2) + DN(3)

IF (AA .GT. 1.E-6) GOTO 60
DN(1) = 1.
DN(2) = 0.
DN(3) = 3.
GOTO 70

60 AA = SORT(AA)
DN(1) = DN(1) / AA
DN(2) = DN(2) / AA
DN(3) = DN(3) / AA

70 CONTINUE
VNORTH = XU(1) + ON(1) + XV(2) + ON(2) + XV(3) + ON(3)
VEAST = (XV(1) + DA(1) + XV(2) + DA(2) + XV(3) + DA(3))

C UPDATE THE STATE TRAJECTORY VARIABLES

H = R - RE
CAM = RAD * ASIN(SG)
ZET = RAD * ATAN2( VEAST, VNORTH )
IF (ZET .LT. 0.) ZET = ZET + 360.
ALAT = RAD * ASIN( XU(3) )
ALON = RAD * ATAN2( XU(2), XU(1) ) = ROTATE*(T-TZERO)*RAD
STATE(1) = H
STATE(2) = V
STATE(3) = CAM
STATE(4) = ZET
STATE(5) = ALAT
STATE(6) = ALON

C 80 RETURN

C 90 WRITE(6,100) STFP
100 FORMAT( // 10X 16HTROUBLE IN TSTEP 4X 6HSTEP = 1PE15.5)
RETURN
END
SUBROUTINE UNIRAN
C GENERATES A UNIFORM RANDOM NUMBER
REAL NG, KX, MU
COMMON /BLK4/ MU, SIGMA, GAUSS, NG(16), KX, ZRAN, ICNT
C
IF (ICNT .LE. 6 .OR. ICNT .GT. 16) ICNT=1
KX = NG(ICNT)*KX
KTEMP = INT(KX/100000000.0)
KX = ABS(KX - FLOAT(KTEMP)*100000000.0)
ZRAN = KX*.00000100100
ICNT = ICNT + 1
IF (ICNT .GT. 16) ICNT = 1
RETURN
END
IDENTIFICATION

Title Scout Trajectory Error Propagation

Routine No. 1801 Date Filed 1974 Security Class. U

Responsible Engineer T. R. Myler

Date Completed 1974 Source FORTRAN

Language: IV

Key Words Covariance matrix, propagation, conic, Monte Carlo, statistics

RESOURCE REQUIREMENTS

Typical CPU 10 sec Machine(s) CDC CYBER 175 No. Source Cards 1125

Core 65k (octal) Tape none Plot no Graphics none

DESCRIPTION

Purpose: To calculate error statistics in the trajectory parameters, including an error covariance matrix, from flight experience. The covariance matrix is propagated on option.

Input: Flight experience errors in the trajectory parameters.

Output: Error statistics in the trajectory parameters, error covariance matrix, propagated covariance matrices, spin-stabilized stage boost covariance matrix, sensitivity matrix which represents the final covariance matrix after propagation.

Functional Description:

Flight samples are combined statistically to obtain an error covariance matrix. The covariance matrix is propagated using a Monte Carlo technique of sampling, propagating the deviated trajectory along the conic, and statistically combining the resulting errors into another covariance matrix. The sensitivity matrix is developed from the eigenvalues and eigenvectors of the covariance matrix.

DOCUMENTATION

Since 1969, flight experience has been used as the basis for predicting Scout orbital accuracy. The data base used for calculating the accuracy consists of errors in the trajectory parameters (altitude, velocity, etc.) at stage burnout as observed on Scout flights. Approximately 50 sets of errors are used in Monte Carlo analysis to generate error statistics in the trajectory parameters. A covariance matrix is formed which may be propagated in time. The mechanization of this process resulted in computer program Scout Trajectory Error Propagation (acronym STEP) and is described herein.

Computer program STEP may be used in conjunction with the Statistical Orbital Analysis Routine (Reference 1) to generate accuracy in the orbit parameters (apogee, perigee, inclination, etc.) based upon flight experience.
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