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SPACE TRAJECTORY ERROR ANALYSIS PROGRAM (STEAP) FOR HALO ORBIT MISSIONS

VOLUME 1: ANALYTIC AND USER'S MANUAL

D. V. Byrnes
P. C. Carney
J. W. Underwood
E. D. Vogt

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Analysis and Operations

MARTIN MARIETTA AEROSPACE
P. O. Box 179
Denver, Colorado 80201

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16. Abstract

The six month effort was responsible for the development, test, conversion, and documentation of computer software for the mission analysis of missions to halo orbits about libration points in the Earth-Sun system. The software consisting of two programs called NOMNAL and ERRAN is part of the Space Trajectories Error Analysis Programs (STEAP) developed by MMC.

The program NOMNAL targets a transfer trajectory from Earth on a given launch date to a specified halo orbit on a required arrival date. Either impulsive or finite thrust insertion maneuvers into halo orbit are permitted by the program. The transfer trajectory is consistent with a realistic launch profile input by the user.

The second program ERRAN conducts error analyses of the targeted transfer trajectory. Measurements including range, doppler, star-planet angles, and apparent planet diameter are processed in a Kalman-Schmidt filter to determine the trajectory knowledge uncertainty. Execution errors at injection, midcourse correction and orbit insertion maneuvers are analyzed along with the navigation uncertainty to determine trajectory control uncertainties and fuel-sizing requirements. The program is also capable of generalized covariance analyses.

The final report consists of two volumes: an Analytic and User's Manual and a Programmer's Manual.

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PREFACE

The objective of this contract (NAS5-24067) is the development of computer software for the preflight mission analysis of missions to earth-sun libration points. This software, designated STEAP-L, extends the capability of the Space Trajectories Error Analysis Programs (STEAP) developed under contracts NAS1-9745, NAS5-11795, and NAS5-11873 and begins the integration of STEAP with the Goddard Trajectory Determination System (GTDS).

The software produced consists of two related programs, both of which use the GTDS Cowell propagator for the computation of the trajectory and state transition matrices. The first program, NOMNAL, is responsible for the generation of the nominal trajectory from launch at earth to insertion into halo orbit about the desired libration point. NOMNAL uses a Newton-Raphson iteration (moving backward in time from the insertion maneuver) to perform the targeting of both impulsive and finite burn insertions into halo orbit. A user-controlled launch profile allows the transfer to be tied to a realistic launch and injection. NOMNAL stores the targeted trajectory and state transition matrices on a file for later analysis by the second program ERRAN.

The program ERRAN performs generalized linear error analyses along specific targeted trajectories. Knowledge and control covariances are propagated along the trajectory through a series of measurements and guidance events in a totally integrated fashion. The knowledge covariance is processed through measurements using a Kalman-Schmidt recursive filter with arbitrary solve-for/consider/ignore state augmentation. Probabilistic midcourse corrections are computed using an exact analytic formulation. ERRAN obtains the trajectory and state transition matrices from a file generated by NOMNAL for program efficiency.

A major conclusion of this effort is that the complementary features of the GTDS and STEAP systems may be effectively combined to yield a significantly improved system. Thus the Cowell file generator/reader capability of the GTDS has been combined with the generalized covariance analysis of STEAP to yield a more efficient, extended error analysis capability than either system had previously. Other conclusions reflect the efficacy of the backward targeting algorithm developed for the libration mission targeting and the analytic formulation implemented for the midcourse correction sizing.

The general recommendations for future effort identified during this study are two-fold. Because of the success of this preliminary integration of the GTDS and STEAP systems it is recommended that this effort be continued and enlarged. In the specific area of libration point mission analysis, it is recommended that more detailed models (e.g., pulsing thrust insertion into halo orbit) be developed and continued studies be made of critical problems (e.g. station-keeping error analysis) for these peculiar missions which are neither interplanetary, lunar, nor earth-orbiting.

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NOMENCLATURE

A. Arabic Symbols

Symbol	Definition
a	Semi-major axis of conic
C_{xx_s}	Correlation between position/velocity state and solve-for parameters
C_{xu}	Correlation between position/velocity state and dynamic consider parameters
C_{xv}	Correlation between position/velocity state and measurement consider parameters
$C_{x_s u}$	Correlation between solve-for parameters and dynamic consider parameters
$C_{x_s v}$	Correlation between solve-for parameters and measurement consider parameters
e	Eccentricity of conic
E	Eccentric anomaly
f	True anomaly on conic
G	Observation matrix relating observables to dynamic consider parameter state
H	Observation matrix relating observables to position/velocity state
i	Inclination of conic (reference body equatorial)
J	Measurement residual covariance matrix
K	Kalman gain constant for position/velocity state
L	Observation matrix relating observables to measurement consider parameter state
	Mean longitude
M	Observation matrix relating observables to solve-for parameter state
	Mean anomaly
n_1	Dimension of solve-for parameter state
n_2	Dimension of dynamic consider parameter state
n_3	Dimension of measurement consider parameter state
p	Semilatus rectum of conic Probability density function
P	Position/velocity covariance matrix
$\hat{P}$	Unit vector to periapsis of conic

Symbol	Definition
P_s	Solve-for parameter covariance matrix
Q	Dynamic noise covariance matrix
$\tilde{Q}$	Execution error matrix
$\hat{Q}$	Unit vector in plane of motion normal to P
r	Radius
r_{CA}	Radius of closest approach
R	Measurement noise covariance matrix
$\underline{R}$	Actual noise covariance matrix
S	Kalman gain constant for solve-for parameters
S_j	Velocity correction covariance matrix
t_{CA}	Time of closest approach to target body
Δt	Time interval
U_o	Dynamic consider parameter covariance matrix
v	Velocity
V_o	Measurement consider parameter covariance matrix
W_j	Target parameter covariance matrix
$\hat{W}$	Unit normal to orbital plane
X	Actual position/velocity state
$\overline{X}$	Targeted nominal position/velocity state

B. Greek Synbols

Γ_j	Guidance matrix
Γ	Flight path angle
δ	Declination of vector
Δv	Velocity increment
ε	Measurement residual Errors in target parameters
η_j	Variation matrix relating position/velocity variations to target conditions
θ_{xx_s}	State transition matrix partition associated with solve-for parameters
θ_{xu}	State transition matrix partition associated with dynamic consider parameters

Symbol	Definition
θ	Longitude or right ascension
Λ_j	Projection of target condition covariance matrix W_j into the impact plane
μ	Gravitational constant of body
$\vec{\mu}$	Biased aimpoint
ν	Sampled measurement noise True anomaly
ρ	Magnitude of midcourse correction Correlation coefficient
σ	Standard deviation
Σ	Launch azimuth
$\vec{\tau}$	Target parameters
Φ	Targeting matrix State transition matrix for position/velocity state Latitude
χ	Sensitivity matrix
ψ_j	Matrix relating guidance corrections to target condition deviations
Ω	Longitude of ascending node
ω	Argument of periapsis
$\tilde{\omega}$	Longitude of periapsis

C. Subscripts

C	Control variable (P_C)
CA	Closest approach (r_{CA})
f	Final variable (t_f)
i	Initial variable (t_i)
j	Index of current guidance event (P_j)
k	Index of current measurement (P_k)
K	Knowledge variable (P_K)
s	Solve-for parameter (x_s)

D. Superscripts

A	Augmented variable (Φ^A)
T	Matrix transpose (Φ^T)

Symbol	Definition
-1	Matrix inverse (Φ^{-1})
$-$	Variable immediately before instant (P_k^- or v^-)
$+$	Variable immediately after instant P_k^+ or v^+)

E. Abbreviations

AU	Astronomical unit
CA	Closest approach to reference body
ERRAN	Error analysis program
FTA	Fixed time of arrival (guidance policy)
GHA	Greenwich hour angle
GSFC	Goddard Space Flight Center
GTDS	Goddard Trajectory Determination System
J.D.	Julian date (referenced either 0^{yr} or 1900^{yr})
km	Kilometers
M/C	Midcourse correction
NOMNAL	Nominal trajectory generation program
S/C	Spacecraft
SF/C	Solve-for/consider
STM	State transition matrix
STEAP	Space Trajectories Error Analysis Programs
VTA	Variable Time of Arrival (Guidance Policy)

1. INTRODUCTION

This Analytic and User's Manual is intended to provide the reader with a detailed description of the capability of the STEAP-L (Space Trajectory Error Analysis Programs - Libration Point Missions) programs. This volume includes descriptions of the mathematical analysis, assumptions and restrictions upon which the STEAP-L programs are based. It also details the usage of the two programs of STEAP-L: NOMNAL, the nominal trajectory generator; and ERRAN, the linear error analysis program. An accompanying volume is the Programmer's Manual which defines the structure and coding of the programs and routines. This volume is divided into three major parts. This introductory chapter discusses the general development of the STEAP library of programs, describes the libration point missions toward which the current effort is directed, and summarizes the capability of each of the programs developed for this application: NOMNAL and ERRAN. Chapters 2 through 5 form an analytical manual comprised of NOMNAL analysis, ERRAN navigational analysis, ERRAN maneuver analysis, and ERRAN generalized covariance analysis respectively. Chapter 6 details the usage of NOMNAL; Chapter 7, the usage of ERRAN. These chapters describe the input and output of each program and discuss sample cases generated with each program.

1.1 Development of STEAP

STEAP is an acronym for Space Trajectory Error Analysis Programs. Rather than a single computer program, STEAP is a library of related programs for the analysis of the navigation and guidance characteristics of space missions. These programs have been developed, modified, and extended over a number of years by the Martin Marietta Corporation (MMC) under the direction of NASA in a variety of contracts.

There are two primary unifying elements in the development of the STEAP system. The first is in the underlying philosophy of STEAP. STEAP has always been directed toward the performance of a totally-integrated analysis of the navigation and guidance processes of space missions. Thus interaction is continually forced between the tracking uncertainties and the maneuver execution errors to determine the evolving uncertainties in the knowledge and control of the spacecraft trajectory. The second element is in general program structure. The STEAP software has continually been divided into three distinct operational modes responsible for nominal trajectory targeting and generation (NOMNAL), linear error analyses (ERRAN), and single-case or Monte Carlo simulations (SIMUL). The current effort does not address the third of these types of programs.

The mathematical foundation for the STEAP system was initially developed under Contract NAS8-21120 for Marshall Space Flight Center. The first version of STEAP (Contract NAS1-8745) was constructed for general interplanetary ballistic missions for Langley Research Center to support the Viking mission analysis and design. Later development of STEAP was performed for Goddard Space Flight Center (Contracts NAS5-11795 and NAS5-11873) where specific extensions required for Planetary Explorer (later known as Pioneer Venus) and general lunar missions were added in a version called STEAP-II. More recently, programs for the navigation and guidance analysis of low thrust interplanetary and near-Earth missions have been developed for Langley Research

Center (NAS1-11686) and Marshall Space Flight Center (Contract NAS8-29666). Throughout this time, improvements in the analytical techniques and program structure have been continually identified and incorporated into the STEAP series of programs. (References 1-5.)

Under the current contractual effort, versions of NOMNAL and ERRAN appropriate for missions to Earth-Sun libration points have been developed (termed STEAP-L). A very significant feature of this effort is that the Goddard Trajectory Determination System (GTDS) Cowell propagator is being integrated into the STEAP-L programs. The Cowell propagator permits the generation of a file containing trajectory and state transition matrix (computed by integration of the variational equations) data during the NOMNAL run. This data may then be efficiently retrieved in subsequent ERRAN runs, thereby eliminating the costly integration cycle from ERRAN.

A number of new analytical features have been added to STEAP under this contract. An unusual approach has been used in the targeting of the libration point missions. Backward integration is used in computing the successive trajectory iterates and targeting matrices required by the Newton Raphson targeting algorithm. This backward targeting scheme efficiently produces a targeted transfer trajectory that is consistent with realistic launch and injection constraints. The approach is well-suited to cometary or lunar missions as well.

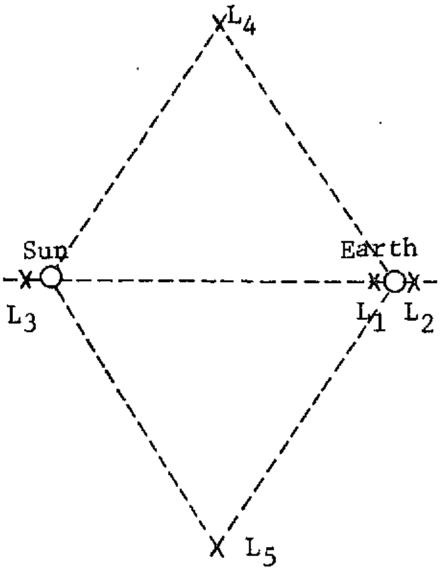
An exact computation of the probabilistic midcourse correction requirements using the recently published technique of Lee-Boain (Reference 6) has been added to ERRAN (see Section 4.4). This replaces the previous model which employed the Hoffman-Young approximation (Reference 7) and which could lead to significant errors at the higher probability levels. This technique is applicable to lunar or interplanetary trajectories as well as the libration point missions.

A third significant item developed during this effort has been the reformulation of the variable time-of-arrival (VTA) guidance policy for the libration point mission application. The guidance policies available in previous versions of STEAP always assumed that the target state was referenced to a gravitational body such as the moon or a planet. This restriction has now been removed (see Section 4.4).

Details of these and other mathematical models and algorithms developed for the libration point mission application are provided in Chapters 2 through 5 of this volume. The characteristics of the libration point missions necessitating these extensions are described in the summary of the libration point missions given in the next section. The capabilities of the resulting programs NOMNAL and ERRAN are then detailed in the next two sections.

1.2 Libration Point Mission Application

The STEAP-L programs developed under this contract are designed for use primarily for the analysis of missions to the two Earth-Sun libration points near the Earth. These are designated L_1 and L_2 in Figure 1.1, which shows schematically the location of all five classical Lagrangian or libration points.



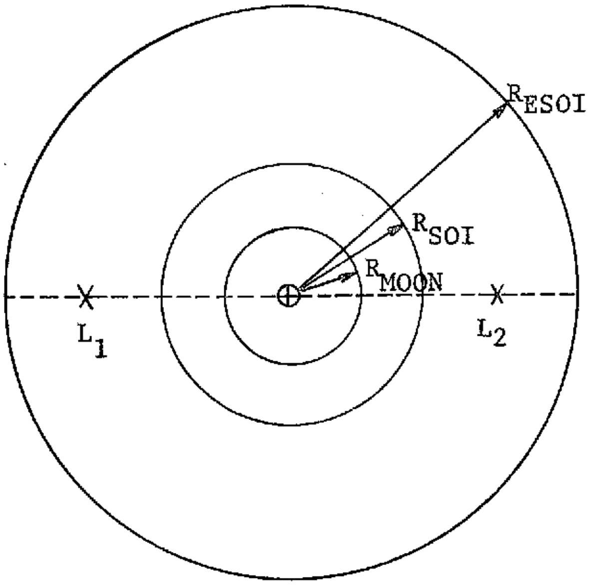


Figure 1.1 Earth-Sun Libration Points

Figure 1.2 Details of L_1 and L_2 Libration Points

Figure 1.2 shows in more detail the location of points L_1 and L_2 with respect to the Earth, with the orbit of the Moon, the classical or Laplacian sphere of influence of the earth, and an enlarged version occasionally used in targeting of swingby missions. The two spheres of influence are defined by

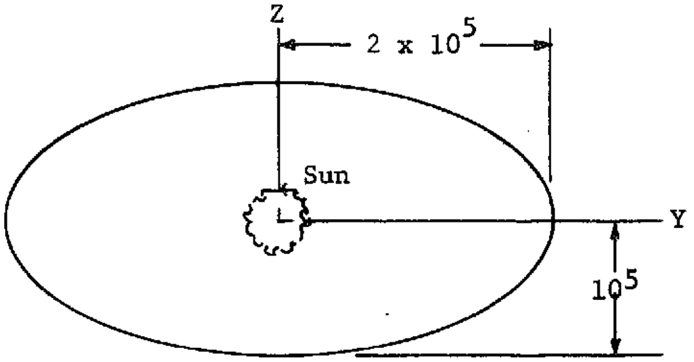
$$R_{SOI} = R_{SE}(M_E/M_S)^{2/5}$$

$$R_{ESOI} = R_{SE}(M_E/M_S)^{1/3}$$

where R_{SE} is the Earth-Sun distance and M_E and M_S are the masses of the Earth and Sun respectively.

Efficient transfers from circular Earth parking orbit to the L_1 and L_2 points have been shown (Reference 8) to fall into at least two major families; those with short (~25 to 50 day) transfer times and those with long (~100 to 135 day) transfer times. The fast transfers require from 341 to about 400 meters/second ΔV to insert into orbit near the libration point, with the minimum ΔV at about 36.4 days. The slow transfers require insertion ΔV of from 272 to about 400 meters/second, with the minimum ΔV at about 116.8 days. These optimum insertion values are based upon the Earth in a circular orbit around the Sun and will vary slightly due to the ellipticity of the orbit of the Earth. The influence of the moon will affect them also. Both of the families discussed above assume a posigrade transfer orbit upon leaving the Earth; corresponding families exist for retrograde departures, but these require higher insertion ΔV at the libration point. For long flight times at least two other families of trajectories exist but have higher ΔV requirements. Even more families exist with longer flight times (~175 days) that have lower ΔV requirements (~200 meters/second) (Reference 8).

The primary feature of the libration points is that they are equilibrium points of the system; i.e., if a spacecraft is placed exactly at a libration point with no motion relative to the system, it will remain at that point relative to the two-body configuration. The collinear points (L_1, L_2, L_3) are unstable while the equilateral triangle points (L_4, L_5) are only quasi-stable. Thus, some form of station-keeping is necessary to maintain the spacecraft in that location. However, the fuel required is still much less than it would be at arbitrary points of the system. Thus, the L_1 and L_2 points offer attractive stations for spacecraft for monitoring solar or solar/earth phenomena (Reference 9). To facilitate communications, the spacecraft would generally be placed in a "halo-orbit" about the libration point so that the sun would not obstruct the view of the spacecraft from earth. A typical halo-orbit in the plane normal to the rotating earth-sun line is illustrated in Figure 1.3.



X-axis from Sun to Earth

Z-axis Normal to Ecliptic

Y-axis Completes Right Hand System

Figure 1.3 Typical Halo-Orbit as Viewed from Earth

The current effort is directed toward the study of the transfer and insertion phases of the libration point mission; the station-keeping while in the halo-orbit was not addressed in this effort. The two programs developed for the analysis of libration point transfers include the nominal trajectory and maneuver targeting program NOMNAL and the navigation and guidance error analysis program ERRAN summarized in the next two sections.

1.3 Summary of NOMNAL

The computer program NOMNAL is responsible for the generation of a nominal trajectory from injection at earth to insertion into a halo orbit about a libration point in the earth-sun system.

NOMNAL uses a specialized version of the GTDS Cowell propagator for the integration of the trajectory equations. The dynamic model used in the reduced Cowell propagator includes the accelerations, on the spacecraft produced by a central body, up to two non-central bodies, and finite thrust engines. The Cowell propagator generates state and control transition matrices by integration of variational equations simultaneously with the equations of motion. These matrices are then used in the targeting of the libration point missions within NOMNAL and in the propagation of covariance matrices and the error analysis of the finite burn insertion maneuver in ERRAN.

NOMNAL has the capability to target transfer trajectories to libration points using both impulsive and finite thrust insertion maneuvers. In either case a backward targeting scheme is employed where conditions at the libration point are iteratively improved to yield trajectories which when propagated backwards in time from the desired arrival point and time to the earth satisfy desired target conditions. The three target conditions at the earth are radius of closest approach, equatorial inclination at closest approach, and time at closest approach. These three conditions are normally selected to be consistent with the desired parking orbit radius, launch site latitude, and desired trip time.

In impulsive targeting the three controls at the libration point are the three components of velocity on the transfer trajectory. In finite thrust targeting the controls are the right ascension and declination of the thrust direction and the duration of the burn; the thrust magnitude, engine specific impulse, and initial spacecraft mass are held constant at the user-supplied values. A Newton-Raphson algorithm is used to iteratively improve the control parameters to determine their required values.

The program includes three options for the determination of the zero iterate values to begin the targeting process: table interrogation, conic approximation, and user-specification. Tables defining targeted velocities have been constructed for transfers to the L_1 and L_2 points with trip times in the vicinity of either optimal transfer (tabulated ΔVs for trip times of from 25 to 50 days and from 102 to 130 days at 1 day intervals). Initial values of velocity may then be interpolated from the data stored in these tables. The second option computes the initial libration point velocity by solving Lambert's theorem for the geocentric conic connecting the libration point radius and the injection radius in the desired time. The third option accepts a user-supplied zero iterate vector computed by the user outside the program.

NOMNAL can adjust the injection time of the transfer to correspond to a realistic launch profile specified by the user. It then adjusts the arrival time by the same amount to hold the trip time at the user-desired value. NOMNAL computes and records such information as the required launch azimuth, coast time, and whether or not a coplanar injection maneuver is required.

1.4 Summary of ERRAN

The error analysis/generalized covariance analysis program ERRAN is a preflight mission analysis tool that is used to determine how selected error sources influence the orbit determination process for libration point missions.

In the error analysis mode, ERRAN provides three primary quantitative results: (1) knowledge covariance matrices, which provide a measure of how well the actual trajectory is known, (2) control covariance matrices, which when propagated forward to the target provide a measure of how well the nominal target conditions will be satisfied by the actual trajectory, and (3) statistical midcourse ΔVs, which provide a measure of the amount of fuel required for a successful mission.

In the generalized covariance analysis mode, ERRAN provides all of the above information plus corresponding "actual" statistical information. The three results discussed in the previous paragraph are all computed on the basis of statistical distributions assumed by the navigation filter to describe the significant error sources. In the generalized covariance analysis mode, "actual" knowledge covariances, control covariances, and statistical midcourse ΔVs are computed on the basis of statistical distributions that actually describe both error sources acknowledged by the navigation filter and the error sources ignored. The primary use of the generalized covariance analysis program is to study the sensitivity of filter performance to off-design conditions.

Up to 15 measurement parameters may be solved-for or considered by the navigation filter employing a Kalman-Schmidt sequential formulation. Parameters not acknowledged in design of the filter may be treated as ignore parameters when ERRAN is run in the generalized covariance analysis mode. Measurement biases include biases in the locations of the three earth-based tracking stations, and biases in all measurements. Available measurement types are range, Doppler, and a simple optical model. Measurement noise for each measurement type is assumed to be constant.

The computational procedure in ERRAN is divided into basic cycle computations and event computations. Basic cycle computations are concerned with the propagation of covariances forward to a measurement time and processing the measurement. Events refer to a set of specialized computations, not directly concerned with measurement processing, that can be scheduled to occur at arbitrary times along the trajectory. State transition matrices interpolated from the file created by NOMNAL are used for all covariance matrix propagation.

The four events available in ERRAN are eigenvector, prediction, guidance, and final insertion into halo orbit. At an eigenvector event the position and velocity partitions of the knowledge covariance matrix are diagonalized to reveal geometric information about the size and orientation of the position and velocity navigation uncertainties. At a prediction event the most recent covariance matrix is propagated forward to some critical trajectory time to determine predicted navigation uncertainties in the absence of further measurements.

The guidance event is the most complex event and yields much useful information for preflight mission analysis. Several types of guidance events are available in ERRAN. At a midcourse guidance event the user can choose from either fixed or variable time of arrival guidance policies (FTA or VTA). Execution error statistics are generated using an impulsive error model defined by a proportionality error, a resolution error, and two pointing angle errors. The execution errors of the insertion maneuver may be modeled as either an impulsive maneuver (defined above) or a finite thrust maneuver (component errors modeled as two pointing errors and a thrust magnitude uncertainty). The target condition covariance matrix both before and after the maneuver is printed out for midcourse and insertion maneuvers.

2. NOMNAL ANALYSIS

This section of the report summarizes the analytical foundation of the NOMNAL subprogram developed for the libration point mission application. It therefore describes the mathematical assumptions, models, and restrictions used in the program. The major topics are discussed in the following order: trajectory and transition matrix generation, zero iterate computation, impulsive targeting, finite burn targeting and launch phase modeling.

2.1 Trajectory and Transition Matrix Generation

NOMNAL uses the Cowell propagator developed for use in the GTDS for the simultaneous integration of the spacecraft equations of motion and the variational equations defining the state transition matrix. This Cowell propagator has been specialized to the libration point mission application to reduce core storage and time requirements. Only the major modifications and critical features of the Cowell propagator will be discussed here as complete documentation of the propagator is available at GSFC.

2.1.1 Trajectory Propagation

The equations of motion of the spacecraft state (R,V) with respect to the central body are assumed to be of the form

$$\frac{dR}{dt} = V \qquad\qquad \frac{dV}{dt} = A_C + A_N + A_T \tag{2.1}$$

In this equation, the central body acceleration A_C is given by

$$A_C = -\frac{\mu R}{|R|^3} \tag{2.2}$$

where μ is the mass of the central body. The non-central body gravitational accelerations A_N is given by

$$A_N = \sum_{i=1}^{n} \left(\frac{\mu_i (R_i - R)}{|R_i - R|^3} - \frac{\mu_i R_i}{|R_i|^3} \right) \tag{2.3}$$

where R_i and μ_i are the relative position and mass of the i^{th} perturbing body. The number of perturbing bodies can be zero, one or two at the option of the user. The ephemerides of the gravitational bodies are obtained from the permanent direct access file of the GTDS as supplied by GSFC. To implement the finite burn targeting (discussed in detail in Section 2.4) a specialized version of the finite thrust acceleration A_T was used. The finite thrust is assumed to be in a fixed direction determined by the heliocentric ecliptic right ascension α and declination β. The thrusting engine is assumed to have a constant mass flow rate $\dot{m}$ given by $\dot{m} = T/(gI_{SP})$ where T is the thrust magnitude, I_{SP} is the engine specific impulse and g is the gravitational acceleration of Earth. The instantaneous spacecraft mass is then computed from $m = m_o - \dot{m}t$, where m_o is the initial spacecraft mass and t is the time from thrust initiation. The parameters m_o, T, and I_{SP} are specified by the user.

The resulting finite burn acceleration is then given by

$$A_T = \begin{bmatrix} (T/m) \cos \alpha \cos \beta \\ (T/m) \sin \alpha \cos \beta \\ (T/m) \sin \beta \end{bmatrix} \qquad (2.4)$$

The actual integration of these equations of motion is performed by the GTDS second sum Cowell integration scheme using the regular vary-step integration mode with the multi-step starter. The evolving components of state are stored sequentially as an orbit file for later use by ERRAN. Thus, the targeted trajectory need be fully integrated only once while all ERRAN studies made of that trajectory are performed off the orbit file generated by the Cowell propagator.

2.1.2 Transition Matrix Generation

Along with the spacecraft equations of motion, the Cowell propagator integrates the variational equations to generate the state transition matrix. The Cowell propagator has been extended to automatically integrate augmented partitions to the variational equations to compute state sensitivities to finite thrust parameters. These matrices are then used in the finite thrust targeting algorithm of NOMNAL and the finite thrust execution error model in ERRAN. The specifics of the state transition matrix generation of the Cowell propagator are detailed in GTDS documentation and will only be briefly summarized here. However, the extensions to the Cowell propagator variational equations for the finite thrust modeling will be discussed in some detail.

The nonlinear equations of motion (2.1) can be rewritten as

$$\dot{X} = F(X,U,t) \qquad (2.5)$$

where X now represents the six-vector of spacecraft position and velocity, U represents a three-vector of finite thrust control parameters (defined below), and t represents time. Small deviations (δX, δU) from the nominal state and controls obey the linearized dynamic equations

$$\delta\dot{X} = f(t)\ \delta X + g(t)\ \delta U \qquad (2.6)$$

where

$$f(t) = \frac{\partial F}{\partial X}\,[X(t),U,t] = \frac{\partial(V_x,V_y,V_z,A_x,A_y,A_z)}{\partial(R_x,R_y,R_z,V_x,V_y,V_z)}$$

$$g(t) = \frac{\partial F}{\partial U}\,[X(t),U,t] = \frac{\partial(V_x,V_y,V_z,A_x,A_y,A_z)}{\partial(U_1,U_2,U_3)} \qquad (2.8)$$

given the form of the above equations, the solution to (2.6) may be written:

$$\delta X(t) = \Phi(t,t_o)\ \delta X_o + \Theta(t,t_o)\ \delta U_o \qquad (2.9)$$

where the state transition matrix Φ and the control transition matrix Θ are the solutions of the linear differential equations:

$$\frac{d}{dt}\begin{bmatrix}\Phi & \Theta \\ \Psi & \Omega\end{bmatrix} = \begin{bmatrix} f_{6x6} & g_{6x3} \\ 0_{3x6} & 0_{3x3}\end{bmatrix}\begin{bmatrix}\Phi & \Theta \\ \Psi & \Omega\end{bmatrix}$$

$$\begin{bmatrix}\Phi & \Theta \\ \Psi & \Omega\end{bmatrix}(t_o) = \begin{bmatrix} I_{6x6} & 0 \\ 0 & I_{3x3}\end{bmatrix} \qquad (2.10)$$

It should be noted that only the equations for Φ and Θ need be integrated here since $\Psi \equiv 0$ and $\Omega \equiv I$. The relevant equations are therefore:

$$\dot{\Phi} = f\,\Phi \qquad \Phi(t_o,t_o) = I \qquad (2.11)$$

$$\dot{\Theta} = f\,\Theta + g \qquad \Theta(t_o,t_o) = 0 \qquad (2.12)$$

The integration of (2.11) was previously included in the Cowell propagator; the augmentation of (2.12) has been added to the integration cycle during this effort.

The form of equations (2.1) through (2.4) results in the f-matrix assuming the form

$$f = \begin{bmatrix} 0 & I \\ G & 0 \end{bmatrix} \qquad (2.13)$$

where the gravity gradient matrix G may be written for an inverse square law

$$F = -\mu \frac{R}{|R|^3}$$

$$G = \frac{\mu}{r^3}\left(\frac{3RR^T}{|R|^2} - I\right) \qquad (2.14)$$

The integration of the control transition matrix equation (2.12) is performed only during the thrusting arc. Within the arc, the three parameters controlling the thrust are the angles defining the thrust direction (α, β) and the thrust magnitude T. A fourth thrust control parameter is t_B, the duration of the burn, whose sensitivity must be handled somewhat differently. Differentiation of (2.4) yields the following form for the g-matrix for the first three control parameters

$$g = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ -\frac{T}{M}\sin\alpha\cos\beta & -\frac{T}{M}\cos\alpha\sin\beta & \frac{1}{M}\cos\alpha\cos\beta \\ \frac{T}{M}\sin\alpha\cos\beta & -\frac{T}{M}\sin\alpha\sin\beta & \frac{1}{M}\sin\alpha\cos\beta \\ 0 & \frac{T}{M}\cos\beta & \frac{1}{M}\sin\beta \end{bmatrix} \qquad (2.15)$$

Equation (2.12) can now be integrated with the aid of equations (2.13-2.15) to yield the control sensitivity matrix Θ_E used in computing insertion dispersions i.e., $\Theta_E = \left[\frac{\partial X}{\partial \alpha} \,\vdots\, \frac{\partial X}{\partial \beta} \,\vdots\, \frac{\partial X}{\partial T}\right]$. This matrix is then used in the computations in ERRAN of the insertion dispersions due to execution errors in α, β, and τ (see Section 4.5).

The control parameters used in the targeting are thrust direction and duration (α, β, and t_B) where the thrust magnitude T is held at its nominal (input) value. The first two columns of the control sensitivity matrix $\frac{\partial X}{\partial \alpha}$ and $\frac{\partial X}{\partial \beta}$ generated in backward integration by Cowell are augmented to the burn duration sensitivity vector which may be simply computed as

$$\frac{\partial X}{t_B} = [0,\ 0,\ 0,\ A_x,\ A_y,\ A_z]^T \tag{2.16}$$

to yield the targeting sensitivity matrix $\Theta_T = \left[\frac{\partial X}{\partial \alpha} \,\vdots\, \frac{\partial X}{\partial \beta} \,\vdots\, \frac{\partial X}{\partial t_B}\right]$ used in the finite burn targeting (see Section 2.4). Thus the Cowell propagator has been effectively modified to automatically and efficiently generate all the trajectory related data required by both NOMNAL and ERRAN.

2.1.3 Trajectory Data Retrieval

The Cowell propagator storage and retrieval of the trajectory and transition matrix data has not been altered during this effort. The data is stored sequentially on a file as the targeted trajectory is propagated in NOMNAL. ERRAN then interrogates the file for the trajectory and transition matrix data required.

Since the transition matrix data is cumulative, some processing of the data is required. Suppose that the state transition matrix $\Phi_{\ell,k}$ over the interval $[t_k, t_1]$ is required. The data available from the file are the cumulative (interpolated) matrices $\Phi_{k,o}$ and $\Phi_{1,0}$. The desired matrix is then given by:

$$\Phi_{1,k} = \Phi_{1,0}\, \Phi_{k,0}^{-1} \tag{2.17}$$

Because of the symplectic property of the state transition matrix (resulting from the form of equations (2.13) and (2.14) the inverse may be computed quite simply as

$$\Phi_{k,0}^{-1} = \left[\begin{array}{c|c} \Phi_4^T & -\Phi_2^T \\ \hline \Phi_3^T & \Phi_1^T \end{array}\right] \tag{2.18}$$

where the form of $\Phi_{k,0}$ is given by

$$\Phi_{k,0} = \left[\begin{array}{c|c} \Phi_1 & \Phi_2 \\ \hline \Phi_3 & \Phi_4 \end{array}\right] \tag{2.19}$$

This property is exploited repeatedly in ERRAN in the computation of required state transition matrices. It should be noted that the state transition matrix storage and interpolation scheme used in the Cowell propagator can be used for any sequence of measurements desired in the error analysis study.

2.2 Zero Iterate Generation

Iterative refinement procedures used in targeting trajectories require a zero iterate value for the initial trajectory state. For the targeting of trajectories to halo orbits a targeting scheme which works backward in time has been developed and is discussed in detail in the next two sections. Thus the control parameters are the three components of velocity at the halo orbit point V_o. In NOMNAL three methods are available to the user for generating V_o. The values can be input directly by the user when he has a priori knowledge of the particular case. A second option is to obtain the value from a set of tables included in the program to provide V_o as a function of the flight time and location of the libration point. The third option is to solve the Lambert problem for the two-body geocentric conic connecting a psuedo injection position and the position at the halo orbit in the desired time interval. These latter two options are discussed below.

2.2.1 Table Interrogation

If the orbit of the Earth around the sun were exactly circular, then in the absence of any other perturbations the characteristics of transfer orbits from the Earth to a libration point are not a function of arrival date. In fact, for orbits confined to the ecliptic plane with a given parking orbit radius, the transfer orbit characteristics are a function of only the time interval of the transfer. This fact has been used to generate a set of zero iterate tables. The assumptions used in the tables are as follows:

1) Earth orbit is circular
2) Earth mass is equal to the sum of the actual masses of the Earth and Moon
3) Transfer orbit is in ecliptic plane and terminates exactly at the libration point
4) Injection occurs from a circular parking orbit of altitude 100 kilometers

The data are tabulated as a function of flight time giving the magnitude of the transfer orbit velocity at arrival at the libration point (V_o) and the angle that this arrival velocity vector makes with the radius vector measured in a clockwise direction (θ). This is illustrated below.

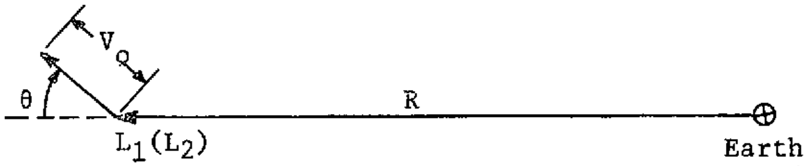


Figure 2.1 Parameters for Zero Iterate Tabulation

Table 2.1 Zero Iterate Velocity Vector for L_1 Point

ΔT (days)	$\|V\|$ (km/sec)	Θ (deg)	ΔV (m/sec)	ΔT (days)	$\|V\|$ (km/sec)	Θ (deg)	ΔV (m/sec)
25	.3593	- 4.32	449.3	102	.6079	-67.72	350.7
26	.3316	- 4.28	429.1	103	.5911	-68.72	331.4
27	.3053	- 4.14	411.1	104	.5790	-69.45	317.5
28	.2808	- 3.88	395.5	105	.5704	-69.99	307.6
29	.2577	- 3.48	382.1	106	.5642	-70.39	300.5
30	.2362	- 2.92	370.9	107	.5590	-70.74	294.4
31	.2165	- 2.17	361.8	108	.5548	-71.03	289.5
32	.1980	- 1.21	354.4	109	.5512	-71.29	285.4
33	.1808	0.04	348.8	110	.5484	-71.50	282.0
34	.1647	1.68	344.9	111	.5461	-71.68	279.2
35	.1498	3.76	342.3	112	.5443	-71.83	277.0
36	.1360	6.40	341.3	113	.5429	-71.96	275.3
37	.1234	9.74	341.5	114	.5419	-72.06	274.1
38	.1122	13.89	342.9	115	.5412	-72.14	273.2
39	.1025	19.05	345.5	116	.5410	-72.20	272.7
40	.0945	25.19	349.0	117	.5410	-72.24	272.6
41	.0885	32.48	353.7	118	.5413	-72.26	272.8
42	.0847	40.49	359.0	119	.5419	-72.27	273.4
43	.0835	49.01	365.3	120	.5428	-72.26	274.2
44	.0846	57.46	372.3	121	.5439	-72.23	275.4
45	.0880	65.38	379.9	122	.5453	-72.19	276.9
46	.0935	72.27	388.3	123	.5469	-72.14	278.6
47	.1008	78.06	397.4	124	.5488	-72.07	280.6
48	.1093	82.99	406.9	125	.5510	-71.98	282.9
49	.1184	87.09	416.5	126	.5533	-71.89	285.4
50	.1279	90.22	426.1	127	.5559	-71.78	288.2
				128	.5587	-71.65	291.2
				129	.5617	-71.52	294.5
				130	.5650	-71.37	298.1
				131	.5685	-71.21	301.9
				132	.5722	-71.04	305.9
				133	.5761	-70.86	310.2
				134	.5801	-70.67	314.6
				135	.5843	-70.47	319.2
				136	.5887	-70.26	324.1
				137	.5932	-70.05	329.0
				138	.5980	-69.82	334.3
				139	.6029	-69.58	339.8
				140	.6080	-69.34	345.4

Table 2.2 Zero Iterate Velocity Vector for L_2 Point

ΔT (days)	$\|V\|$ (km/sec)	Θ (deg)	ΔV (m/sec)	ΔT (days)	$\|V\|$ (km/sec)	Θ (deg)	ΔV (m/sec)
25	.3641	− 4.63	452.8	102	.6443	−65.27	392.3
26	.3363	− 4.23	434.0	103	.6214	−66.64	365.7
27	.3101	− 3.78	417.1	104	.6030	−67.75	344.5
28	.2855	− 3.36	402.0	105	.5888	−68.63	328.0
29	.2623	− 2.94	388.4	106	.5782	−69.30	315.8
30	.2407	− 2.46	376.6	107	.5703	−69.80	306.6
31	.2209	− 1.86	366.9	108	.5647	−70.18	300.1
32	.2023	− 1.09	358.8	109	.5606	−70.47	295.3
33	.1850	− 0.11	352.3	110	.5566	−70.74	290.6
34	.1687	1.19	347.4	111	.5534	−70.98	286.8
35	.1536	2.88	344.0	112	.5509	−71.18	283.8
36	.1395	5.11	342.1	113	.5487	−71.35	281.2
37	.1266	8.01	341.7	114	.5471	−71.49	279.2
38	.1150	11.74	342.6	115	.5458	−71.61	277.6
39	.1047	16.52	344.9	116	.5449	−71.71	276.4
40	.0961	22.35	348.3	117	.5444	−71.78	275.7
41	.0895	29.49	352.9	118	.5442	−71.83	275.4
42	.0851	37.47	358.4	119	.5443	−71.87	275.4
43	.0831	46.13	364.7	120	.5447	−71.89	275.7
44	.0835	54.81	371.5	121	.5453	−71.89	276.2
45	.0864	62.86	379.1	122	.5463	−71.88	277.2
46	.0911	70.14	387.1	123	.5475	−71.85	278.4
47	.0974	76.25	395.5	124	.5489	−71.80	279.9
48	.1049	81.42	404.2	125	.5506	−71.74	281.7
49	.1133	85.74	413.3	126	.5525	−71.67	283.7
50	.1222	89.27	422.4	127	.5546	−71.58	286.0
				128	.5570	−71.48	288.6
				129	.5595	−71.37	291.3
				130	.5623	−71.25	294.3
				131	.5653	−71.12	297.6
				132	.5684	−70.97	301.0
				133	.5718	−70.81	304.7
				134	.5754	−70.64	308.7
				135	.5791	−70.46	312.8
				136	.5830	−70.27	317.1
				137	.5870	−70.08	321.5
				138	.5912	−69.88	326.1
				139	.5956	−69.67	331.0
				140	.6002	−69.45	336.1

The tables are in two parts corresponding to transfer times in the neighborhood of both the "fast" and "slow" optimum transfers, i.e., flight times of from 25 to 50 days and from 102 to 130 days. The data for V_o and θ are stored internally in the program for generating the zero iterate value. Tables 2.1 and 2.2 display these data; in addition the value of the required ΔV to rendezvous with the libration point is tabulated.

2.2.2 Lambert Theorem and Solution

If one of the first two options is not chosen or if a flight time outside the range of tables is specified, a zero iterate using the solution of Lambert's Theorem is provided. This zero iterate is quite good for the short transfer times, but is of questionable value for longer transfer times.

The method used is to assume that a good estimate for the periapse vector is given by the vector 179 degrees from the Earth to libration point vector, of magnitude equal to the desired parking orbit radius and such as to give the proper motion--whether posigrade or retrograde. The geocentric conic between these two vectors with the desired flight time is then found by solving Lambert's problem by the method of Battin (Reference 10). For a greater than 360 degree transfer the solution to Lambert's problem is solved using the method of Lancaster-Blanchard (Reference 11).

2.3 Impulsive Targeting

The special characteristics of libration point missions make it advisable to use a somewhat unusual approach in the targeting of these missions. For interplanetary missions the specification of a launch planet and date and an arrival planet and date essentially determines the heliocentric conic which in turn fixes the launch asymptote. A realistic launch phase can then be modeled using the fixed asymptote and the assumed launch parameters (launch site latitude, azimuth, and selection of either long or short coast time) to yield an accurate estimate of injection time of day and position and velocity (Reference 3).

For libration point missions there is no immediately-available parameter which is analogous to the launch asymptote of the interplanetary missions in its ability to tie down the launch phase. This causes difficulty in determining a realistic initial guess for the trans-libration point injection state which has led to the development of a targeting algorithm which works backward in time. The libration point position R_{LP} at the desired arrival time is easily computed. The conditions defining a reasonable near-earth conic are conveniently stated in terms of the perigee radius (equal to the desired parking orbit radius), the geocentric equatorial inclination (which should equal the launch site latitude to be consistent with a launch azimuth of 90 deg and a coplanar launch and injection) and a time at closest approach (consistent with the desired arrival time and flight time). These parameters denoted r_{CA}, i_{CA}, t_{CA} define three terminal conditions. Thus the system of six differential equations (2.1) corresponding to ballistic flight

$$\begin{aligned} \dot{R} &= V \\ \dot{V} &= A_C + A_N \end{aligned} \qquad (2.22)$$

in conjunction with the six boundary value conditions

$$\begin{aligned} R(t_L) &= R_{LP} \\ r(t_{CA}) &= r_{CA} \\ i(t_{CA}) &= i_{CA} \\ \dot{r}(t_{CA}) &= 0 \end{aligned} \qquad (2.23)$$

(where upper case symbols denote vectors; lower case, scalars)

defines a consistent two-point boundary value problem.

The inclusion of inclination as a target parameter is a natural choice but introduces some ambiguity which must be eliminated. For a given value of inclination such that $0 \leq i \leq 90$ deg, there are four possible near-earth trajectories that make an angle i with the geocentric equator. These solutions correspond to either posigrade or retrograde motion in either of two planes making an angle i with respect to the equator (see Figure 2.1). The two planes A and B both make an angle i with the equator. The two planes may be distinguished by the argument of perigee ω however; one will have $0 \leq |\omega| \leq 90$ deg while the other will have $90 \leq |\omega| \leq 180$ deg. Therefore to allow either solution to be targeted the program permits posigrade inclinations to be specified as $i_{CA} = i$, $0 \leq i \leq 90$ deg and retrograde solutions as $i_{CA} = 180 - i$, $0 \leq i \leq 90$ deg.

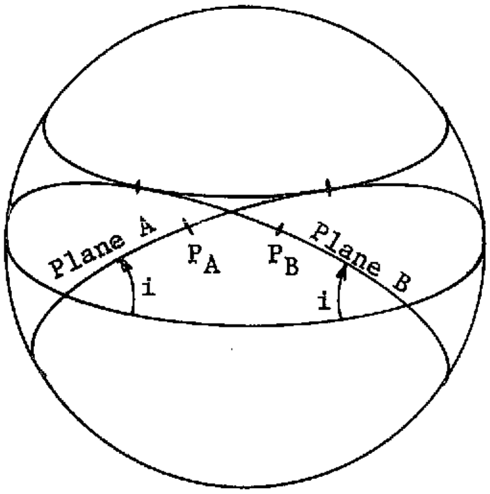


Figure 2.2 Trajectory Options for Single Inclination

NOMNAL then signs the inclination according to i_{CA} = sgn (sin ω) i_{CA}.

In the impulsive case the term A_T is missing from (2.1). In this case the problem becomes the determination of the velocity V_L at the libration point such that when the system (2.22) is integrated backwards in time from the initial conditions at the libration point (R_{LP}, V_L) the state at time t_{CA} satisfies the last three conditions of (2.23). The t_{CA} initially determined may not be consistent with a realistic launch and injection. If that is the case the incorrect time is replaced by the nearest realistic injection time t_{CA} and the arrival time t_L at the libration point is adjusted by the same amount to hold the flight time constant. One iteration of the backward targeting is generally sufficient to produce a time-adjusted solution which is now consistent with a realistic launch (see Section 2.5).

The actual targeting of the trajectory employs a standard Newton-Raphson iteration. The iteration is started with the zero iterate or initial guess generated by one of the methods described in Section 2.2. The iterative scheme then proceeds as follows. Let the initial guess of the velocity at the libration point be denoted V_0. Then the equations of motion (2.22) are integrated backward in time from the state (R_{LP}, V_0) to the fixed time t_{CA} which may or may not actually be the time at closest approach. The state at this time (R_E, V_E) is then used to compute the near-earth conic and the actual (or achieved) values of the target parameters are evaluated:

$$\tau^A = \begin{bmatrix} r^A_{CA} \\ i^A_{CA} \\ t^A_{CA} \end{bmatrix} = \begin{bmatrix} a\ (1 - e) \\ \text{sgn}\ (\sin \omega)\ i \\ t_{CA} + \sqrt{\frac{\mu}{a^3}}\ M \end{bmatrix} \tag{2.24}$$

The errors in the actual values of the target parameters relative to the desired values are then computed

$$\varepsilon = \begin{bmatrix} r^{D}_{CA} - r^{A}_{CA} \\ i^{D}_{CA} - i^{A}_{CA} \\ t^{D}_{CA} - t^{A}_{CA} \end{bmatrix} \qquad (2.25)$$

If each component of ε is less than the user-specified tolerance the process is terminated. Otherwise a new estimate $\mathring{V}_1$ of the velocity at the libration point is computed. The integration of the current iterate simultaneously produces the state transition matrix Φ (t_E, t_L) (see Section 2.1). The state transition matrix has the property that linear variations at the libration point map into variations at the earth according to

$$\delta\chi_E = \Phi_{EL}\ \delta\chi_L \qquad (2.26)$$

Now the target parameters τ are functions of the state at the earth. The sensitivity of changes in the targets to changes in state may be computed efficiently by numerical differentiation since no trajectory propagation is involved. The matrix η_E thereby computed then satisfies

$$\delta\tau_E = \eta_E\ \delta\chi_E \qquad (2.27)$$

where η_E is the (3x6) matrix defined by

$$\eta_E = \frac{\partial(R_{CA}, I_{CA}, T_{CA})}{\partial(r_x, r_y, r_z, v_x, v_y, v_z)} \qquad (2.28)$$

Combining (2.26) and (2.27) yields in partition form

$$\delta\tau_E = \left[\eta^{r}_{E} \,\middle|\, \eta^{v}_{E}\right] \left[\begin{array}{c|c} \Phi_1 & \Phi_2 \\ \hline \Phi_3 & \Phi_4 \end{array}\right] \begin{bmatrix} \delta r_L \\ \delta v_L \end{bmatrix} \qquad (2.29)$$

Substituting the desired change in target parameters ϵ for $\delta\tau_E$ and the condition that $\delta r_L = 0$ yields the equation

$$\varepsilon = (\eta^{r}_{E}\ \Phi_2 + \eta^{r}_{E}\ \Phi_4)\ \delta V_L \qquad (2.30)$$

The change to the velocity at the libration point is then given by

$$\delta V_L = \Gamma\varepsilon \qquad \Gamma = (\eta^{r}_{E}\ \Phi_2 + \eta^{v}_{E}\ \Phi_4)^{-1} \qquad (2.31)$$

This process is repeated until the errors in the actual target values (2.25) are less than the specified tolerance or a maximum allowable number of iterations has been made. If the maximum number of iterations is made without successful convergence the initial guess probably needs to be improved.

The impulsive insertion ΔV then is given by

$$\Delta V = V_{LP} - V_L \qquad (2.32)$$

where V_{LP} is the velocity of the libration point and V_L is the final targeted velocity of the spacecraft at the libration point.

2.4 Finite Thrust Targeting

A very efficient algorithm has been developed for the targeting of libration point missions using finite thrust models for the insertion into halo orbit. The operation is essentially identical to the backward integration scheme described in the previous section for impulsive targeting. The main difference is in the new control vector $U_T = (\alpha, \beta, t_B)$ of finite thrust direction (α, β) and duration t_B instead of the three components of impulsive velocity.

The two point boundary problem is slightly altered from the impulsive case. The differential equations are now

$$\begin{aligned} \dot{R} &= V \\ \dot{V} &= A_C + A_N + A_T \\ \dot{U} &= 0 \\ \dot{m} &= T/g\ I_{sp} \end{aligned} \tag{2.33}$$

where the finite thrust acceleration A_T must be computed over the thrust arc. The parameters U_T defining the finite thrust are assumed to be constants. The boundary conditions are

$$\begin{aligned} R(t_L) &= R_{LP} \\ V(t_L) &= V_{LP} \\ r(t_{CA}) &= r_{CA} \\ i(t_{CA}) &= i_{CA} \\ \dot{r}(t_{CA}) &= 0 \\ m(t_{CA}) &= m_0 \end{aligned} \tag{2.34}$$

where upper case symbols denote vectors; lower case, scalars.

The vectors R_{LP} and V_{LP} are the position and velocity vectors of the libration point relative to the central body at the desired time. The target conditions at the earth are identical to those for the impulsive targeting discussed in Section 2.3. The ten conditions (2.34) imposed on the system of ten differential equations (2.33) results in a consistent targeting problem. Our formulation determines the three controls U_T to meet targets of r_{CA}, i_{CA}, and t_{CA}.

The finite thrust model is defined by specification (by user input) of the thrust magnitude T, the thrust specific impulse I_{SP} and the initial spacecraft mass m_o. During the course of the targeting the program determines the thrust right ascension α, declination β, and thrust duration t_B, which comprise the control vector U_T.

The initial values for the control vector are determined from the impulsive approximation of the problem; that is, the impulsive targeting defined in the previous section is automatically performed before any finite burn targeting. Let the impulsive solution (2.32) be denoted ΔV. Then the initial values of the controls are

$$\alpha = \text{arc tan } (\Delta V_y/\Delta V_x)$$

$$\beta = \text{arc sin } (\Delta V_z/|\Delta V|) \qquad (2.35)$$

$$t_B = \frac{m_o - m_f}{\dot{m}} \qquad \text{where } m_f = m_o \, e^{-\frac{\Delta V}{g \, I_{sp}}}$$

The iteration process used for finite thrust targeting is formally identical to the impulsive targeting algorithm using a Newton-Raphson iteration with backward integration. The only difference is in the computation of the targeting matrix Γ required for the new controls.

The trajectory is schematically depicted in Figure 2.2. The natural trajectory begins with injection from earth at t_E, a coasting arc until time t_B when the finite thrust is initiated, and the thrusting arc from t_B until t_L when the desired conditions of the libration point are attained. For the targeting however the direction is reversed. Using the current controls the final spacecraft mass m_f at the time t_L is computed. The equations of motion (2.33) are integrated backwards from time t_L, state (R_{LP}, V_{LP}), and the current thrust direction (α, β) through the thrusting arc to the predicted time t_B, continually increasing the mass until the "initial" spacecraft mass m_O is obtained at t_B. The ballistic trajectory is then propagated backwards in time to the target time $t_{CA}(t_E)$. The actual values of the target parameters τ^A are evaluated by the equations (2.24). The correction to the current value of the controls U_F is then given by

Figure 2.3 Finite Thrust Trajectory Schematic

$$\Delta U_F = \Gamma \, \varepsilon \qquad (2.36)$$

where the error ε in the current targets is given by $\varepsilon = \tau^D - \tau^A$.

The computation of the targeting matrix Γ proceeds along lines similar to that of the impulsive targeting. The control sensitivity matrix Θ_{BL} relating changes in state at time t_B to changes in the controls α, β over the arc (t_L, t_B) is determined by the integration of the variational equations (performed by the Cowell propagator and discussed in Section 2.1)

$$\dot{\Theta} = f\Theta + g \qquad \Theta(t_L, t_L) = 0 \qquad (2.37)$$

where the matrices f and g are defined in (2.13) and (2.15). Following this integration the first two columns of the control transition matrix are available:

$$\Theta(t_B, t_L) = \left[\frac{\partial X_B}{\partial \alpha} \;\middle|\; \frac{\partial X_B}{\alpha\beta} \;\middle|\; \frac{\partial X_B}{\partial t_B} \right] \qquad (2.38)$$

The definition of the third column immediately leads to its computation. If the duration of the burn is shortened by the infinitesimal amount Δt_B the state at t_B (the nominal value) is changed by

$$\begin{aligned} \Delta R_B &= \tfrac{1}{2} A_T \; \Delta t_B^2 \\ \Delta V_B &= A_T \; \Delta t_B \end{aligned} \qquad (2.39)$$

and therefore from the definition of the derivative

$$\frac{\partial X_B}{\partial t_B} = \lim_{\Delta t \to 0} \begin{bmatrix} \Delta R_B/\Delta t \\ \Delta V_B/\Delta t_B \end{bmatrix} = \left[\begin{array}{c} 0 \\ \hline A_T \end{array}\right] \qquad (2.40)$$

Therefore the control transition matrix $_{BL}$ is easily computed and

$$\delta X_B = \Theta_{BL} \; \delta U_F \qquad (2.41)$$

The variation in state elements at the time t_{CA} (t_E) caused by state deviations at t_B is given by

$$\delta X_E = \Phi_{EB} \; \delta X_B \qquad (2.42)$$

Thus combining (2.41) and (2.42) we obtain

$$\delta X_E = \Phi_{EB} \; \Theta_{BL} \; \delta U_F \qquad (2.43)$$

and using the η_E matrix defined in (2.28) we have

$$\delta \tau_E = \eta_E \; \Phi_{EB} \; \Theta_{BL} \; \delta U_F \qquad (2.44)$$

Thus the targeting matrix is

$$\Gamma = [\eta_E \; \Phi_{EB} \; \Theta_{BL}]^{-1} \qquad (2.45)$$

where the matrices Φ_{EB} and Θ_{BL} are automatically computed by the Cowell propagator and the matrix η_E (requiring no integration) is computed by simple numerical differencing. The succeeding iteration then uses the control correction $\Delta U_F = \Gamma \; \varepsilon$ and the process is repeated until convergence is obtained.

2.5 Launch Phase

The targeting algorithms discussed in the previous two sections use backward integration to allow the generation of a transfer which is consistent with realistic launch constraints. The process by which these requirements are factored into the transfer trajectory design is the subject of this section.

The result of either the impulsive or the finite thrust targeting is a trajectory which when evaluated at closest approach to the earth satisfies input constraints of radius r_{CA}, equatorial inclination i_{CA}, and time t_{CA}. This trajectory, when propagated forward for the desired flight time Δt_f, arrives at the selected libration point with the proper velocity after performing the targeted insertion maneuver (impulsive ΔV or finite thrust controls U_T). The purpose of the launch phase analysis is twofold: 1) to correct the initial time at closest approach to the earth (injection time) to be compatible with a realistic launch profile, and 2) to compute the launch profile (launch time of day, launch energy, coast time, etc.) corresponding to the targeted transfer.

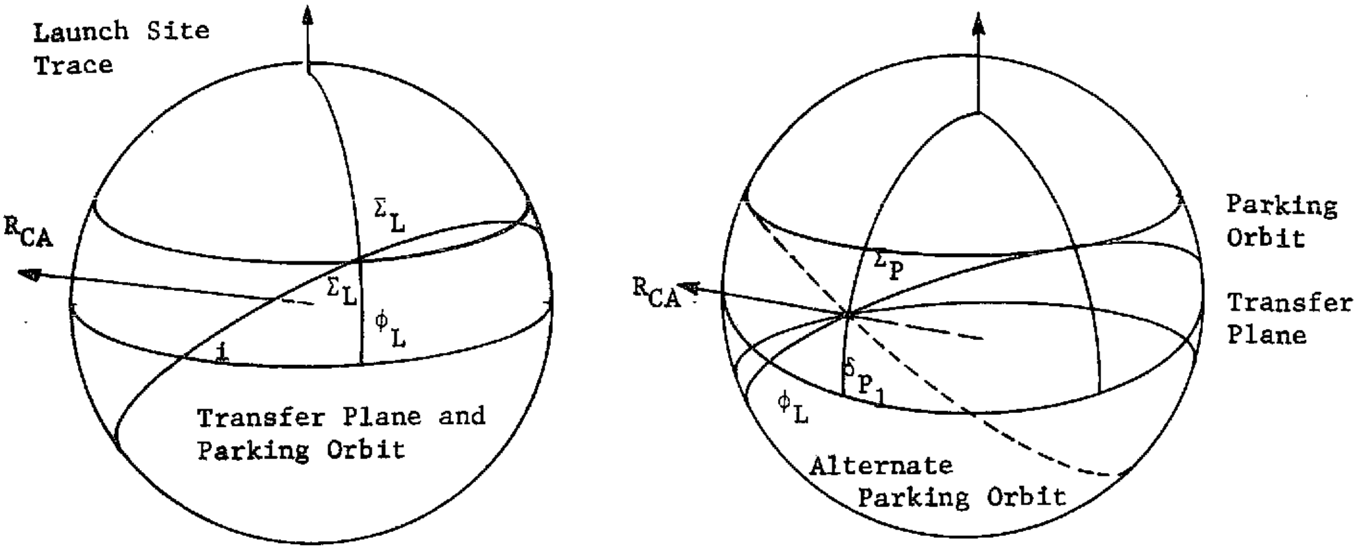
The first of these two objectives is caused by the initial user uncertainty as to the required injection time. The user inputs the desired injection time t_{CA} and flight time Δt_f. The time at the libration point t_L is then computed as $t_L = t_{CA} + \Delta t_f$. The libration point position R_{LP} and velocity V_{LP} are computed at that time and the backward targeting to the desired near-earth conditions is performed.

However the injection time input by the user may be incompatible with a realistic launch profile and the geometry of the targeted near-earth conic. Thus it may be necessary to compute a corrected injection time $t^*_{CA} = t_{CA} + \Delta t_c$. If this is necessary the flight time is held constant at Δt_f and the arrival time is adjusted to $t^*_L = t_L + \Delta t_c$. The targeting cycle is reentered with the corrected times and one iteration generally produces a targeted transfer that is now compatible with launch requirements.

The launch profile analysis will now be discussed in detail. The targeted state at closest approach (injection state) is given in equatorial coordinates as (R_{CA}, V_{CA}). The unit normal to the osculating transfer orbit plane at that point is then

$$W_T = \frac{R_{CA} \times V_{CA}}{|R_{CA} \times V_{CA}|} \tag{2.46}$$

The inclination of the orbit plane i ($= \arccos W_z$) should equal the desired input value. The orbit plane inclination must equal or exceed the latitude of the launch site ϕ_L to permit a coplanar parking orbit and transfer orbit as indicated in Figure 2.4a.



a. $|\sin i| \geq |\sin \phi_L|$ b. $|\sin i| < |\sin \phi_L|$

Figure 2.4 Transfer Plane/Parking Orbit Geometry

In the case that $|\sin i| \geq |\sin \phi_L|$ the launch azimuth is defined by

$$\sin \Sigma_L = \frac{\cos i}{\cos \phi_L} \tag{2.47}$$

and the solution with $0 \leq \Sigma_L \leq 90$ degrees is selected. In this case the parking orbit normal is identical to that of the transfer plane given by (2.46).

If $|\sin i| < |\sin \phi_L|$, the parking orbit and the transfer orbit cannot be coplanar (Figure 2.4b). In this case the parking orbit is defined to be in the plane having a launch azimuth of $\Sigma_L = 90$ deg, containing the closest approach radius vector R_{CA}, and nearest the transfer plane. (Note the alternate parking orbit plane in Figure 2.4b which also satisfies the first two of these requirements.) The unit normal to the parking orbit plane is given by

$$W_P = \frac{R_{CA} \times V_P}{|R_{CA} x V_P|} \tag{2.48}$$

where V_P is the velocity vector at the injection point in the parking orbit. V_P is given by

$$V_P(\Sigma_P) = \begin{bmatrix} -\cos \theta_p \sin \delta_p \cos \Sigma_P - \sin \theta_p \sin \Sigma_P \\ -\sin \theta_p \sin \delta_p \cos \Sigma_P + \cos \theta_p \sin \Sigma_P \\ \cos \delta_p \cos \Sigma_P \end{bmatrix} \tag{2.49}$$

where (θ_p, δ_p) are the equatorial right ascension and declination of the periapsis position R_{CA}. For the specific parking orbit plane having Σ_L = 90 deg, including R_{CA}, and nearest the transfer plane Σ_p must satisfy

$$\sin \Sigma_p = \left| \frac{\cos \phi_L}{\cos \delta_p} \right| \qquad (2.50)$$

$$\operatorname{sgn}(\cos \Sigma_p) = \operatorname{sgn} [V_{CA} \cdot V_P(0)]$$

where $0 \leq \Sigma_p \leq 180$ deg and where the equation (2.49) is used.

Thus the unit normal to the parking orbit plane W may be computed by either (2.46) or (2.48) and the launch azimuth is either given by (2.47) or Σ_L = 90 deg. In either case the remaining calculations proceed as follows. The right ascension at launch Θ_L is defined by

$$\cos \Theta_L = \frac{W_x \sin \Phi_L \sin \Sigma_L + W_y \cos \Sigma_L}{W_z^2 - 1}$$

$$\sin \Theta_L = \frac{W_y \sin \Phi_L \sin \Sigma_L - W_x \cos \Sigma_L}{W_z^2 - 1} \qquad (2.51)$$

The launch date input by the user is recalculated as the integer day (0^h UT) closest to the initial date input by the user. The Greenwich hour angle at 0^h UT of the launch date is then

$$\mathrm{GHA} = 100^{\circ}.07554260 + 0^{\circ}.9856473460\ T_d$$

$$2^{\circ}.9015 \times 10^{-13}\ T_d^{\ 2} \qquad (2.52)$$

The launch time on the day of launch is

$$t_L = \frac{(\Theta_L - \theta_L - \mathrm{GHA}) \bmod 2\pi}{\omega} \qquad (2.53)$$

where ω is the rotation rate of the launch planet and
θ_L is the longitude of the launch site, both being read in as input.

The unit vector toward the launch position is the

$$\hat{R}_L = (\cos \Phi_L \cos \Theta_L,\ \cos \Phi_L \sin \Theta_L,\ \sin \Phi_L) \qquad (2.54)$$

The true anomaly of the launch site f_L is calculated as:

$$\cos f_L = \hat{R}_L \cdot \hat{R}_{CA}$$

$$\sin f_L = \hat{R}_L \cdot \hat{V}_{CA} \qquad (2.55)$$

The angle between launch and injection is

$$\psi_B = 2\pi - f_L \qquad (2.56)$$

The coast time t_c may now be computed

$$t_c = [\psi_B - (\psi_1 + \psi_2)]\ k_\Phi \tag{2.57}$$

where ψ_1 and ψ_2 are the angles of the first and second burns and k_Φ is the inverse parking orbit coast rate, all of which are input.

The time between launch and injection is therefore

$$t_B = t_1 + t_2 + t_c \tag{2.58}$$

where t_1 and t_2 are the input time durations of the first and second burns.

The injection time is then

$$t_I = t_L + t_B \tag{2.59}$$

The first time through the injection date so calculated is compared to the desired value of closest approach t_{CA}. The difference $\Delta t = t_I - t_{CA}$ is then added to the time at the libration point and the target time at closest approach is set equal to t_I. One iteration of the targeting generally results in a totally consistent trajectory.

3. ERRAN NAVIGATION ANALYSIS

3.1 General Description of ERRAN

The error analysis program ERRAN is a preflight mission analysis tool and is concerned primarily with the propagation of covariance matrices along selected trajectories. All random variables are assumed to have gaussian distributions, and linear theory is assumed for propagation of all covariance matrices.

There are four main quantitative results that come from the error analysis program, all of which are very important for trajectory design during preflight mission analysis. The first output is the orbit determination or navigation uncertainty at selected trajectory times. The processed (knowledge) covariance matrix of orbit determination uncertainty gives a probabilistic answer, for a specific reference trajectory, to the question "how well will the actual trajectory be known after optimal processing of the tracking information?" The error analysis program can be used to study the effects of dynamic model errors, sensor errors, and measurement schedules and types on the orbit determination process. This chapter addresses the navigation analyses of ERRAN.

A second result obtained from the error analysis program is equally important. Orbit determination uncertainties, although they are significant, do not by themselves answer all the pertinent questions related to mission success. Another question that must be answered is, "how close will the actual trajectory come to meeting the specified target conditions?" Because of injection errors and dynamic model errors the actual trajectory will depart from the original targeted nominal trajectory. The statistical measure of such dispersion is represented by the control covariance matrix which, unlike the knowledge covariance discussed above, is unaffected by the processing of tracking information. The propagation of this control covariance forward to the target will provide us with probabilistic information relating to target miss in the absence of midcourse guidance corrections. However, a midcourse guidance correction can be performed to reduce the actual trajectory dispersion about the target. Propagation of the sum of the knowledge covariance and the guidance execution error covariance forward from the midcourse correction time to the target will provide us with probabilistic information relating to target miss following a midcourse guidance correction. This maneuver-related data is highlighted in Chapter 4.

The third main result from the error analysis program is concerned with the probabilistic determination of likely fuel budgets required for the mission. Without performing any estimation, the different probability levels of the midcourse correction magnitudes can be computed along with means and variances. This computation permits the mission analyst to calculate reasonable fuel loading requirements that are critical in the design of an actual system. This topic is also discussed in Chapter 4.

The fourth critical capability of the error analysis program is in generalized covariance analysis. This allows the mission analyst to determine how the navigation and guidance algorithms will perform in the presence of unmodeled or erroneously-modeled dynamic and measurement parameters. The discussion of generalized covariance is deferred to Chapter 5.

In the navigational analysis of ERRAN, two matrix quantities are carried along for analysis. One is the nominal or reference state vector, which is needed for many computations, and the second is the covariance matrix of navigation uncertainties associated with the state vector. The state vector is comprised of spacecraft position and velocity plus any augmentation parameters included in the analysis. The covariance matrix is a square, symmetric, positive definite matrix of associated uncertainties whose dimension corresponds to that of the state vector.

The computational operation of the error analysis program may be separated into two distinct calculation procedures. The first of these is called the basic cycle and refers to the process of propagating uncertainties from one measurement to the next. A Kalman recursive filtering algorithm with a consider option is used to process the measurement and compute the state vector associated covariance matrix that begins the next step in the basic cycle. Events refer to computations in the error analysis that are not simply propagations of the navigation uncertainty covariance matrix from one measurement to the next and subsequent optimal filtering of the new measurement. In the error analysis program, four kinds of events are permitted.

The four events allowed in the error analysis program are eigenvector events, prediction events, guidance events, and final insertion events. At an eigenvector event, the position and velocity covariance matrix partitions are diagonalized to reveal geometric information about the size and orientation of the position and velocity navigation uncertainties. At a prediction event, the most recent covariance matrix is propagated forward to some critical trajectory time, usually a guidance correction time, to determine predicted orbit determination uncertainties in the absence of further measurements. When a guidance event occurs, a rather lengthy computational process determines the likely magnitude of the guidance correction together with execution error statistics based on an underlying physical model for the correction process. The final insertion event computes the execution errors associated with the final impulsive or finite burn and adds them to the covariances.

The next section of this chapter details the Kalman recursive estimation algorithm that is assumed to be the underlying orbit determination procedure. Section 3.3 discusses dynamic and measurement noise covariance matrices. Section 3.4 treats the methods used in the error analysis program for computing state transition matrices. Section 3.5 presents the equations required for the computation of observation matrices for each type of measurement. Finally, Section 3.6 discusses eigenvector and prediction events. The guidance and insertion events are discussed in Chapter 4 and the generalized covariance analysis is summarized in Chapter 5.

3.2 Recursive Estimation Algorithm

The recursive estimation algorithm refers to the computational procedure which combines dynamic model and measurement information to generate estimates of spacecraft position and velocity deviations from the nominal trajectory, estimates of certain dynamic and measurement parameters, and the knowledge covariances associated with these estimates. The error analysis program treats the estimation process in an ensemble sense. Only the knowledge covariances are generated in ERRAN, and not the estimates themselves. The Kalman recursive estimation algorithm with a consider option is modeled in the STEAP programs. But before presenting this estimation algorithm, the linear dynamic and observation models will be described.

The linearized system is assumed to be described by the augmented state vector

$$x^A = \begin{bmatrix} x \\ x_s \\ u \\ v \end{bmatrix} \tag{3.1}$$

where

x = spacecraft position/velocity state (dimension 6)

x_s = solve-for parameter state (dimension n_1)

u = dynamic consider parameter state (dimension n_2) (included only for generality since none are available in STEAP-L)

v = measurement consider parameter state (dimension n_3)

All the above state vectors represent deviations from nominal state vectors and all parameters are assumed to be constant. The distinction between solve-for and consider parameters will be clarified subsequently.

The linearized dynamic model is assumed to have form

$$x_{k+1} = \Phi(t_{k+1}, t_k)x_k + \Theta_{xx_s}(t_{k+1}, t_k)x_{s_k} + \Theta_{xu}(t_{k+1}, t_k)\, u_k + q_k \tag{3.2}$$

where

$\Phi(t_{k+1}, t_k)$, $\Theta_{xx_s}(t_{k+1}, t_k)$, and $\Theta_{xu}(t_{k+1}, t_k)$

are state transition matrices over the time interval $[t_k, t_{k+1}]$ relating changes in x, x_s, and u, respectively, at time t_k to changes in x at time t_{k+1}. The variable q_k represents the effect of dynamic noise over the interval.

The linearized observation model is assumed to have form

$$y_k = H_k x_k + M_k x_{s_k} + G_k u_k + L_k v_k + \eta_k \tag{3.3}$$

where observation matrices H_k, M_k, G_k, and L_k relate changes in x, x_s, u, and v, respectively, to changes in the observable y. All observation matrices are evaluated at the nominal condition. The variable η_k represents measurement noise.

Under the usual assumption of white noise, the dynamic and measurement noise statistics are describe by

$$E [q_k] = E[\eta_k] = 0$$

$$E [q_k q_j^T] = Q_k \delta_{jk}$$

$$E [\eta_k \eta_j^T] = R_k \delta_{jk}$$

An estimation algorithm with no consider option treats all assumed dynamic and measurement parameters as "solve-for" parameters, i.e., the estimation algorithm generates estimates of the parameters, as well as estimates of the spacecraft position and velocity. Continued processing of measurements will often reduce knowledge covariances to unrealistically low values, a situation which can induce divergence in the estimation algorithm. Divergence is said to occur when the actual estimation error grows without bound. One method used to prevent divergence is to incorporate a consider option into the algorithm and divide all assumed parameter into either solve-for or consider parameters. Consider parameters are not estimated by the algorithm, nor can their knowledge covariances be reduced by measurement processing. In essence, by not solving for all parameters in the assumed parameter set the algorithm acknowledges the fact that its assumed set of dynamic and measurement parameters do not fully describe the real world, and that it is impossible to reduce parameter uncertainties indefinitely.

The knowledge covariance for the augmented state is defined as

$$P_k^A = E [(\hat{x}^A - x^A) (\hat{x}^A - x^A)^T] \tag{3.4}$$

where $\hat{x}$ indicates estimated values and x indicates actual values. Introducing equation (3.1) into equation (3.4) and expanding the result permits us to write the covariance matrix in the following partitioned form:

$$P_k^A = \begin{bmatrix} P_k & C_{xx_{s_k}} & C_{xu_k} & C_{xu_k} \\ C^T_{xx_{s_k}} & P_{s_k} & C_{x_s u_k} & C_{x_s v_k} \\ C^T_{xu_k} & C^T_{x_s u_s} & U_o & C_{uv_k} \\ C^T_{xv_k} & C^T_{x_s v_k} & C^T_{uv_k} & V_o \end{bmatrix} \tag{3.5}$$

Covariance matrix partitions P, P_s, U_o, and V_o are all symmetric and represent the covariance of the spacecraft position/velocity state, solve-for parameters, dynamic consider parameters, and measurement consider parameters, respectively. The off-diagonal covariance matrix partitions represent the correlations between the two variables indicated by the subscripts. Thus, $C_{x_s u}$ represents the correlation between solve-for parameters and dynamic consider parameters.

The assumptions implicit in the consider option require that covariances U_o and V_o remain constant with time. Estimates u and v are always zero. Although the consider option does not require it, it is realistic to assume no correlation between dynamic consider parameters and measurement consider parameters exists, so that C_{uv} is always zero.

The covariance equations involved in the estimation algorithm are of two types: prediction equations and filtering equations. The prediction equations describe the behavior of the covariance matrix partitions as they are propagated forward in time with no measurement processing. The filtering equations define the covariance updating procedure whenever a measurement is processed.

The prediction equations are summarized below:

$$P^-_{k+1} = (\Phi P^T_k + \Theta_{xx_s} C^{+T}_{xx_{s_k}} + \Theta_{xu} C^{+T}_{xu_k}) \Phi^T$$

$$+ C^-_{xx_{s_{k+1}}} \Theta^T_{xx_s} + C^-_{xu_{k+1}} \Theta^T_{xu} + Q_k \quad (3.6)$$

$$C^-_{xx_{s_{k+1}}} = \Phi C^+_{xx_{s_k}} + \Theta_{xx_s} P^+_{s_k} + \Theta_{xu} C^{+T}_{x_s u_k} \quad (3.7)$$

$$P^-_{s_{k+1}} = P^+_{s_k} \quad (3.8)$$

$$C^-_{xu_{k+1}} = \Phi C^+_{xu_k} + \Theta_{xx_s} C^+_{x_s u_k} + \Theta_{xu} U_o \quad (3.9)$$

$$C^-_{x_s u_{k+1}} = C^+_{x_s u_k} \quad (3.10)$$

$$C^-_{xv_{k+1}} = \Phi C^+_{xv_k} + \Theta_{xx_s} C^+_{x_s v_k} \quad (3.11)$$

$$C^-_{x_s v_{k+1}} = C^+_{x_s v_k} \quad (3.12)$$

A minus superscript on covariance partitions indicates the covariance partition immediately prior to processing a measurement; a plus superscript, immediately after processing a measurement.

The filtering equations involve equations for the measurement residual covariance matrix J, Kalman gain matrices K and S, and covariance updating. The measurement residual covariance matrix is given by

$$J_{k+1} = H_{k+1} A_{k+1} + M_{k+1} B_{k+1} + G_{k+1} D_{k+1} + L_{k+1} E_{k+1} + R_{k+1} \quad (3.13)$$

where

$$A_{k+1} = P^-_{k+1} H^T_{k+1} + C^-_{xx_{s_{k+1}}} M^T_{k+1} + C^-_{xu_{k+1}} G^T_{k+1} + C^-_{xv_{k+1}} L^T_{k+1}$$

$$B_{k+1} = P^{-}_{s_{k+1}} M^{T}_{k+1} + C^{-T}_{xx_{s_{k+1}}} H^{T}_{k+1} + C^{-}_{x_s u_{k+1}} G^{T}_{k+1} + C^{-}_{x_s v_{k+1}} L^{T}_{k+1}$$

$$D_{k+1} = C^{-T}_{xu_{k+1}} H^{T}_{k+1} + C^{-T}_{x_s u_{k+1}} M^{T}_{k+1} + U_o G^{T}_{k+1}$$

$$E_{k+1} = C^{-T}_{xv_{k+1}} H^{T}_{k+1} + C^{-T}_{x_s v_{k+1}} M_{k+1} + V_o L^{T}_{k+1}$$

The Kalman gain matrices for both position/velocity state and solve-for parameters are given by

$$K_{k+1} = A_{k+1} J^{-1}_{k+1} \tag{3.14}$$

$$S_{k+1} = B_{k+1} J^{-1}_{k+1} \tag{3.15}$$

The covariance partitions immediately after processing a measurement are given by

$$P^{+}_{k+1} = P^{-}_{k+1} - K_{k+1} A^{T}_{k+1} \tag{3.16}$$

$$C^{+}_{xx_{s_{k+1}}} = C^{-}_{xx_{s_{k+1}}} - K_{k+1} B^{T}_{k+1} \tag{3.17}$$

$$P^{+}_{s_{k+1}} = P^{-}_{s_{k+1}} - S_{k+1} B^{T}_{k+1} \tag{3.18}$$

$$C^{+}_{xu_{k+1}} = C^{-}_{xu_{k+1}} - K_{k+1} D^{T}_{k+1} \tag{3.19}$$

$$C^{+}_{x_s u_{k+1}} = C^{-}_{x_s u_{k+1}} - S_{k+1} D^{T}_{k+1} \tag{3.20}$$

$$C^{+}_{xv_{k+1}} = C^{-}_{xv_{k+1}} - K_{k+1} E^{T}_{k+1} \tag{3.21}$$

$$C^{+}_{x_s v_{k+1}} = C^{-}_{x_s v_{k+1}} - S_{k+1} E^{T}_{k+1} \tag{3.22}$$

It should be noted that the covariance matrices themselves are not printed out in STEAP. Rather, all variances appearing along the diagonal of the augmented covariance matrix defined by equation (3.5) are converted to standard deviations and all off- diagonal covariances are converted to correlation coefficients. Thus, if covariance a_{ij} is an element of the augmented covariance matrix, then the correlation coefficient is given by

$$\rho_{ij} = \frac{a_{ij}}{\sigma_i \sigma_j} \quad , i \neq j$$

where standard deviations σ_i and σ_j are given by $\sigma_i = a_{ii}^{1/2}$ and $\sigma_j = a_{jj}^{1/2}$.

Following these transformations all standard deviations and correlation matrix partitions are then printed out.

3.3 Dynamic and Measurement Noise Covariance Matrices

The problem of filter divergence has been mentioned in the previous section in connection with the consider option. The basic cause of divergence is modeling insufficiency and many separate categories of this insufficiency can be enumerated. The causes of the divergence proble and possible solutions to it are given in greater depth in the analytical discussion of the simulation program. The purpose of including a dynamic noise matrix Q in the error analysis program is to examine the effect of dynamic model insufficiency on the key outputs of the error analysis program. Some dynamic or unmodeled noise always corrupts an interplanetary trajectory; what is interesting, from the point of view of the error analysis program, is how the primary quantitative outputs are affected by various levels of dynamic noise.

The dynamic noise model used in the error analysis program is somewhat arbitrary and its interpretation is difficult. Over any time interval Δt between measurements, the dynamic noise matrix Q is computed from three input constants that remain the same throughout a trajectory run. These three constant inputs K_1, K_2, and K_3, whose units are km^2/sec^4, roughly correspond to variances of assumed unmodeled accelerations. The dynamic noise matrix Q added over any interval Δt is diagonal. Specifically, if Δt is the interval between measurements, the six nonzero terms of Q are given by

$$\begin{aligned}
Q_{11} &= \tfrac{1}{4}K_1\Delta t^4 \\
Q_{22} &= \qquad \tfrac{1}{4}K_2\Delta t^4 \\
Q_{33} &= \qquad\qquad \tfrac{1}{4}K_3\Delta t^4 \\
Q_{44} &= \qquad\qquad\qquad K_1\Delta t^2 \\
Q_{55} &= \qquad\qquad\qquad\qquad K_2\Delta t^2 \\
Q_{66} &= \qquad\qquad\qquad\qquad\qquad K_3\Delta t^2
\end{aligned} \tag{3.23}$$

Some explanation of this form for the dynamic noise is necessary. It was decided early in the design of the program that the physical interpretation of arbitrary dynamic noise must be made possible by relating the Q matrix, in some fashion, to unmodeled accelerations. Similarly, it appeared that the magnitude of the dynamic noise should be a function of the specific time interval over which it was added; in other words, the dynamic noise added when two days were between measurements should be greater than that added when only two hours separated the two measurements.

The first attempt to satisfy these two constraints resulted in the assumption that the unmodeled accelerations could be represented as biases with zero mean and variances K_1, K_2, K_3. Consider, for example, a vector random variable $(\delta\ddot{X}, \delta\ddot{Y}, \delta\ddot{Z})^T$

$$\sigma^2_{\delta\ddot{X}} = K_1 \qquad \sigma^2_{\delta\ddot{Y}} = K_2 \qquad \sigma^2_{\delta\ddot{Z}} = K_3$$

and correlation coefficients set equal to zero. If these accelerations represent biases, then over any interval Δt they are related to position and velocity uncertainties through

$$\delta\dot{X} = \delta\ddot{X}\ (\Delta t); \quad \delta X = \frac{1}{2}\ (\delta\ddot{X})\ (\Delta t)^2$$

and similarly for the other components. Under this model for the dynamic noise, the Q matrix would be the same as that given in equation (3.23) except for the completely correlated off-diagonal terms resulting in

$$Q_{14} = \frac{1}{2} K_1 \Delta t^3, \quad Q_{25} = \frac{1}{2} K_2\ \Delta t^3, \quad Q_{36} = \frac{1}{2} K_3\ \Delta t^3$$

Clearly, if the unmodeled accelerations are indeed biases, the δX and $\delta\dot{X}$ uncertainties due strictly to the dynamic noise must be completely correlated.

This initial model for the dynamic noise was unsatisfactory for two reasons. First, the resulting error analysis was forced to assume that the unmodeled acceleration was a constant bias throughout the trajectory as well as over each interval. The physics of the problem suggests that unmodeled accelerations are probably constant biases over short periods, but over an entire trajectory they probably vary considerably. Secondly, if the values for K_j are large enough for the dynamic noise to significantly affect the processed covariance matrices, their total correlation induces an unrealistically high correlation between the same terms in the resulting uncertainty matrices.

A more careful modeling of the stochastic process was discarded due to the arbitrary nature of the Q matrix. The dynamic noise matrix was chosen as in equation (3.23) because uncoupling the position and velocity uncertainties due to unmodeled accelerations retained a physical feel for the meaning of Q and permitted its computation to be viewed as a combination of random and bias error in the unmodeled accelerations.

The measurement noise covariance matrix R requires little comment. We simply assume the measurement noise for each measurement type has constant statistics, and hence constant covariance matrix R, for a given mission.

3.4 State Transition Matrices

State transition matrices describe the dynamic behavior of linear systems. The derivation of the general form of the linear system modeled in STEAP will be summarized here. The computation of the state transition matrices is performed by the Cowell propagator and was discussed in Section 2.1.

The nonlinear equations describing the motion of the spacecraft have form

$$\dot{X} = f(X, W, t) \tag{3.24}$$

where X denotes the spacecraft position/velocity state and W is a vector of dynamic parameters which define the dynamic model. The linearized version of equation (3.24) is given by

$$x = \frac{\partial f}{\partial X} x + \frac{\partial f}{\partial W} w \tag{3.25}$$

where X and W represent linear deviations from nominal states X and W, respectively. Partial derivative matrices $\frac{\partial f}{\partial X}$ and $\frac{\partial f}{\partial W}$ are evaluated along the nominal state.

The discrete solution of equation (3.25) over the time interval $[t_k, t_{k+1}]$ is given by

$$x_{k+1} = \Phi(t_{k+1}, t_k) x_k + \Theta(t_{k+1}, t_k) w_k \tag{3.26}$$

where state transition matrices $\Phi(t_{k+1}, t_k)$ and $\Theta(t_{k+1}, t_k)$ are required to define the solution. In STEAP the parameter deviation vector w is assumed to be constant. By dividing parameters into solve-for and consider parameters, we could expand equation (3.26) into equation (3.2).

In the current version of STEAP, all state transition matrices required by ERRAN are computed from a file created by the Cowell propagator during the NOMNAL run. This permits a very efficient operation of the ERRAN program. The generation of retrieval of this data was discussed in Section 2.1.

3.5 Observation Matrices

Observation matrices relate deviations in spacecraft position/velocity state and deviations in dynamic and measurement parameters from nominal values. Before discussing the observation or measurement types available in STEAP and the technique used to construct observation matrices, the derivation of the linearized observation equation will be summarized.

The general nonlinear observation equation has form

$$Y = f(X, W, t) \tag{3.27}$$

where Y denotes the observable, X denotes the spacecraft position/velocity state, and W is a vector of dynamic and measurement parameters. The linearized version of equation (3.27) is given by

$$y = \frac{\partial f}{\partial X} x + \frac{\partial f}{\partial W} w \tag{3.28}$$

where y, x, and w represent deviations from nominal $\overline{Y}$, $\overline{X}$, and $\overline{W}$, respectively, and partial derivative matrices

$\frac{\partial f}{\partial X}$ and $\frac{\partial f}{\partial W}$ are evaluated at the nominal condition.

If we partition the parameter vector w into a solve-for parameter vector x_s, a dynamic consider parameter vector u, and a measurement consider vector v, then equation (3.28) can be written as

$$y = Hx + Mx_s + Gu + Lv \tag{3.29}$$

where we have defined $H = \frac{\partial f}{\partial X}$, and partitioned $\frac{\partial f}{\partial W}$ into three sub-matrices M, G, and L. Adding measurement noise to this equation, we would obtain equation (3.3)

Earth-based range and range-rate measurements are availabe in STEAP: Earth-based range and range-rate measurements can be taken from 4 tracking stations, one of which is an idealized station located at the center of the earth, while the remaining three can be positioned at arbitrary locations on the surface of the earth. The relevant geometry for such measurements is depicted in Figure 3.1 The X, Y, Z coordinate system represents the inertial ecliptic coordinate system. The x, y, z coordinate system represents the geocentric equatorial coordinate system. Axis x is always aligned with axis X. The rotation of this coordinate system relative to X, Y, Z system is defined by ε, the obliquity of the ecliptic. The states of the spacecraft and the Earth relative to inertial space are given by

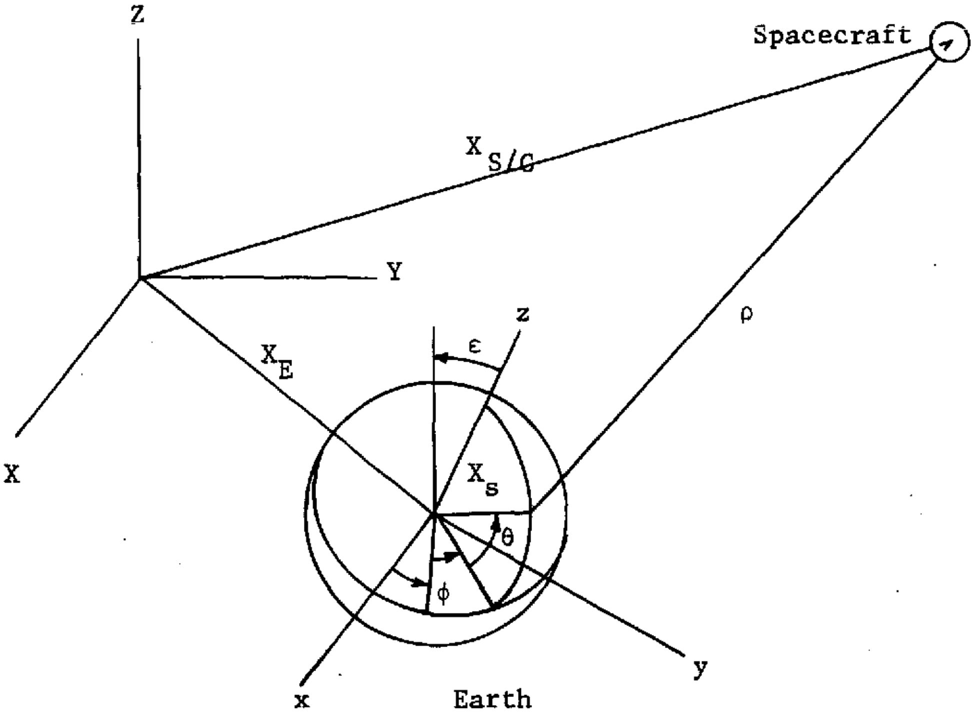


Figure 3.1 Earth-based Tracking

$X_{S/C}$ and X_E, respectively. The tracking station state relative to the center of the Earth is denoted by X_S. The geographical location of the station is defined by radius $R = |X_S|$, latitude θ, and longitude ϕ. Longitude is measured positive east from the Greenwich meridian. The hour angle of Greenwich is denoted by GHA. Finally, the position of the spacecraft relative to the tracking station is given by the vector ρ. The scalar observables are range, also denoted by ρ, and range-rate $\dot{\rho}$. Also available is a simple optical model including star-Earth angle measurements and apparent Earth diameter.

The nonlinear observation equations for all measurement types are summarized in the subroutine TRAKS analysis section. Also presented there are expressions for the partial derivatives required to construct the observation matrix partitions H, M, G, and L.

3.6 Eigenvector and Prediction Events

At an eigenvector event we simply transform the knowledge or navigation uncertainty covariance matrix P into useful geometrical information, which includes eigenvalues, eigenvectors, and hyperellipsoids. Define t_k at the time of the last processed measurement before the eigenvector event and let $\overline{X}_k$ and P_k^+ be, respectively, the nominal trajectory and the orbit determination uncertainty covariance matrix after processing the measurement at t_k. If t_j is the time of the eigenvector event, then $\overline{X}_j$, the nominal state vector at t_j, is computed from the trajectory file reader subroutine. The navigation uncertainty covariance matrix at t_j defined by P_j is given by equation (3.6) with subscript k+1 replaced by j. All state transition matrix partitions are understood to be defined over the time interval $[t_k, t_j]$.

The eigenvalues and eigenvectors could be obtained for the 6 x 6 P_j matrix, but their geometrical interpretation is difficult. If, instead, we operate on the 3 x 3 position and velocity partitions of P_j we can obtain geometrical information which is both useful and readily interpreted.

Let P_R and P_V denote the position and velocity partitions, respectively, of covariance P_j. Then at an eigenvector event these partitions are diagonalized to produce position and velocity eigenvalues and eigenvectors. The principal axis associated with the minimum eigenvalue defines the direction of minimum uncertainty; the axis associated with the maximum eigenvalue defines the direction of maximum uncertainty. The method employed is described in more detail in the subroutine JAC0BI analysis section.

At a prediction event at time t_j, the nominal trajectory X_j and associated knowledge covariance P_j are first computed just as at an eigenvector event. Now define t_p as the time to which the prediction is being made. Then the knowledge covariance at t_p, assuming no measurements over the time interval $[t_j, t_p]$, can be computed using equation (3.6) with $t_k = t_j$ and $t_{k+1} = t_p$.

Within the prediction event algorithm of the error analysis program the resulting covariance matrix P_p at the prediction time is also diagonalized to produce eigenvector and eigenvalue information. Thus, by superimposing this geometrical information about P_p for different prediction event times t_j, one can observe the effect of additional tracking on predicted navigation uncertainties.

4. ERRAN MANEUVER ANALYSIS

4.1 Introduction

Of the many types of events available in the STEAP programs, maneuvers are the most complex. The purpose of Chapter 4 is to provide a comprehensive and unified discussion of the analytical basis for all types of guidance events modeled in ERRAN.

Guidance events yield much useful information for preflight mission analysis. Using ERRAN we can evaluate, in a statistical sense, the efficacy of the guidance process in achieving desired target conditions. Equally important is the determination of the statistical ΔV requirements for the mission. The coupling of the guidance and navigation processes has been carefully modeled in ERRAN.

At a midcourse guidance event the user can choose from two midcourse guidance policies: fixed-time-of-arrival (FTA) and variable-time-of-arrival (VTA). Midcourse corrections are modeled as impulsive velocity corrections. An insertion maneuver model is provided for the insertion into the halo orbit about the libration point. Either impulsive or finite thrust models are available for the error analysis of this maneuver.

In the following section the concept of control covariance will be presented, and all features of the guidance event which are independent of the specific guidance policy will be discussed. Section 4.3 treats the execution error model employed for impulsive ΔVs. Section 4.4 treats linear midcourse guidance. The insertion maneuver analysis is discussed in Section 4.5.

4.2 General Analysis

Most variables used in the general analysis have been defined previously. We shall assume an arbitrary guidance event is to be executed at guidance event time t_j. In the following analysis the notation $(\ )_j^-$ will be used to indicate the values of variables immediately prior to the execution of the event; $(\ )_j^+$, immediately after. Although denoted simply by P earlier, the knowledge covariance will now be denoted by P_K to distinguish it from the control covariance P_c. Only the spacecraft position/velocity knowledge and control covariance partitions are required for guidance analysis, although the entire set of covariance prediction equations given in Section 3.2 are used whenever covariances matrices are to be propagated over some interval of time.

Before proceeding with the general analysis of a guidance event, it is necessary to digress briefly to discuss the control covariance P_c and how it differs from knowledge covariance P_K. Recall that the knowledge covariance represents the statistical dispersions of the estimation errors about the spacecraft state estimate and is defined as

$$P_K = E\ [\delta e\ \delta e^T] \tag{4.1}$$

where estimation error δe is defined as

$$\delta e = \delta\tilde{\hat{X}} - \delta\tilde{X} \tag{4.2}$$

Here $\delta\tilde{\hat{X}}$ and $\delta\tilde{X}$ denote the estimated and actual deviations, respectively, from the most recent nominal trajectory. Processing of measurements normally reduces the knowledge covariance, which, in geometrical terms, corresponds to a contraction of the knowledge covariance hyperellipsoid. The control covariance represents the statistical dispersions of the actual trajectory about the targeted nominal trajectory and is defined as

$$P_c = E\ [\delta X\ \delta X^T] \tag{4.3}$$

where δX denotes the actual deviation from the targeted nominal trajectory. The time behavior of the control covariance depends solely on modeled spacecraft dynamics and is in no way (except at a guidance event) influenced by measurement processing. Control covariances, like knowledge covariances, are propagated across an interval of time using the covariance prediction equations given in Section 3.2. However, the covariance filtering equations, which are also presented in Section 3.2, are never used to update control covariances. Control covariances are used in ERRAN to predict statistical target miss dispersions. The control covariance is also important in the computation of statistical midcourse guidance corrections in ERRAN.

We return now to the discussion of a general guidance event. At each guidance event a commanded velocity correction $\Delta\hat{V}_j$ is computed. The nature of this computation is, of course, policy-dependent and will be treated in subsequent sections. In general, ΔV_j will be a function of the desired target conditions and the estimated spacecraft state. Since midcourse guidance corrections are treated in an ensemble sense in ERRAN, only the statistical "$E\ [\Delta\hat{V}_j]$" can be computed.

Due to execution errors the actual velocity correction will differ from the commanded correction. The actual velocity correction ΔV_j is given by

$$\Delta V_j = \Delta\hat{V}_j + \delta\Delta V_j \tag{4.4}$$

where $\delta\Delta V_j$ is the execution error. The guidance process acknowledges the existence of an execution error by generating the assumed statistics of the execution error. The execution error is assumed to have zero mean and covariance $\tilde{Q}_j$, which is defined as

$$\tilde{Q}_j = E\ [\delta\Delta V_j\ \delta\Delta V_j^{\ T}] \tag{4.5}$$

This matrix is generated using the execution error model described in Section 4.3.

The covariance matrices associated with the spacecraft state are altered when a guidance event is executed. The remainder of this section develops all the equations required in this updating process for an impulsive velocity correction.

At a guidance event our estimation error δe is changed by the execution error. Thus

$$\delta e_j^{+} = \delta e_j^{-} - \left[\begin{array}{c} 0 \\ \hline \delta \Delta V_j \end{array}\right] \tag{4.6}$$

where

$$\delta e_j^{-} = \delta \overset{x}{X}_j^{-} - \delta \tilde{X}_j^{-}. \tag{4.7}$$

The minus sign appears in equation (4.6) since, according to equation (4.4), $\delta \Delta V_j$ is defined as the actual minus the estimate, while the estimation error δe is defined as the estimate minus the actual. The knowledge covariance immediately following the guidance correction is defined by

$$P_{K_j}^{+} = E\ [\delta e_j^{+}\ \delta e_j^{+T}] \tag{4.8}$$

Substitution of equation (4.6) into equation (4.8) readily yields the required knowledge covariance update equation:

$$P_{K_j}^{+} = P_{K_j}^{-} + \left[\begin{array}{c|c} 0 & 0 \\ \hline 0 & \tilde{Q}_j \end{array}\right] \quad . \tag{4.9}$$

The control covariance following the maneuver $P_{c_j}^{+}$ is then set equal to this updated knowledge covariance, i.e. $P_{c_j}^{+} = P_{K_j}^{+}$.

4.3 Execution Error Model

The computation of the execution error covariance matrix $\tilde{Q}$ is based on an execution error model defined by four independent error sources. The first error source is called proportionality error and is in the direction of the velocity correction vector ΔV with magnitude determined by the proportionality factor k. A second error source, in the direction of ΔV but independent of its magnitude, is the resolution error s that corresponds to a thrust tailoff error from the engines. Two pointing errors defined in terms of angles δα and δβ complete the error model. From this description of the error model, the equation for δΔV can be written as

$$\delta \Delta V = k\ \Delta V + s\ \frac{\Delta V}{|\Delta V|} + \delta \Delta V_{\text{pointing}} \tag{4.10}$$

where $\delta \Delta V_{\text{pointing}}$ is defined by two angular pointing errors, δα and δβ.

For purposes of unique specification, assume that δα is a pointing error angle measured in a plane parallel to the ecliptic plane and along a vector orthogonal to the velocity correction vector ΔV. If $\delta \Delta V_1$ is the velocity error due to the angular pointing error δα and $\hat{i}$, $\hat{j}$, $\hat{k}$ form the unit triad in the ecliptic system, then for small angles δα, $\delta \Delta V_1$ is given by

$$\delta \Delta V_1 = \rho\, \delta\alpha \left[\frac{\Delta V_Y}{\left(\Delta V_X^2 + \Delta V_Y^2\right)^{1/2}}\ \hat{i} - \frac{\Delta V_X}{\left(\Delta V_X^2 + \Delta V_Y^2\right)^{1/2}}\ \hat{j} \right] \tag{4.11}$$

where ΔV_X and ΔV_Y are the X and Y ecliptic components of the velocity correction vector ΔV and ρ is the magnitude of ΔV. Note that the velocity error $\delta \Delta V_1$ resulting from δα has components only in a plane parallel to the ecliptic.

The second pointing angle $\delta\beta$ defines a velocity error $\delta\Delta V_2$ that is orthogonal to both $\delta\Delta V_1$ and the velocity correction vector ΔV. Again for small angles $\delta\beta$, the velocity error resulting from this pointing error, referenced to the ecliptic system, is given by

$$\delta\Delta V_2 = \frac{\Delta V_X \; \Delta V_Z \; \delta\beta}{(\Delta V_X^2 + \Delta V_Y^2)^{\frac{1}{2}}} \, \hat{i} + \frac{\Delta V_Y \; \Delta V_Z \; \delta\beta}{(\Delta V_X^2 + \Delta V_Y^2)^{\frac{1}{2}}} \, \hat{j} - \delta\beta(\Delta V_X^2 + \Delta V_Y^2)^{\frac{1}{2}} \, \hat{k} \tag{4.12}$$

From these equations it is clear that the vector set ΔV, $\delta\Delta V_1$ and $\delta\Delta V_2$ satisfies the mutual orthogonality imposed by the model. The complete description of the execution error vector $\delta\Delta V$ may then be written in ecliptic coordinates as

$$\begin{aligned} \delta\Delta V = & \left[\left(k + \frac{s}{\rho}\right) \Delta V_X + \frac{\rho\Delta V_Y \; \delta\alpha + \Delta V_X \; \Delta V_Z \; \delta\beta}{u}\right]\hat{i} \\ & + \left[\left(k + \frac{s}{\rho}\right) \Delta V_Y + \frac{\Delta V_Y \; \Delta V_Z \; \delta\beta - \rho\Delta V_X \; \delta\alpha}{u}\right]\hat{j} \\ & + \left[\left(k + \frac{s}{\rho}\right) \Delta V_Z - u\delta\beta\right]\hat{k} \end{aligned} \tag{4.13}$$

where ΔV_X, ΔV_Y, and ΔV_Z are the ecliptic coordinates of the velocity correction; $\hat{i}$, $\hat{j}$, $\hat{k}$ are unit vectors in the X, Y, and Z directions; ρ is the magnitude of ΔV; k, s, $\delta\alpha$, $\delta\beta$ are the four independent error sources; and u is an intermediate variable defined by

$$u = (\Delta V_X^2 + \Delta V_Y^2)^{\frac{1}{2}} \tag{4.14}$$

The expression for the execution error covariance $\tilde{Q}_j$ is obtained by substituting equation (4.13) into equation (4.5). The equations which result from this operation are summarized in the subroutine GQCOMP analysis and will not be presented here. However, these equations have form given by

$$\tilde{Q}_j = \tilde{Q}_j \; (\Delta V, \; \sigma_k^2, \; \sigma_s^2, \; \sigma_{\delta\alpha}^2, \; \sigma_{\delta\beta}^2) \tag{4.15}$$

where σ_k^2 through $\sigma_{\delta\beta}^2$ are the assumed variances for the four error sources which define the error model. No cross-correlations appear in this equation since all the error sources are assumed to be independent. Since for a statistical midcourse guidance maneuver, no commanded ΔV is available, ERRAN computes an effective velocity correction which is used. The derivation of this quantity is described at the end of the next section.

4.4 Linear Midcourse Guidance

Linear impulsive midcourse guidance policies have form

$$\Delta\hat{V}_j = \Gamma_j \, \delta\hat{X}_j^- \tag{4.16}$$

where $\Delta\hat{V}_j$ is the commanded velocity correction required to null out deviations from the nominal target state, Γ_j is the guidance matrix, and $\delta\hat{X}_j^-$ is the estimated spacecraft deviation from the targeted nominal trajectory just prior to the guidance correction.

Two midcourse guidance policies are modeled in ERRAN: fixed-time-of-arrival (FTA) and variable-time-of-arrival (VTA). The derivation of the Γ_j matrix for each policy will be summarized below.

The variation matrix η_j relates deviations in spacecraft state at t_j to target state deviations. If τ is a vector which defines the target state, then

$$\delta\tau = \eta_j \, \delta X_j \tag{4.17}$$

For FTA guidance the target state τ is the nominal position vector at the target time t_F. State deviations at t_j are related to state deviations at t_F by the equation

$$\delta X_F = \Phi(t_F,t_j) \, \delta X_j \tag{4.18}$$

where $\Phi(t_F,t_j)$ is the state transition matrix over the interval $[t_j,t_F]$. Thus, for FTA guidance the variation matrix is given by

$$\eta_j = [\phi_1 \mid \phi_2] \tag{4.19}$$

where ϕ_1 and ϕ_2 denote the two upper 3x3 partitions of Φ. We wish to select a $\Delta\hat{V}_j$ such that $\delta\tau = 0$ in equation (4.17). Employing equation (4.19), this condition reduces to the equation

$$0 = [\phi_1 \mid \phi_2] \left(\delta\hat{X}_j + \begin{bmatrix} 0 \\ \hline \Delta\hat{V}_j \end{bmatrix} \right)$$

which, when solved for $\Delta\hat{V}_j$, yields

$$\Delta\hat{V}_j = [-\phi_2^{-1}\phi_1 \mid -I] \, \delta X_j \tag{4.20}$$

and

$$\Gamma_{FTA} = [-\phi_2^{-1} \, \phi_1 \mid -I]. \tag{4.21}$$

For VTA guidance the target state τ will be defined by assuming again that all deviations are linear. Then when the nominal trajectory is at the nominal target time, only deviations from the nominal which are normal to the insertion velocity vector are corrected while any deviations along this vector are left uncorrected. This philosophy is exactly equivalent to the two variable B-plane (2VBP) targeting mode used in interplanetary targeting. To determine the VTA target state, the state deviations at the nominal target time must be rotated to a coordinate system whose Z-axis is along the nominal insertion velocity vector. These are given by multiplying equation (4.18) by an appropriate rotation matrix R, thus the rotated state deviations $\delta X_F'$ are given by

$$\delta X_F' = R\delta X_F = R\phi(t_F,t_j)\ \delta X_j \tag{4.22}$$

The target vector, then is just the first two components of $\delta X_F'$, and the variation matrix for VTA is simply given by the upper 2x6 portion of the 6x6 matrix product $R\phi(t_F,t_j)$. This 2x6 η_j matrix is partitioned into two 2x3 matrices A and B as follows

$$\eta_j = [A \mid B] \tag{4.23}$$

We wish now to select a $\Delta\hat{V}_j$ such that $\delta\tau = 0$ in equation (4.17). Employing equation (4.23) and defining $\delta\hat{X}_j = [\delta\hat{R}_j,\ \delta\hat{V}_j]^T$, this condition reduces to the equation

$$A\ \delta\hat{R}_j + B(\delta\hat{V}_j + \Delta\hat{V}_j) = 0 \tag{4.24}$$

This equation has no unique solution for $\Delta\hat{V}_j$ since the inverses of A and B do not exist. Non-uniqueness of $\Delta\hat{V}_j$ is to be expected since three components of $\Delta\hat{V}_j$ can be varied to satisfy the two components of τ. One degree of freedom remains and it will be used to minimize the magnitude of $\Delta\hat{V}_j$, which is equivalent to minimizing $\Delta\hat{V}_j^T\ \Delta\hat{V}_j$. Using standard constrained minimization techniques, the solution for $\Delta\hat{V}_j$ is given by

$$\Delta\hat{V}_j = \Gamma_{VTA}\ \delta\hat{X}_j \tag{4.25}$$

where

$$\Gamma_{VTA} = [-B^T(BB^T)^{-1}\ A \mid -B^T(BB^T)^{-1}\ B]. \tag{4.26}$$

This concludes the derivation of the guidance matrices for the two midcourse guidance policies modeled in ERRAN.

A quantity which is particularly useful in ERRAN since it provides the basis for the computation of statistical ΔVs is the velocity correction covariance matrix S_j, defined as follows:

$$S_j = E\ [\Delta\hat{V}_j\ \Delta\hat{V}_j^T] \tag{4.27}$$

A useful expression for S_j will be developed below. The derivation follows Reference 2.

Substitution of equation (4.16) into equation (4.27) yields

$$S_j = \Gamma_j\ E\ [\delta\hat{X}_j^-\ \delta\hat{X}_j^{-T}]\ \Gamma_j^T \tag{4.28}$$

But according to equation (4.2)

$$\delta\hat{X}_j^- = \delta X_j^- + \delta e_j^- \tag{4.29}$$

Substituting equation (4.29) into equation (4.28) and expanding yields

$$S_j = \Gamma_j \Big(E\,[\delta X_j^- \; \delta X_j^{-T}] + E[\delta e_j^- \; \delta X_j^{-T}] \qquad (4.30)$$
$$+ E\,[\delta X_j^- \; \delta e_j^{-T}] + E\,[\delta e_j^- \; \delta e_j^{-T}] \Big) \Gamma_j^T$$

Employing the definitions given by equations (4.1) and (4.3) the preceding equation reduces to

$$S_j = \Gamma_j \left(P_{c_j}^- + E\,[\delta e_j^- \; \delta X_j^{-T}] + E\,[\delta X_j^- \; \delta e_j^{-T}] + P_{K_j}^- \right) \Gamma_j^T \qquad (4.31)$$

Pre-multiplying the transpose of equation (4.29) by δe_j^-, and taking the expected value of the result yields

$$E\,[\delta e_j^- \; \delta X_j^{-T}] = E\,[\delta e_j^- \; \delta \hat{X}_j^{-T}] - P_{K_j} \qquad (4.32)$$

If we assume that the estimate $\delta \hat{X}_j^-$ and the error in the estimate δe_j^- are orthogonal, as is the case if the recursive estimation algorithm is optimal, then

$$E\,[\delta e_j^- \; \delta \hat{X}_j^{-T}] = 0 \qquad (4.33)$$

so that equation (4.32) reduces to

$$E\,[\delta e_j^- \; \delta X_j^{-T}] = -P_{K_j} \qquad (4.34)$$

If we substitute equation (4.34) into equation (4.31), we obtain the desired result:

$$S_j = \Gamma_j \; (P_{c_j}^- - P_{K_j}^-) \; \Gamma_j^T \qquad (4.35)$$

It was stated previously that ERRAN treats the midcourse guidance correction in an ensemble sense. State estimates are not generated in ERRAN, so that equation (4.16) cannot be used to determine $\Delta\hat{V}_j$. Instead, we compute a statistical or effective velocity correction in ERRAN. Simply taking the expected value of equation (4.16) does not yield useful information. The expected value of $\Delta\hat{V}_j$ is zero since $E\,[\delta\hat{X}_j]$ is zero, which is a consequence of the fact that our recursive estimation algorithm is an unbiased estimator. However, if we define the effective velocity correction to be

$$\text{"}E\,[\Delta\hat{V}_j]\text{"} = \rho_j \frac{\alpha_j}{|\alpha_j|} \qquad (4.36)$$

where

$$\rho_j = E\,[|\Delta\hat{V}_j|] \qquad (4.37)$$

and $\alpha_j/|\alpha_j|$ is a unit vector aligned with the most likely direction of the velocity correction, then information which is useful for fuel sizing studies can be obtained. This effective velocity correction is also used to evaluate the execution error covariance $\tilde{Q}_j$ in ERRAN.

It remains to define expressions for magnitude ρ_j and direction α_j. Lee and Boain (Reference 6) have developed an analytic technique for computing probablistic levels of ΔV required for a midcourse maneuver as a function only of the trace and eigenvalue ratios of the S_j matrix. This analytic method produces the ΔV requirement for any desired percentile level, replacing the approximate method of Hoffman and Young used in previous versions of STEAP (Reference 7) which found approximations of the values of ρ_j and the variance $\sigma^2_{|\Delta\hat{V}_j|}$. Not only does the analytic method produce exact, rather than approximate, values for ρ_j and σ_j but also exact values for arbitrary percentile levels (i.e., 90%, 99%, 99.9%, 99.99%) without having to assume a Gaussian distribution for $|\Delta\hat{V}_j|$ and using ρ_j and σ_j to compute the percentile levels. Given the eigenvalues of the $\hat{S}_j$ matrix expressed as $(\sigma^2, \ell^2\sigma^2, k^2\sigma^2)$ where $1 \geq k^2 \geq \ell^2 \geq 0$ the Lee-Boain method expresses the probability density function for the square of the velocity function ($z = |\Delta V|^2$) as

$$f(z) = C \sum_{m=0}^{\infty} \frac{\Gamma(m+1/2)(\alpha-\beta)^m}{\Gamma(m+3/2)\ m!}\ {}_1F_1\ [(m+1);\ (m+3/2);\ (\gamma-\alpha)z] \qquad (4.38)$$

where

$$\alpha = \frac{1}{2\sigma^2},\quad \beta = \frac{1}{2\ell^2\sigma^2},\quad \gamma = \frac{1}{2k^2\sigma^2},\quad C = \frac{1}{2\ell k\sigma^3\sqrt{2\pi}}\, e^{-\gamma z}$$

and where Γ is the gamma function and ${}_1F_1$ is the confluent hypergeometric function. This expression for f(z) can be reduced to Horn's confluent hypergeometric function in two variables, and further reduced for computer evaluation to an infinite series involving a triple Cauchy product. Although this exact method is amenable to computer evaluation and is far faster than Monte Carlo analysis, it can still represent a small but significant fraction of the total computation time (of the order perhaps, of one to ten per cent of the total time used for a typical ERRAN run). By using the exact method to generate tables covering all possible eigenvalue ratios for several percentile levels (i.e., 90%, 99%, 99.9%, 99.99%), a simple two dimensional interpolation scheme allows three to four significant figure accuracy to be maintained. Thus the output of ERRAN at a guidance event will now include as before the mean and sigma of the ΔV distribution (although the values will now be exact) as well as the required ΔV-load at several pre-set probability levels. The computation cost for this process is negligible.

The velocity correction covariance S_j can also be used to determine the direction α_j. Let λ_1, λ_2, and λ_3 be the eigenvalues of S_j. It can be shown that, under the assumption that some correction takes place, the most likely direction for the midcourse maneuver, defined probabilistically, is the direction of the eigenvector associated with the maximum eigenvalue of S_j. Define α_j as the eigenvector associated with the maximum eigenvalue.

It should be stressed that the computation of the effective midcourse correction vector "E $[\Delta V_j]$" within ERRAN is only an artifice to permit a realistic, a priori computation of the execution error covariance $\tilde{Q}_j$. The nominal trajectory returned to the basic cycle is not affected by the computation. However, the calculated information concerning likely magnitudes and directions for the maneuvers is critical for fuel sizing studies.

To determine the efficacy of the midcourse correction at time t_j in meeting specified target conditions, it is necessary to compute the target condition covariance matrix W_j, both before and after the correction. Covariance W_j is defined by

$$W_j = E\,[\delta\tau\ \delta\tau^T] \tag{4.39}$$

where $\delta\tau$ represents the actual target state deviation. Thus W_j represents the statistical dispersions of actual target state deviations about the nominal target state. Substitution of equation (4.17) shows that

$$W_j = \eta_j\ E\,[\delta X_j\ \delta X_j^T]\ \eta_j^T = \eta_j\ P_{c_j}\ \eta_j^T$$

Thus, immediately prior to the midcourse correction

$$W_j^- = \eta_j\ P_{c_j}^-\ \eta_j^T \tag{4.40}$$

while immediately after the correction

$$W_j^+ = \eta_j\ P_{c_j}^+\ \eta_j^T \tag{4.41}$$

Recall that control covariance $P_{c_j}^-$ is obtained by propagating $P_{c_{j-1}}^+$ over the time interval $[t_{j-1}, t_j]$, where t_{j-1} is the time of the previous guidance event, using the standard covariance prediction equations in Section 3.2. Recall also that $P_{c_j}^+$ is equal to $P_{K_j}^+$. Thus, the total target error can be divided into the target error due to the navigation error

$$\varepsilon_{nav_j} = -\eta_j\ \delta e_j^-. \tag{4.42}$$

and the target error due to the execution error

$$\varepsilon_{ex_j} = \eta_j \begin{bmatrix} 0 \\ \hline \delta\Delta V_j \end{bmatrix} \tag{4.43}$$

It will be helpful to summarize all the quantities computed at a midcourse guidance event in ERRAN. A summary is presented below:

t_j^-: X_j^-, $P_{K_j}^-$, $P_{c_j}^-$, W_j^-

t_j: Γ_j, "$E\,[\Delta\hat{V}_j]$", $\tilde{Q}_j$

t_j^+: $\overline{X}_j^+$, $P_{K_j}^+$, $P_{c_j}^+$, W_j^+

4.5 Insertion Maneuver Analysis

The analysis of the terminal insertion maneuver is similar in many ways to a normal guidance maneuver as discussed in the Section 4.4, however, there are several important differences. First, of course, is that the insertion maneuver may be either an impulsive or a finite burn. Second, since the time of insertion is in fact the final time, no guidance can be performed. All that is necessary is for execution errors associated with the insertion maneuver to be calculated (for either the impulsive or finite burn cases) and added to both the knowledge (P_{K_F}) and control (P_{c_F}) covariances.

For the case of an impulsive insertion maneuver the nominal ΔV is determined by simply differencing the velocity of the nominal trajectory at T_F with the desired velocity at the target point. The components of this ΔV are then used in the execution error model as described in Section 4.3, with the exception that there is no need to generate an effective ΔV from the statistics since the actual ΔV is available. Once the execution error matrix $\tilde{Q}$ has been calculated then the knowledge and control covariances after the insertion are computed as

$$P_{K_F}^{+} = P_{K_F}^{-} + \left[\begin{array}{c|c} 0 & 0 \\ \hline 0 & \tilde{Q} \end{array}\right] \tag{4.44}$$

$$P_{c_F}^{+} = P_{c_F}^{-} + \left[\begin{array}{c|c} 0 & 0 \\ \hline 0 & \tilde{Q} \end{array}\right] \tag{4.45}$$

For the case of a finite burn insertion maneuver, the computation of the final knowledge and control are somewhat different. Dispersions at the final time for this case arise from two sources, namely the state dispersions at the start of the burn arc and the errors associated with the burn itself. The effects of both of these error sources are found by the use of the state transition matrices $\phi_{F,B}$ and $\Theta_{F,B}$ over the arc from t_B the initiation of the burn to the final time t_F. The first of these is the 6x6 state to state transition matrix, relating deviations in the final state to deviations in the initial state. The second is the 6x3 control to state transition matrix, relating deviations in the final state to deviations in the control parameters. For the finite burn model used here, the three control parameters are the two angles (α, β) specifying the inertial direction of the burn and the thrust magnitude(T). Both of the matrices $\phi_{F,B}$ and $\Theta_{F,B}$ are generated by NOMNAL and stored on the trajectory file. The final knowledge and control covariances are found as

$$P_{K_F}^{+} = \phi_{F,B} \, P_{K_B}^{-} \, \phi_{F,B}^{T} + \Theta_{F,B} \, U \, \Theta_{F,B}^{T} \tag{4.46}$$

$$P_{c_F}^{+} = \phi_{F,B} \, P_{c_B}^{-} \, \phi_{F,B}^{T} + \Theta_{F,B} \, U \, \Theta_{F,B}^{T} \tag{4.47}$$

Where $P_{K_B}^{-}$ and P_{c_B} are the knowledge and control covariances at the start of the burn and U is a diagonal 3x3 covariance with elements σ_α^2, σ_β^2 and σ_T^2 describing the assumed statistics of the finite burn errors. It should be noted that equations (4.46) and (4.47) have presumed that no correlation can exist between the thrust control parameters and the state deviations at the start of the burn arc.

5. GENERALIZED COVARIANCE ANALYSIS

5.1 Introduction

The performance of navigation filters for orbit determination depends on how well the physical environment and ground-based or onboard measurement instrumentation can be modeled. The design of a navigation filter involves not only selection of an algorithm for processing measurements, but also specification of error models for all error sources thought to be important. The use of an error analysis technique, such as the one described in Chapter 5, is not sufficient for determining actual filter performance in the presence of incorrectly modeled or unmodeled error sources. Although one could, of course, resort to a simulation technique such as SIMUL (Reference 3) to study filter performance, the operation of simulation programs is expensive and only a single sample of the navigation process can be generated on each run. A generalized covariance program, however, can provide much useful information relating to the design and performance of navigation filters, with a significant reduction in program operating costs.

The generalized covariance technique described in this chapter is primarily concerned with the propagation and update (at a measurement) of both actual and assumed, i.e., filter-generated, estimation error statistics along a nominal trajectory. The deviation of the generalized covariance equations assumes linearity and gaussian statistics. Actual error statistics, however, are not required to have zero means. The equations are written in recursive form and are filter-independent, i.e., filter gains are not assumed to have been generated by any specific type of navigation filter.

The generalized covariance equations for the basic cycle (measurement processing) are derived in section 5.2. These equations can be used to determine filter sensitivity to differences between assumed (by filter) and actual:

1) Injection statistics;

2) Measurement noise statistics -- doppler, range measurements;

3) Dynamic parameter statistics -- gravitational constants, target planet ephemerides;

4) Measurement parameter statistics -- instrument biases, station location errors;

5) Dynamic noise statistics.

The differences between assumed and actual error statistics can involve differences in means, standard deviations, and correlation coefficients. Actual error statistics can also be defined for parameters whose uncertainty has been ignored in filter design.

In section 5.3 the generalized covariance technique is extended to the guidance process. The equations presented there permit one to determine the sensitivity of the guidance process to differences between assumed and actual execution error statistics, as well as to differences in the previously described error statistics. Although execution errors are assumed to be uncorrelated, they are permitted to have nonzero means. The generalized covariance technique, as applied to the guidance process, primarily involves the computation of both assumed and actual target dispersions and velocity correction statistics.

The notation employed in this chapter is very similar to the notation used in previous chapters, except for the following differences:

1) Estimation errors are denoted by $\tilde{x}$, etc instead of by δe, etc;

2) Actual errors, deviations, means, covariances, etc are usually denoted by $(\ )'$.

5.2 Generalized Covariance Propagation and Update

5.2.1 The Basic Cycle

The generalized covariance basic cycle consists of the propagation of both actual and assumed estimation error means and covariances from the previous measurement time (or event) to the present measurement time, and the updating of each of these quantities after the measurement has been processed. The propagation and update of the assumed covariances was treated in Chapter 3 (assumed estimation error means are zero). The equations required to propagate and update the actual estimation error means and covariances are derived in this section. These equations are filter-independent and are expressed in terms of arbitrary filter gain matrices.

The filter employs an augmented state vector x^A partitioned as

$$x^A = \begin{bmatrix} x \\ x_s \\ u \\ v \end{bmatrix} \tag{5.1}$$

where x denotes assumed position/velocity deviations (from nominal); x_s, assumed solve-for parameter deviations; u, assumed dynamic consider parameter deviations; and v, assumed measurement consider parameter deviations. The assumed dynamics are described by

$$x_{k+1} = \Phi x_k + \theta_{xx_s} x_{s_k} + \theta_{xu} u_k + \omega_{k+1} \tag{5.2}$$

where state transition matrix partitions Φ, θ_{xx_s}, and θ_{xu} are defined over the time interval $[t_k, t_{k+1}]$, and ω_{k+1} denotes the contribution of assumed unmodeled accelerations over the same time interval. Parameter deviations are constant. The assumed measurement is given by

$$y_{k+1} = Hx_{k+1} + Mx_{s_{k+1}} + Gu_{k+1} + Lv_{k+1} + \nu_{k+1} \tag{5.3}$$

where H, M, G, and L are observation matrix partitions evaluated at time t_{k+1}, and ν_{k+1} denotes the assumed measurement noise.

The actual augmented state vector x'^A is partitioned as

$$x'^A = \begin{bmatrix} x' \\ x'_s \\ u' \\ v' \\ w' \end{bmatrix} \tag{5.4}$$

where x' denotes actual position/velocity deviations; x'_s, actual solve-for parameter deviations; u', actual dynamic consider parameter deviations; v', actual measurement consider parameter deviations; and w', actual dynamic and measurement ignore parameter deviations. The parameters x'_s, u', and v' correspond to x_s, u, and v, respectively, but have different statistical representations. Ignore parameters w' are parameters whose statistical uncertainty is completely ignored by the filter, but not by the actual estimation error mean and covariance propagation process. (Parameters not treated by either the filter or the actual propagation process will be referred to as neglect parameters.) The actual dynamics are described by

$$x'_{k+1} = \Phi x'_k + \theta_{xx_s} x'_{s_k} + \theta_{xu} u'_k + \theta_{xw} w'_k + \omega'_{k+1} \qquad (5.5)$$

where ω'_{k+1} denotes the contribution of actual unmodeled accelerations over the time interval $[t_k, t_{k+1}]$. State transition matrix partition θ_{xw} relates changes in ignore parameters to changes in x'. All parameter deviations are constant. The actual measurement is given by

$$y'_{k+1} = Hx'_{k+1} + Mx'_{s_{k+1}} + Gu'_{k+1} + Lv'_{k+1} + Nw'_{k+1} + \nu'_{k+1} \qquad (5.6)$$

where ν'_{k+1} denotes the actual measurement noise at t_{k+1}.

The actual estimation errors are defined by

$$\tilde{x}'_{k+1} = \hat{x}_{k+1} - x'_{k+1} \qquad (5.7)$$

$$\tilde{x}'_{s_{k+1}} = \hat{x}_{s_{k+1}} - x'_{s_{k+1}} \qquad (5.8)$$

$$\tilde{u}'_{k+1} = \hat{u}_{k+1} - u'_{k+1} = -u'_o \qquad (5.9)$$

$$\tilde{v}'_{k+1} = \hat{v}_{k+1} - v'_{k+1} = -v'_o \qquad (5.10)$$

$$\tilde{w}'_{k+1} = \hat{w}_{k+1} - w'_{k+1} = -w'_o \qquad (5.11)$$

where equations (5.9), (5.10), and (5.11) have used the fact that estimates $\hat{u}$, $\hat{v}$, and $\hat{w}$ are always zero.

The estimates propagate over the time interval $[t_k, t_{k+1}]$ according to

$$\hat{x}^-_{k+1} = \Phi\hat{x}^+_k + \theta_{xx_s} \hat{x}^+_{s_k} \qquad (5.12)$$

and

$$\hat{x}^-_{s_{k+1}} = \hat{x}^+_{s_k} , \qquad (5.13)$$

where $(\ )^-$ denotes values immediately before processing a measurement and $(\ )^+$ immediately after. Substitution of equations (5.5) and (5.12) into equation (5.7) yields the following equation for the propagation of the actual estimation error:

$$\tilde{x}^{-\prime}_{k+1} = \Phi\tilde{x}^{+\prime}_{k} + \theta_{xx_s}\tilde{x}^{+\prime}_{s_k} - \theta_{xu}u'_o - \theta_{xw}w'_o - \omega'_{k+1} \quad . \tag{5.14}$$

Similarly,

$$\tilde{x}^{-\prime}_{s_{k+1}} = \tilde{x}^{+\prime}_{s_k} \quad . \tag{5.15}$$

At measurement time t_{k+1} the estimates are updated using the equations

$$\hat{x}^{+}_{k+1} = \hat{x}^{-}_{k+1} + K_{k+1}\,\varepsilon'_{k+1} \tag{5.16}$$

$$\hat{x}^{+}_{s_{k+1}} = \hat{x}^{-}_{s_{k+1}} + S_{k+1}\,\varepsilon'_{k+1} \tag{5.17}$$

where K_{k+1} and S_{k+1} are the filter gain matrices (generated by an arbitrary filter). The actual measurement residual ε' is defined as the difference between the actual and predicted measurements

$$\varepsilon'_{k+1} = y'_{k+1} - H\hat{x}^{-}_{k+1} - M\hat{x}^{-}_{s_{k+1}} \quad . \tag{5.18}$$

Substitution of equation (5.6) into equation (5.18) yields

$$\varepsilon'_{k+1} = -\,H\tilde{x}^{-\prime}_{k+1} - M\tilde{x}^{-\prime}_{s_{k+1}} + Gu'_o + Lv'_o + Nw'_o + \nu'_{k+1} \quad . \tag{5.19}$$

The update equation for the actual estimation error is obtained by substituting equation (5.16) into equation (5.7). The resulting equation is

$$\tilde{x}^{+\prime}_{k+1} = \tilde{x}^{-\prime}_{k+1} + K_{k+1}\,\varepsilon'_{k+1} \quad . \tag{5.20}$$

Similarly,

$$\tilde{x}^{+\prime}_{s_{k+1}} = \tilde{x}^{-\prime}_{s_{k+1}} + S_{k+1}\,\varepsilon'_{k+1} \quad . \tag{5.21}$$

The propagation and update equations for the means of the actual estimation errors and the actual measurement residuals can now be derived. The filter assumes zero means for all estimates and all error sources. Except for actual dynamic and measurement noises, this is not the case for the actual propagation and update process. Thus,

$$\begin{aligned} E[\tilde{u}'_{k+1}] &= -\bar{u}'_o \\ E[\tilde{v}'_{k+1}] &= -\bar{v}'_o \\ E[\tilde{w}'_{k+1}] &= -\bar{w}'_o \\ E[\omega'_{k+1}] &= 0 \\ E[\nu'_{k+1}] &= 0 \quad . \end{aligned} \tag{5.22}$$

No generality is lost by setting the mean of the actual measurement noise ν' to zero, since a nonzero measurement mean can be absorbed into the mean of the actual measurement bias. The model for the actual dynamic noise ω' will be assumed to have the same form as the model for the assumed dynamic noise described in section 3.3 so the mean of ω' is also set to zero.

Applying the expectation operator to equations (5.14) and (5.15) yields the following equations for the propagation of the means of the actual estimation errors:

$$E[\tilde{x}^{-\prime}_{k+1}] = \Phi \cdot E[\tilde{x}^{+\prime}_{k}] + \theta_{xx_s} \cdot E[\tilde{x}^{+\prime}_{s_k}] - \theta_{xu}\,\bar{u}'_o - \theta_{xw}\,\bar{w}'_o \tag{5.23}$$

$$E[\tilde{x}^{-\prime}_{s_{k+1}}] = E[\tilde{x}^{+\prime}_{s_k}] \quad . \tag{5.24}$$

To initiate the propagation process described by the previous two equations requires initial values for the means of $\tilde{x}'$ and $\tilde{x}'_s$. At initial time t_o we have

$$E[\tilde{x}'_o] = E[\hat{x}_o] - E[x'_o] \tag{5.25}$$

and

$$E[\tilde{x}'_{s_o}] = E[\hat{x}_{s_o}] - E[x'_{s_o}] \quad . \tag{5.26}$$

Because initial estimates are always assumed to be zero, equations (5.25) and (5.26) become

$$E[\tilde{x}'_o] = -\bar{x}'_o \tag{5.27}$$

$$E[\tilde{x}'_{s_o}] = -\bar{x}'_{s_o} \tag{5.28}$$

where $\bar{x}'_o$ and $\bar{x}'_{s_o}$ are the initial means of the actual position/velocity and solve-for parameter deviations, respectively.

Applying the expectation operator to equation (5.19) yields the following equation for the mean of the actual measurement residual:

$$E[\varepsilon'_{k+1}] = -H \cdot E[\tilde{x}^{-\prime}_{k+1}] - M \cdot E[\tilde{x}^{-\prime}_{s_{k+1}}] + G\bar{u}'_o + L\bar{v}'_o + N\bar{w}'_o \quad . \tag{5.29}$$

The update equations for the means of the actual estimation errors are obtained by applying the expectation operator to equations (5.20) and (5.21). The resulting equations are:

$$E[\tilde{x}^{+\prime}_{k+1}] = E[\tilde{x}^{-\prime}_{k+1}] + K_{k+1} \cdot E[\varepsilon'_{k+1}] \tag{5.30}$$

$$E[\tilde{x}^{+\prime}_{s_{k+1}}] = E[\tilde{x}^{-\prime}_{s_{k+1}}] + S_{k+1} \cdot E[\varepsilon'_{k+1}] \quad . \tag{5.31}$$

The remainder of this section will treat the derivation of the propagation and update equations for the actual knowledge covariance matrix partitions. Since the actual estimation errors do not, in general, have zero means, it becomes more convenient, from both an analytical and a computational standpoint, to develop propagation and update equations for the 2nd moment matrices rather than for the covariance matrices, and then simply convert the 2nd moment matrices to covariance matrices using the standard relationship

$$\text{cov}\ (x,y) = E[xy^T] - \bar{x}\,\bar{y}^T \tag{5.32}$$

where cov (x,y) denotes the covariance of x and y, and $E[xy^T]$ denotes the 2nd moment matrix of x and y.

The required actual 2nd moment matrix partitions are defined in the following pages. Note that primes have been dropped from the 2nd moment variables to make the equations more readable in the remainder of this section. The 2nd moment matrix partitions that must be updated whenever a measurement is processed are listed first.

$$\begin{aligned}
P &= E[\tilde{x}'\ \tilde{x}'^T] & P_s &= E[\tilde{x}_s'\ \tilde{x}_s'^T] \\
C_{xx_s} &= E[\tilde{x}'\ \tilde{x}_s'^T] & C_{x_su} &= E[\tilde{x}_s'\ \tilde{u}'^T] \\
C_{xu} &= E[\tilde{x}'\ \tilde{u}'^T] & C_{x_sv} &= E[\tilde{x}_s'\ \tilde{v}'^T] \\
C_{xv} &= E[\tilde{x}'\ \tilde{v}'^T] & C_{x_sw} &= E[\tilde{x}_s'\ \tilde{w}'^T]\ . \\
C_{xw} &= E[\tilde{x}'\ w'^T] & &
\end{aligned} \tag{5.33}$$

The remaining 2nd moment matrix partitions do not change with time:

$$\begin{aligned}
C_{uv} &= E[\tilde{u}'\ \tilde{v}'^T] = C_{uv_o} & U &= E[\tilde{u}'\ \tilde{u}'^T] = U_o \\
C_{uw} &= E[\tilde{u}'\ \tilde{w}'^T] = C_{uw_o} & V &= E[\tilde{v}'\ \tilde{v}'^T] = V_o \\
C_{vw} &= E[\tilde{v}'\ \tilde{w}'^T] = C_{vw_o} & W &= E[\tilde{w}'\ \tilde{w}'^T] = W_o\ .
\end{aligned} \tag{5.34}$$

The 2nd moment matrix propagation equations for the time interval $[t_k, t_{k+1}]$ are obtained by substituting equations (5.14) and (5.15) into (5.33) and expanding. All equations are simplified by assuming ω'_k and $(\tilde{x}'_k, \tilde{x}'_{s_k}, \tilde{u}'_k, \tilde{v}'_k, \tilde{w}'_k)$ are uncorrelated. Thus, for example,

$$E[\tilde{x}'_k \, \omega'^T_k] = E[\tilde{x}'_k] \cdot E[\omega'^T_k] = 0$$

since the mean of ω'_k has been assumed to be zero. The final propagation equations are summarized below:

$$P^-_{k+1} = \left(\Phi P^+_k + \theta_{xx_s} C^{+T}_{xx_{s_k}} + \theta_{xu} C^{+T}_{xu_k} + \theta_{xw} C^{+T}_{xw_k}\right)\Phi^T + C^-_{xx_{s_{k+1}}} \theta^T_{xx_s} + C^-_{xu_{k+1}} \theta^T_{xu} + C^-_{xw_{k+1}} \theta^T_{xw} + Q_{k+1} \qquad (5.35)$$

$$C^-_{xx_{s_{k+1}}} = \Phi C^+_{xx_{s_k}} + \theta_{xx_s} P^+_{s_k} + \theta_{xu} C^{+T}_{x_s u_k} + \theta_{xw} C^{+T}_{x_s w_k} \qquad (5.36)$$

$$C^-_{xu_{k+1}} = \Phi C^+_{xu_k} + \theta_{xx_s} C^+_{x_s u_k} + \theta_{xu} U_o + \theta_{xw} C^T_{uw_o} \qquad (5.37)$$

$$C^-_{xv_{k+1}} = \Phi C^+_{xv_k} + \theta_{xx_s} C^+_{x_s v_k} + \theta_{xu} C_{uv_o} + \theta_{xw} C^T_{vw_o} \qquad (5.38)$$

$$C^-_{xw_{k+1}} = \Phi C^+_{xw_k} + \theta_{xx_s} C^+_{x_s w_k} + \theta_{xu} C_{uw_o} + \theta_{xw} W_o \qquad (5.39)$$

$$P^-_{s_{k+1}} = P^+_{s_k} \qquad (5.40)$$

$$C^-_{x_s u_{k+1}} = C^+_{x_s u_k} \qquad (5.41)$$

$$C^{-}_{x_s v_{k+1}} = C^{+}_{x_s v_k} \tag{5.42}$$

$$C^{-}_{x_s w_{k+1}} = C^{+}_{x_s w_k} \quad . \tag{5.43}$$

The actual dynamic noise 2nd moment matrix Q will be assumed to have form

$$Q_{k+1} = \text{diag}\,(\tfrac{1}{4} K_1' \Delta t^4, \tfrac{1}{4} K_2' \Delta t^4, \tfrac{1}{4} K_3' \Delta t^4, K_1' \Delta t^2, K_2' \Delta t^2, K_3' \Delta t^2) \tag{5.44}$$

where $\Delta t = t_{k+1} - t_k$, and K_1', K_2', and K_3' are constants which roughly correspond to the variances of the actual unmodeled accelerations. The form of this equation is identical to that of equation (3.23).

The actual measurement residual 2nd moment matrix is defined by

$$J_{k+1} = E[\varepsilon'_{k+1} \varepsilon'^{T}_{k+1}] \quad . \tag{5.45}$$

Substituting equation (5.19) into equation (5.45) yields

$$J_{k+1} = HA_{k+1} + MB_{k+1} + GD_{k+1} + LE_{k+1} + NF_{k+1} + R_{k+1} \tag{5.46}$$

where observation matrix partitions H, M, G, L, and N have been defined previously, R is the actual measurement noise 2nd moment matrix defined by

$$R_{k+1} = E[\nu'_{k+1} \nu'^{T}_{k+1}] \tag{5.47}$$

and

$$A_{k+1} = P^{-}_{k+1} H^T + C^{-}_{xx_{s_{k+1}}} M^T + C^{-}_{xu_{k+1}} G^T + C^{-}_{xv_{k+1}} L^T + C^{-}_{xw_{k+1}} N^T \tag{5.48}$$

$$B_{k+1} = P^{-}_{s_{k+1}} M^T + C^{-T}_{xx_{s_{k+1}}} H^T + C^{-}_{x_s u_{k+1}} G^T + C^{-}_{x_s v_{k+1}} L^T + C^{-}_{x_s w_{k+1}} N^T \tag{5.49}$$

$$D_{k+1} = C^{-T}_{xu_{k+1}} H^T + C^{-T}_{x_s u_{k+1}} M^T + U_o G^T + C^{-}_{uw_o} N^T + C^{-}_{uv_o} L^T \tag{5.50}$$

$$E_{k+1} = C^{-T}_{xv_{k+1}} H^T + C^{-T}_{x_s v_{k+1}} M^T + C^{-}_{vw_o} N^T + V_o L^T + C^{-T}_{uv_o} G^T \tag{5.51}$$

$$F_{k+1} = W_o N^T + C^{-T}_{xw_{k+1}} H^T + C^{-T}_{x_s w_{k+1}} M^T + C^{-T}_{vw_o} L^T + C^{-T}_{uw_o} G^T \; . \tag{5.52}$$

The 2nd moment matrix update equations, which correspond to the processing of a measurement, are obtained by substituting equations (5.20) and (5.21) into (5.33) and expanding. The final update equations are summarized as

$$P^{+}_{k+1} = P^{-}_{k+1} - K_{k+1} A^T - AK^T_{k+1} + K_{k+1} J_{k+1} K^T_{k+1} \tag{5.53}$$

$$C^{+}_{xx_{s_{k+1}}} = C^{-}_{xx_{s_{k+1}}} - K_{k+1} B^T - AS^T_{k+1} + K_{k+1} J_{k+1} S^T_{k+1} \tag{5.54}$$

$$C^{+}_{xu_{k+1}} = C^{-}_{xu_{k+1}} - K_{k+1} D^T \tag{5.55}$$

$$C^{+}_{xv_{k+1}} = C^{-}_{xv_{k+1}} - K_{k+1} E^T \tag{5.56}$$

$$C^{+}_{xw_{k+1}} = C^{-}_{xw_{k+1}} - K_{k+1} F^T \tag{5.57}$$

$$P^{+}_{s_{k+1}} = P^{-}_{s_{k+1}} - S_{k+1} B^T - BS^T_{k+1} + S_{k+1} J_{k+1} S^T_{k+1} \tag{5.58}$$

$$C^{+}_{x_s u_{k+1}} = C^{-}_{x_s u_{k+1}} - S_{k+1} D^T \tag{5.59}$$

$$C^{+}_{x_s v_{k+1}} = C^{-}_{x_s v_{k+1}} - S_{k+1} E^T \tag{5.60}$$

$$C^{+}_{x_s w_{k+1}} = C^{-}_{x_s w_{k+1}} - S_{k+1} F^T \tag{5.61}$$

where K_{k+1} and S_{k+1} are the filter gain constants.

5.2.2 Eigenvector and Prediction Events

The generalized covariance treatment of eigenvector and prediction events is quite similar to their treatment in an error analysis. At an eigenvector event, eigenvalues and eigenvectors are computed for both assumed and actual knowledge covariances. At a prediction event, both assumed and actual knowledge covariances are propagated forward to t_p, the time to which the prediction is to be made.

5.3 Generalized Midcourse Guidance Analysis

5.3.1 Target Condition Dispersion Analysis

To generate actual target condition dispersions (mean plus covariance) requires that equations be developed, first, for propagating actual deviation means (control means) and actual control 2nd moment matrix partitions over the time interval $[t_{j-1}, t_j]$ separating two successive guidance events. Second, equations must be developed for updating actual knowledge and control means and 2nd moment matrices following the execution of a guidance event. These equations are derived in this section.

The actual dynamics over the time interval $[t_{j-1}, t_j]$ are described by

$$x'^{-}_{j} = \Phi x'^{+}_{j-1} + \theta_{xx_s} x'_{s_o} + \theta_{xu} u'_{o} + \theta_{xw} w'_{o} + \omega'_{j} \qquad (5.62)$$

where actual parameter deviations x'_s, u', v', and w' do not change with time. Notation $(\ )^-$ and $(\ )^+$ indicates values immediately before and after a guidance correction, respectively. Applying the expectation operator to equation (5.62) yields the following mean propagation equation:

$$\bar{x}'^{-}_{j} = \Phi \bar{x}'^{+}_{j-1} + \theta_{xx_s} \bar{x}'_{s_o} + \theta_{xu} \bar{u}'_{o} + \theta_{xw} \bar{w}'_{o} \qquad (5.63)$$

where we have assumed that the mean of actual unmodeled acceleration ω'_j is zero.

The dispersions of the actual deviations about the targeted nominal trajectory are represented by the control 2nd moment matrix

$$P'_{c_j} = E\left[x'_j \; x'^T_j\right] \tag{5.64}$$

and related partitions. Equations (5.35) through (5.43) can be used to propagate all control 2nd moment matrix partitions over the interval $[t_{j-1}, t_j]$ if we treat all 2nd moment variables appearing in these equations as control 2nd moment variables.

Initial control 2nd moment matrix partitions are identical to initial knowledge 2nd moment matrix partitions since all initial estimates are zero.

The updating of actual knowledge and control means and 2nd moment matrices following the execution of a guidance event reflects the introduction of actual execution error statistics into the mean and 2nd moment matrix propagation processes. The actual estimation error at a guidance event is increased by the actual execution error

$$\delta\Delta V'_j = \Delta V'_j - \Delta\hat{V}'_j \tag{5.65}$$

where $\Delta V'_j$ is the actual velocity correction and $\Delta\hat{V}'_j$ is the actual commanded velocity correction. Therefore, the estimation error immediately following the velocity correction is given by

$$\tilde{x}'^{+}_j = \tilde{x}'^{-}_j - A \cdot \delta\Delta V'_j \tag{5.66}$$

where

$$A = [0 \,\vdots\, I]^T \quad .$$

The actual knowledge 2nd moment matrix immediately following the correction is defined by

$$P'^{+}_{K_j} = E\left[\tilde{x}'^{+}_j \;\; \tilde{x}'^{+T}_j\right] \quad . \tag{5.67}$$

Substitution of equation (5.66) into equation (5.67) yields

$$P'^{+}_{K_j} = P'^{-}_{K_j} + A \cdot E\left[\delta\Delta V'_j \; \delta\Delta V'^{T}_j\right] \cdot A^T - A \cdot E\left[\delta\Delta V'_j \; \tilde{x}'^{-T}_j\right]$$

$$- E\left[\tilde{x}'^{-}_j \; \delta\Delta V'^{T}_j\right] \cdot A^T \ . \qquad (5.68)$$

Defining the actual execution error 2nd moment matrix by

$$\tilde{Q}'_j = E\left[\delta\Delta V'_j \; \delta\Delta V'^{T}_j\right] \qquad (5.69)$$

and assuming the estimation error immediately prior to the correction and the execution error to be uncorrelated permits us to rewrite equation (5.68) as

$$P'^{+}_{K_j} = P'^{-}_{K_j} + A\tilde{Q}'_j \, A^T - A \cdot E\left[\delta\Delta V'_j\right] \cdot E\left[\tilde{x}'^{-T}_j\right]$$

$$- E\left[\tilde{x}'^{-}_j\right] \cdot E\left[\delta\Delta V'^{T}_j\right] \cdot A^T \ . \qquad (5.70)$$

The mean of the actual estimation error immediately following the correction is obtained simply by applying the expectation operator to equation (5.66) to obtain

$$E\left[\tilde{x}'^{+}_j\right] = E\left[\tilde{x}'^{-}_j\right] - A \cdot E\left[\delta\Delta V'_j\right] \ . \qquad (5.71)$$

The propagation equation for $E\left[\tilde{x}'^{-}_j\right]$ is given by equation (5.23). An expression for $E\left[\delta\Delta V'_j\right]$ is given in section 5.3.3.

The actual estimation error following the correction is defined by

$$\tilde{x}'^{+}_j = \hat{x}'^{+}_j - x'^{+}_j \ . \qquad (5.72)$$

But, since we assume that the nominal state is updated with the most recent estimate at a guidance event,

$$\hat{x}'^{+}_j = 0 \ . \qquad (5.73)$$

Then, substituting equations (5.72) and (5.73) into equation (5.66) yields

$$x'^{+}_{j} = - \tilde{x}'^{-}_{j} + A \cdot \delta\Delta V'_{j} \quad . \qquad (5.74)$$

The actual control 2nd moment matrix following the correction is defined by

$$P'^{+}_{c_j} = E\left[x'^{+}_{j} \; x'^{+T}_{j}\right] \quad . \qquad (5.75)$$

Substitution of equation (5.74) into equation (5.75) and comparing the result with equation (5.68) shows that

$$P'^{+}_{c_j} = P'^{+}_{K_j} \quad . \qquad (5.76)$$

Taking the expected value of equation (5.74) and comparing the results with equation (5.71) shows that

$$E\left[x'^{+}_{j}\right] = - E\left[\tilde{x}'^{+}_{j}\right] \quad . \qquad (5.77)$$

Similarly, under the assumption that we update the nominal solve-for state, we can write

$$E\left[x'^{+}_{s_j}\right] = - E\left[\tilde{x}'^{+}_{s_j}\right] \quad . \qquad (5.78)$$

The remaining control 2nd moment matrix partitions are updated in the same manner as the position/velocity partition is updated in equation (5.76).

Equations for the actual target dispersions can now be developed. The actual target state deviation $\delta\tau'_j$ is related to the actual state deviation x'_j at time t_j according to

$$\delta\tau'_j = \eta_j \, x'_j \qquad (5.79)$$

where η_j is the variation matrix (see section 4.4) for the appropriate midcourse guidance policy. The mean of $\delta\tau'_j$ is given by

$$E\,[\delta\tau'_j] = \eta_j\, E\,[x'_j] \quad . \qquad (5.80)$$

The statistical target dispersions are represented by the actual target condition 2nd moment matrix W'_j, which is defined as

$$W'_j = E\left[\delta\tau'_j\ \delta\tau'^T_j\right] \quad . \qquad (5.81)$$

Substitution of equation (5.79) into equation (5.81) yields

$$W'_j = \eta_j\, P'_{c_j}\, \eta_j^T \quad . \qquad (5.82)$$

Equations (5.80) and (5.82) are evaluated immediately before and after the guidance correction at time t_j.

5.3.2 Velocity Correction Analysis

The actual commanded velocity correction 2nd moment matrix is defined by

$$S'_j = E\left[\Delta\hat{V}'_j\ \Delta\hat{V}'^T_j\right] \qquad (5.83)$$

where the actual commanded velocity correction is given by

$$\Delta\hat{V}'_j = \Gamma_j\, \hat{x}'_j = \Gamma_j\, (x'_j + \tilde{x}'_j) \quad . \qquad (5.84)$$

The guidance matrix Γ_j corresponds to the appropriate linear mid-course guidance·policy (see section 4.4).

Substitution of equation (5.84) into equation (5.83) yields

$$S'_j = \Gamma_j \left\{E\left[x'_j\ x'^T_j\right] + E\left[\tilde{x}'_j\ \tilde{x}'^T_j\right] + E\left[x'_j\ \tilde{x}'^T_j\right] + E\left[\tilde{x}'_j\ x'^T_j\right]\right\} \Gamma_j^T \cdot \qquad (5.85)$$

We can write

$$E\left[x'_j\ \tilde{x}'^T_j\right] = E\left[\hat{x}'_j\ \tilde{x}'^T_j\right] - E\left[\tilde{x}'_j\ \tilde{x}'^T_j\right] \quad . \qquad (5.86)$$

Then, substituting equation (5.86) into equation (5.85), we obtain

$$S'_j = \Gamma_j \left\{ E\left[x'_j\ x'^T_j\right] - E\left[\tilde{x}'_j\ \tilde{x}'^T_j\right] + E\left[\hat{x}'_j\ \tilde{x}'^T_j\right] + E\left[\tilde{x}'_j\ \hat{x}'^T_j\right]\right\}\Gamma_j^T \quad . \qquad (5.87)$$

If we define

$$C'_{E_j} = E\left[\hat{x}'_j \; \tilde{x}'^T_j\right] \tag{5.88}$$

and use the definitions of control and knowledge 2nd moment matrices, we can write equation (5.87) as

$$S'_j = \Gamma_j \left(P'_{C_j} - P'_{K_j} + C'_{E_j} + C'^T_{E_j}\right) \Gamma^T_j \quad . \tag{5.89}$$

The corresponding expression for the assumed velocity correction covariance (section 4.4 is given by

$$S_j = \Gamma_j \left(P_{C_j} - P_{K_j}\right) \Gamma^T_j \quad . \tag{5.90}$$

The assumed covariance C_{E_j} does not appear in equation (5.90) since the navigation filter assumed the estimate and the estimation error to be orthogonal (if the filter employs an optimal estimation algorithm).

The proper evaluation of equation (5.89) for S'_j requires that C'_{E_j} and associated partitions be propagated between measurements and updated at each measurement. A set of propagation and update equations for C'_{E_j} and associated partitions can be developed in a straightforward fashion. These is some question, however, about the feasibility of carrying along an additional set of 2nd moment partitions merely to obtain a better value for S'_j. The programmed generalized covariance guidance model will assume C_{E_j} can be neglected in equation (5.89).

The mean of the actual commanded velocity correction is obtained by applying the expectation operator to equation (5.84):

$$E\left[\Delta\hat{V}'_j\right] = \Gamma_j \left\{E\left[x'_j\right] + E\left[\tilde{x}'_j\right]\right\} \quad . \tag{5.91}$$

Expressions for $E[x'_j]$ and $E[\tilde{x}'_j]$ are already available.

Equation (5.91) gives us no useful information for fuel sizing studies. Instead, we operate on the S' matrix (5.89) to define $E\,[|\Delta\hat{V}'_j|]$ using the Lee-Boain technique exemplified by equation (4.38) of Section 4.4.

The actual effective or statistical ΔV is then defined as

$$"E[\Delta\hat{V}_j']" = E[|\Delta\hat{V}_j'|] \cdot \alpha_j' \tag{5.92}$$

where α_j' denotes the unit eigenvector of S_j' corresponding to the maximum eigenvalue.

8.3.3 Execution Error Model

The actual execution error $\delta\Delta V_j'$ will be assumed to have form

$$\delta\Delta V_j' = k'\Delta V_j' + s' \frac{\Delta V_j'}{|\Delta V_j'|} + \delta\Delta V_{\text{pointing}}' \tag{5.93}$$

where k' denotes the actual proportionality error; s', the actual resolution error; and $\delta\Delta V_{\text{pointing}}'$ the actual pointing error. These actual execution errors are not required to have zero-mean statistics.

Both the mean and 2nd moment of $\delta\Delta V_j'$ are difficult to evaluate because of the complicated functional dependence of $\delta\Delta V_j'$ on $\Delta\hat{V}_j'$. This problem is also encountered in the generation of assumed execution error statistics, and will be resolved by making certain simplifying assumptions.

The components of $\delta\Delta V_j'$ can be found in equation (4.13) and are reproduced as

$$\delta\Delta V_x' = \left(k' + \frac{s'}{\rho'}\right)\Delta\hat{V}_x' + \frac{\rho'\Delta\hat{V}_y'\,\delta\alpha' + \Delta\hat{V}_x'\,\Delta\hat{V}_z'\,\delta\beta'}{\mu'} \tag{5.94}$$

$$\delta\Delta V_y' = \left(k' + \frac{s'}{\rho'}\right)\Delta\hat{V}_y' + \frac{\Delta\hat{V}_y'\,\Delta\hat{V}_z'\,\delta\beta' - \rho'\Delta\hat{V}_x'\,\delta\alpha'}{\mu'} \tag{5.95}$$

$$\delta\Delta V_z' = \left(k' + \frac{s'}{\rho'}\right)\Delta\hat{V}_z' - \mu'\delta\beta' \tag{5.96}$$

where $\rho' = |\Delta\hat{V}'|$, $\mu' = [\Delta\hat{V}_x'^2 + \Delta\hat{V}_y'^2]^{\frac{1}{2}}$, and $\delta\alpha'$ and $\delta\beta'$ are the actual pointing angle errors.

Before operating on equations (5.94), (5.95), and (5.96) to obtain expressions for $E\left[\delta\Delta V_j'\right]$ and $\tilde{Q}_j' = E\left[\delta\Delta V_j'\ \delta\Delta V_j'^T\right]$, we shall assume that $\Delta\hat{V}_x'$, $\Delta\hat{V}_y'$, and $\Delta\hat{V}_z'$ can be replaced by the components of the actual statistical velocity correction "$E[\Delta V_j']$". This means only k', s', $\delta\alpha'$, and $\delta\beta'$ need be treated as random variables when we apply the expectation operator to these equations or to any products of these equations.

Under the previous assumption, we obtain the following expression for the mean of $\delta\Delta V_j'$:

$$E[\delta\Delta V_j'] = E[\delta\Delta V_x']\, e_x + E[\delta\Delta V_y']\, e_y + E[\delta\Delta V_z']\, e_z \tag{5.97}$$

where

$$E[\delta\Delta V_x'] = \left(\overline{k}' + \frac{\overline{s}'}{\rho'}\right)\Delta\hat{V}_x' + \frac{\rho'\Delta\hat{V}_y'\,\overline{\delta\alpha}' + \Delta\hat{V}_x'\,\Delta\hat{V}_z'\,\overline{\delta\beta}'}{\mu'} \tag{5.98}$$

$$E[\delta\Delta V_y'] = \left(\overline{k}' + \frac{\overline{s}'}{\rho'}\right)\Delta\hat{V}_y' + \frac{\Delta\hat{V}_y'\,\Delta\hat{V}_z'\,\overline{\delta\beta}' - \rho'\Delta\hat{V}_x'\,\overline{\delta\alpha}'}{\mu'} \tag{5.99}$$

$$E[\delta\Delta V_z'] = \left(\overline{k}' + \frac{\overline{s}'}{\rho'}\right)\Delta\hat{V}_z' - \mu'\,\overline{\delta\beta}' \tag{5.100}$$

and e_x, e_y, and e_z denote three unit vectors aligned with the inertial ecliptic coordinate axes.

Denoting the elements of $\tilde{Q}_j'$ by $\tilde{Q}_{ik}'$, we will define

$$\left.\begin{aligned} &\tilde{Q}_{11}' = E[\delta\Delta V_x'^2],\ \tilde{Q}_{22} = E[\delta\Delta V_y'^2],\ \tilde{Q}_{33} = E[\delta\Delta V_z'^2] \\ &\tilde{Q}_{12}' = \tilde{Q}_{21}' = E[\delta\Delta V_x'\ \delta\Delta V_y'] \\ &\tilde{Q}_{13}' = \tilde{Q}_{31}' = E[\delta\Delta V_x'\ \delta\Delta V_z'] \\ &\tilde{Q}_{23}' = \tilde{Q}_{32}' = E[\delta\Delta V_y'\ \delta\Delta V_z'] \end{aligned}\right\} \tag{5.101}$$

Substituting equations (5.94), (5.95), and (5.96) into (5.101) and assuming all execution error sources to be uncorrelated, yields

$$\begin{aligned}\tilde{Q}'_{11} = {} & \xi' \, \Delta\hat{V}_x'^2 + \frac{1}{\mu'^2} \Big(\rho'^2 \, \Delta\hat{V}_y'^2 \, \overline{\delta\alpha'\delta\alpha'} \quad \Delta\hat{V}_x'^2 \, \Delta\hat{V}_z'^2 \, \overline{\delta\beta'\,\delta\beta'} \\ & + 2\rho' \, \Delta\hat{V}'_x \, \Delta\hat{V}'_y \, \Delta\hat{V}'_z \, \overline{\delta\alpha'} \, \overline{\delta\beta'} \Big) + \frac{2\Delta\hat{V}'_x}{\mu'} \, \zeta' \Big(\rho' \Delta\hat{V}'_y \, \overline{\Delta\alpha'} + \Delta\hat{V}'_x \, \Delta\hat{V}'_z \, \overline{\delta\beta'} \Big)\end{aligned} \tag{5.102}$$

$$\begin{aligned}\tilde{Q}'_{22} = {} & \xi' \, \Delta\hat{V}_y'^2 + \frac{1}{\mu'^2} \Big(\Delta\hat{V}_y'^2 \, \Delta\hat{V}_z'^2 \, \overline{\delta\beta'\,\delta\beta'} + \rho'^2 \, \Delta\hat{V}_x'^2 \, \overline{\delta\alpha'\,\delta\alpha'} \\ & - 2\rho' \, \Delta\hat{V}'_x \, \Delta\hat{V}'_y \, \Delta\hat{V}'_z \, \overline{\delta\alpha'} \, \overline{\delta\beta'} \Big) + \frac{2\Delta\hat{V}'_y}{\mu'} \, \zeta' \Big(\Delta\hat{V}'_y \, \Delta\hat{V}'_z \, \overline{\delta\beta'} - \rho' \, \Delta\hat{V}'_x \, \overline{\delta\alpha'} \Big)\end{aligned} \tag{5.103}$$

$$\tilde{Q}'_{33} = \xi' \, \Delta\hat{V}_z'^2 + \mu'^2 \, \overline{\delta\beta'\delta\beta'} - 2 \, \Delta\hat{V}'_z \, \mu' \, \zeta' \, \overline{\delta\beta'} \tag{5.104}$$

$$\begin{aligned}\tilde{Q}'_{12} = \tilde{Q}'_{21} = {} & \xi' \, \Delta\hat{V}'_x \, \Delta\hat{V}'_y + \frac{\zeta'}{\mu'} \Big[2 \, \Delta\hat{V}'_x \, \Delta\hat{V}'_y \, \Delta\hat{V}'_z \, \overline{\delta\beta'} - \rho' \Big(\Delta\hat{V}_x'^2 - \Delta\hat{V}_y'^2 \Big) \overline{\delta\alpha'} \\ & + \frac{1}{\mu'^2} \Big[- \rho'^2 \, \Delta\hat{V}'_x \, \Delta\hat{V}'_y \, \overline{\delta\alpha'\,\delta\alpha'} + \rho' \, \Delta\hat{V}'_z \Big(\Delta\hat{V}_y'^2 - \Delta\hat{V}_x'^2 \Big) \overline{\delta\alpha'} \, \overline{\delta\beta'} \\ & + \Delta\hat{V}'_x \, \Delta\hat{V}'_y \, \Delta\hat{V}_z'^2 \, \overline{\delta\beta'\,\delta\beta'} \Big]\end{aligned} \tag{5.105}$$

$$\begin{aligned}\tilde{Q}'_{13} = \tilde{Q}'_{31} = {} & \xi' \, \Delta\hat{V}'_x \, \Delta\hat{V}'_z + \zeta' \left[\frac{\Delta\hat{V}'_z}{\mu'} \Big(\rho' \, \Delta\hat{V}'_y \, \overline{\delta\alpha'} + \Delta\hat{V}'_x \, \Delta\hat{V}'_z \, \overline{\delta\beta'} \Big) - \mu' \, \Delta\hat{V}'_x \, \overline{\delta\beta'} \right] \\ & - \rho' \, \Delta\hat{V}'_x \, \overline{\delta\alpha'} \, \overline{\delta\beta'} - \Delta\hat{V}'_x \, \Delta\hat{V}'_z \, \overline{\delta\beta'\,\delta\beta'}\end{aligned} \tag{5.106}$$

$$\begin{aligned}\tilde{Q}'_{23} = \tilde{Q}'_{32} = {} & \xi' \, \Delta\hat{V}'_y \, \Delta\hat{V}'_z + \zeta' \left[\frac{\Delta\hat{V}'_z}{\mu'} \Big(\Delta\hat{V}'_y \, \Delta\hat{V}'_z \, \overline{\delta\beta'} - \rho' \, \Delta\hat{V}'_x \, \overline{\delta\alpha'} \Big) - \mu' \, \Delta\hat{V}'_y \, \overline{\delta\beta'} \right] \\ & + \rho' \, \Delta\hat{V}'_x \, \overline{\delta\alpha'} \, \overline{\delta\beta'} - \Delta\hat{V}'_y \, \Delta\hat{V}'_z \, \overline{\delta\beta'\,\delta\beta'}\end{aligned} \tag{5.107}$$

where

$$\xi' = \overline{k'k'} + \frac{2}{\rho'}\,\overline{k'}\;\overline{s'} + \frac{\overline{s's'}}{\rho'^2} \qquad (5.108)$$

and

$$\zeta' = \overline{k'} + \frac{\overline{s'}}{\rho'} \quad . \qquad (5.109)$$

6. NOMNAL USAGE

This chapter details the usage of the NOMNAL program for the person who needs to operate the program. Section 6.1 defines the input requirements of NOMNAL. The input to NOMNAL is entered via the NAMELIST option with default values stored internally for most variables to simplify program input. Section 6.2 describes the output generated by the NOMNAL program. Finally Section 6.3 discusses several sample cases made with NOMNAL. Sample output from these cases are included in Appendix A.

6.1 NOMNAL Input Description

1. An option card must be the first card read. The character string 'HALO' (punched in columns 1 through 4), will cause execution of NOMNAL halo orbit routines. If any other character string is present, the program will attempt to execute the non halo orbit routines. No default is provided.

2. Namelist &HALOIN is read by subroutine HPRELM. The variables in this namelist and their definitions are as follows:

ALPHA	Right ascension of finite burn vector (0.0 degrees)
ATRY	Initial guess to start solution to Lamberts problem for transfers involving one or more full revolutions prior to encounter (-0.1)
BETA	Declination of finite burn vector (0.0 degrees)
BTIME	Finite burn duration (1296.0 seconds)
CSUBR	Spacecraft reflectivity constant ($1.0/AU^2$)
DTAR	Array of target values (1) = Radium of closest approach (6560.0 kilometers) (2) = Inclination (28.317 degrees) (3) = Packed calendar date of closest approach in format YYMMDD.HHMMSS (740411.0)
DTOL	Array of target value tolerances (1) = RCA tolerance (10.0 kilometers) (2) = ICA tolerance (1.0 degrees) (3) = TCA tolerance (0.01 days)
DVMAX	Maximum change allowed to velocity controls in the targeting process, if $(\Delta V_x^2 + \Delta V_y^2 + \Delta V_z^2)^{\frac{1}{2}}$ exceeds DVMAX, the vector $(\Delta V_x, \Delta V_y, \Delta V_z)$ is normalized to that magnitude.
IBIAS	Flag to indicate that a bias vector is to be added to the libration state prior to targeting = 0 Target to libration state (default) = 1 Target to libration state + ZBIAS = 2 Target to ZBIAS = 3*Target to libration state + ZBIAS as calculated from rotating coordinate system variables
IBTYPE	Burn option = 0 Impulsive burn only (default) = 1 Target impulsive burn; calculate ALPHA, BETA and BTIME and then target finite burn = 2 Target finite burn only

---

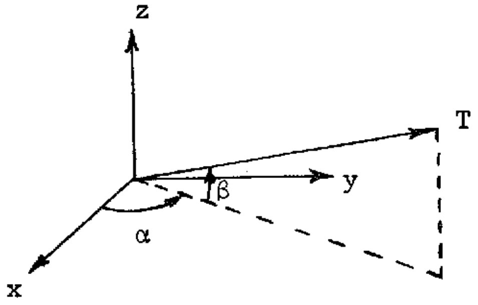
* See Table 6-1 for figures and definitions.

IDISK	Spacecraft trajectory file = 0 Do not write trajectory tile (default) = 1 Write sequential trajectory file with partials
INSYS	Flag to indicate input system of all input vectors (XINT, ZBIAS and ZDAT) (0) = 0 Cartesian state in inertial ecliptic = 1 Magnitude, right ascension and declination with respect to the coordinate system rotating with libration points
ITMAX	Maximum number of targeting iterations (6)
IZERO	Flag to indicate source of initial state vector = 5 User supplied initial velocity of spacecraft at libration point in vector ZDAT = 6 Initial velocity of spacecraft at libration point found by interpolation of time-of-flight table = 7 Initial velocity of spacecraft at libration point found by solving Lamberts problem (default)
LAUNCH	Flag for launch profile data = 0 Launch profile data is printed only = 1 Launch profile data is printed and trajectory is retargeted for updated launch time (default)
LIBR	Libration point of interest = 1 Earth Sun libration point (default) = 2 Earth anti-Sun libration point
MSGLVL	Flag for printing debug output, the higher the number the more debug print (0)
NB	Array of bodies used during integration 1 = Sun, 2 = Mercury, 3 = Venus, 10 = Pluto, 11 = Moon (1) = Central body (4) (2) = First non-central body (1) (3) = Second non-central body (11)
NBOD	Number of bodies used during integration maximum of 6 (1)
NFR	Number of full revolutions around Earth from injection to libration point encounter
NPOINT	Number of special print points (0)
PERT	Perturbation levels (1) = Position perturbation level (2.0 kilometers) (2) = Velocity perturbation level (5.0D-4 kilometers/seconds)
PHILS	Latitude of launch site (28.317 degrees)
PSI1	First injection burn arc (17.0 degrees)
PSI2	Second injection burn arc (8.0 degrees)
RLIBR	Array of Earth state scaling constants required to generate libration state according to the following definition: (1) = -0.0100109819 (2) = 0.0100782451
RPRAT	Inverse parking orbit rate (15.041)
SCAREA	Spacecraft area (30.D-6 kilometers^2)
SCMASS	Spacecraft mass (1000.0 kilograms)
SIGMAL	Nominal launch azimuth (90.0 degrees)

SMU(11) Gravitational constants of bodies (kilometers^3/seconds^2)

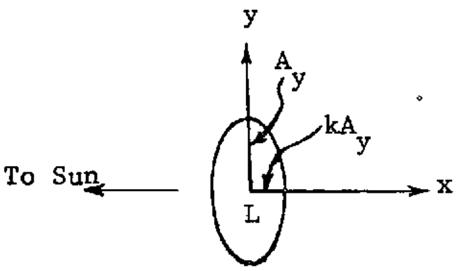
(1) Sun (1.32715445D11)
(2) Mercury (2.21815976934672D4)
(3) Venus (3.2477627D5)
(4) Earth (3.986008D5)
(5) Mars (4.2977368D4)
(6) Jupiter (1.2670935D8)
(7) Saturn (3.79187D7)
(8) Uranus (5.787732462712586D6)
(9) Neptune (6.890576272066444D6)
(10) Pluto (7.324089348785859D4)
(11) Moon (4.902778D3)

Table 6-1 Input Description for Finite Burn and L Point Target Variables



Finite Burn Parameter Description

ALPHA and BETA are measured with respect to the inertial ecliptic co-ordinate system.



Rotating Co-ordinate Parameter Description

$$x = kA_y \sin T_1 \qquad \dot{x} = k\omega_{xy} A_y \cos T_1$$

$$y = A_y \cos T_1 \qquad \dot{y} = -\omega_{xy} A_y \sin T_1$$

$$z = A_z \sin T_2 \qquad \dot{z} = \omega_z A_z \cos T_1$$

where,

$$T_1 = \omega_{xy}t + \theta_1$$

$$T_2 = \omega_z t + \theta_2$$

$$k = \frac{2C\,\omega_{xy}}{\omega_{xy}^2 + (2\omega_z^2 + C^2)}$$

$$C = \frac{360 \text{ degrees}}{\text{number of seconds/yr}}$$

Input Variables (IBIAS = 3)

$$\left.\begin{array}{l} \text{ZBIAS (1)} = A_y \\ \text{ZBIAS (2)} = A_z \end{array}\right\} \text{kilometers}$$

$$\left.\begin{array}{l} \text{ZBIAS (3)} = \omega_{xy} \\ \text{ZBIAS (4)} = \omega_z \end{array}\right\} \text{deg/sec}$$

$$\left.\begin{array}{l} \text{ZBIAS (5)} = \theta_1 \\ \text{ZBIAS (6)} = \theta_2 \end{array}\right\} \text{deg}$$

TDUR	Time of flight (days)
THEDOT	Rotation rate of launch planet (15.041 degrees/hours)
THELS	Longitude launch site (279.457 degrees)
THRMAG	Thrust magnitude (1.0 Newtons)
TIM1	Duration of first injection burn (500.0 seconds)
TIM2	Duration of second injection burn (100.0 seconds)
TMPR	Number of days between print points (10.0 days)
TP	Array of special print points in days from injection (100*0.0)
XINT	Injection state vector to be integrated if ITMAX = 0 (6*0.0)
XISP	Specific impulse (265.0 seconds)
ZBIAS	6 vector added to libration state for targeting when IBIAS = 1,2 or 3 (6*0.0) (See IBIAS)
ZDAT	3 vector of initial guess of spacecraft velocity at libration point, if IZERO = 5 (3*0.0)

6.2 NOMNAL Output Description

The output from the nominal trajectory generator NOMNAL is divided into four sections: Initial Conditions, Launch Profile Targeting and Trajectory Data. Each section is discussed individually.

6.2.1 Initial Conditions

The banner of the initial conditions section indicates to the user that the source of the initial conditions is 'from input', 'from table' look up or 'from Lamberts Equation'. The following data is printed:

INJECTION DATE	The proposed Julian and calendar date of injection. This date is derived from input and does not take into account the launch related data.
FLIGHT DURATION	Time from injection to arrival at the libration point (days)
ARRIVAL DATE	The proposed Julian and calendar date of arrival at the libration point. This date is a function of the initial conditions injection date and the flight duration.
LIBRATION POINT	The number of the injection point of interest (1 = Earth-Sun, 2 = Earth-antiSun)
BIAS VECTOR	A 6 element state vector added to the state of the libration point prior to targeting.
STATE AT L-POINT	6 element state vector at the libration point (X, Y, Z (km) and XDOT, YDOT, ZDOT (kilometers/seconds) in ecliptic coordinate system.
STATE AT INJECTN	Similar to 'state at L-point' except this state is at closest approach.
CENTRAL BODY	Name of the central gravitating body.
NO. OF BODIES	Number of bodies used during integration.
BODY NO. 1	Name of first body in Universe
BODY NO. 2	Name of second body in Universe
BODY NO. 3	Name of third body in Universe

6.2.2 Launch Profile

The banner of the launch profile section indicates to the user that the following information has been used to update the trajectory for targeting ('Launch Profile for Targeting') or is printed for information only ('Projected Launch Profile'). The following data is printed in either case:

INJECTION DATE	Julian and calendar date of injection
AZIMUTH	The launch azimuth required for launch into parking orbit (degrees)
LS LONGITUDE	The launch site longitude (degrees)
LS LATITUDE	The launch site latitude (degrees)
BURN1 ANGLE	The first injection burn arc (degrees)
BURN2 ANGLE	The second injection burn arc (degrees)
LAUNCH TOD	Launch time of day (days from 0 hours input)
BURN1 DUR-SEC	The duration of the first injection burn (seconds)
COAST TIME-SEC	Coast time in parking orbit (seconds)
BURN2 DUR-SEC	The duration of the second injection burn (seconds)
INJECTION TOD	Injection time of day (days from 0 hours input)
INJECTION GHA	Injection Greenwich hour angle
INJ DV IN OUT	Injection ΔV (kilometers/second) and an indication of in- or out-of-plane
STATE (ECL)	6 element state vector: X, Y, Z (km) and XDOT, YDOT, ZDOT (kilometers/seconds) in ecliptic coordinate system.
ELEMENTS (ECL)	6 element vector: Semi-major axis (km), eccentricity, inclination (degrees), longitude of ascending node (degrees, longitude of periapsis (degrees) and true anomaly (degrees).
STATE (ECQ)	6 element state vector similar to 'SAATE (ECL)' except in Earth equatorial coordinates.
ELEMENTS (ECQ)	6 element vector similar to 'ELEMENTS (ECL)' except in Earth equatorial coordinates.

6.2.3 Targeting

The banner of the targeting section indicates to the user the libration point being targeted and the iteration number. The following data is printed:

TARGETING EVENT AT JULIAN DATE	Julian date at libration point
DESIGNATED TARGET TIME AT JULIAN DATE	Julian date at closest approach
SPACECRAFT STATE VECTOR AT INITIAL JULIAN DATE	
GEO-EC	6 element state vector at the libration point (X, Y, Z (km) and XDOT, YDOT, ZDOT (kilometers/seconds) in Geocentric Ecliptic Coordinates.
GEO-EQ	6 element state vector similar to 'GEO-EC'.

CONTROL VARIABLES NAME OF CONTROL VARIABLES

VX - XDOT at the libration point
VY - YDOT at the libration point
VZ - ZDOT
ALPH - Right ascension of finite burn vector
BETA - Declination of finite burn vector
TBRN - Finite burn duration

TARGET VARIABLES

RCA - Radius of closest approach
ICA - Inclination of closest approach
TCA - Time of closest approach

ACTUAL TARGET VALUES - Values of RCA (km), ICA (deg) and TCA (days) resulting from integration.

TARGET ERROR Error resulting from comparison of actual target values with desired target values.

TARGET TOLERANCES Maximum allowable error between the actual target values and the desired target values.

TOTAL CHANGE TO THE CONTROL VARIABLES - The change to the control variables from the first to last iteration

NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY - The values of the control variables used during previous integration

DIFFERENTIAL TRANSFORMATION MATRIX - Partials of target variables with respect to Earth equatorial state vector at the libration point. The format is as follows:

```
RCA/X  RCA/Y  RCA/Z  RCA/XD  RCA/YD  RCA/ZD
ICA/X  ICA/Y  ICA/Z  ICA/XD  ICA/YD  ICA/ZD
TCA/X  TCA/Y  TCA/Z  TCA/XD  TCA/YD  TCA/ZD
```

STATE TRANSITION MATRIX - Partials of state vector at closest approach to the state at thrust initiation in the ecliptic coordinate system. The format is as follows:

```
X/X  X/Y  X/Z  X/XD  X/YD  X/ZD
Y/X  Y/Y  Y/Z  Y/XD  Y/YD  Y/ZD
Z/X  Z/Y  Z/Z  Z/XD  Z/YD  Z/ZD
XD/X XD/Y XD/Z XD/XD XD/YD XD/ZD
YD/X YD/Y YD/Z YD/XD YD/YD YD/ZD
ZD/X ZD/Y ZD/X ZD/XD ZD/YD ZD/ZD
```

PARTIALS OF STATE VECTOR AT THE TARGET TIME WITH RESPECT TO THE FINITE BURN CONTROL VARIABLES. The format is as follows:

X/ALPH X/BETA X/TBRN
Y/ALPH Y/BETA Y/TBRN
Z/ALPH Z/BETA Z/TBRN
XD/ALPH XD/BETA XD/TBRN
YD/ALPH YD/BETA YD/TBRN
XD/ALPH ZD/BETA ZD/TBRN

PARTIALS OF STATE VECTOR AT THE TARGET TIME WITH RESPECT TO THE FINITE BURN CONTROL VARIABLES. The format is identical to previously mentioned format of state with respect to finite burn control variables.

TARGET SENSITIVITY MATRIX - Partials of target variables with respect to control variables. For the impulsive burn case the format is:
RCA/XD RCA/YD RCA/ZD
ICA/XD ICA/YD ICA/ZD
TCA/ALPH TCA/BETA TCA/TBRN

TARGETING MATRIX - Inverse of target sensitivity matrix

PREDICTED CONTROL CHANGES - The delta that must be added to the current values of the control variables to target the trajectory.

6.2.4 Trajectory

The banner of the trajectory section indicates to the user that the information printed is a normal print point, a 'special point' or a 'special print for burn point'. The following data is printed:

DATE	The Julian and calendar date associated with the following trajectory data

DAYS FROM INJECTION - Self explanatory

DATA WITH RESPECT TO - The name of body to which the following data is referenced

STATE (ECL)	6 element state vectory of the spacecraft (X, Y, Z (km) and XDOT, YDOT, ZDOT (km/sec)) in the ecliptic coordinate system
R-MAG	Magnitude of the radius vector (km)
V-MAG	Magnitude of the velocity vectory (km/sec)
RA (ECL)	Right ascension of the radius vector in the ecliptic coordinate system (deg)
DEC (ECL)	Declination of the radius vector in the ecliptic coordinate system (deg)

STATE (ECQ)	Similar to 'state (ECL)' except in the Earth equatorial system.
RA (ECQ)	Right ascension of the radius vector in the Earth equatorial coordinate system (deg)
STATE PARTIALS	State transition matrix (FEOM injection to current print point) in units of km and km/sec in the following format:

X/X	X/Y	X/Z	X/XD	X/YD	X/ZD
Y/X	Y/Y	Y/Z	Y/XD	Y/YD	Y/ZD
Z/X	Z/Y	Z/Z	Z/XD	Z/YD	Z/ZD
XD/X	XD/Y	XD/Z	XD/XD	XD/YD	XD/ZD
YD/X	YD/Y	YD/Z	YD/XD	YD/YD	YD/ZD
ZD/X	ZD/Y	ZD/Z	ZD/XD	ZD/YD	ZD/ZD

DATA IN RLP SYSTEM - Magnitude, right ascension and declination of both the position and velocity in the rotating libration point system. The impulse magnitude, right ascension, declination and vector to rendezvous with the libration point are also output.

6.3 NOMNAL Sample Case Description

Two targeting cases performed by the targeting program NOMNAL will be described in this section to illustrate the operation of the targeting process. The cases to be discussed are:

Case N-1. Short (36 day) transfer time mission to the L_1 point with finite burn insertion.

Case N-2. Long (118 day) transfer time mission to the L_2 point with impulsive insertion.

6.3.1 Input data

Table 6.1 is a copy of the input data for both cases as indicated. The purpose of the NOMNAL run is to first target the desired trajectory and then generate a file containing trajectory and state transition matrix information for subsequent ERRAN runs. Any values not specified in the namelist will take the default values as specified in Section 6.1. The case N-1 will illustrate essentially all of the capability of NOMNAL, since a finite burn case can use a targeted impulsive case as a first guess. This option is specified by IBTYPE = 1, targeting an impulsive case backwards in time from the libration point at DTAR(3) + TDUR to injection at DTAR(3). The tolerances are specified by the DTOL array, the maximum number of iterations by ITMAX, use of the built in zero iterate table by IZERO = 6, the number of bodies and which ones by NBOD and NB, the mass of the Earth (SMU(4)) is taken here to be equal to the sum of the Earth-Moon system, and the spacecraft parameters by SCMASS and XISP. Similarly in case N-2 the flight time, libration point (LIBR = 2) and insertion type are specified.

```
&HALOIN
 NPOINT=2,  TP=0.5, 5.0,
 DTAR(3)=740709.1608,
 DTOL(1)=1.,.001,.00001,
 IBTYPE=1,
 IDISK=1,
 ITMAX=10,
 IZERO=6,
 NB(1)=4,1,0,
 NBOD=2,
 SCMASS=400.,
 SMU(4)=403503.97887,
 TDUR=36.,
 XISP=215.,
&END
```

a. Case N-1 Input

```
&HALOIN
 DTAR(3)=740709.2216,
 DTOL(1)=1.,.001,.00001,
 ITMAX=10,
 IZERO=6,
 IDISK=1,
 LIBR=2,
 NB(1)=4,1,0,
 NBOD=2,
 SMU(4)=403503.97887,
 TDUR=118.,
&END
```

b. Case N-2 Input

Table 6.1 NOMNAL Sample Input

6.3.2 Discussion

From these runs it is seen that both of these cases take several iterations to converge, case N-2 due to the much greater sensitivity of the long flight time cases (use of DVMAX advised) and case N-1 due to the greater non-linearity of the finite burn controls. For case N-1, it is seen that after the impulsive case converges, the burn parameters are approximated and targeting proceeds in the finite burn phase. After convergence on the date specified the launch phase adjusts the injection time for a realistic launch and retargets the case holding the flight time constant.

For both cases after convergence has occurred, the trajectory file is generated (if IDISK = 1) and the trajectory is printed out forwards in time from injection once every TMPR days and at any special print points desired, at the initiation of the finite burn if there is one and at the final time.

7. ERRAN USAGE

7.1 ERRAN Input Description

The input of the error analysis/generalized covariance analysis program consists of:

a) An error analysis namelist section entitled ERRAN;

b) The measurement schedule;

c) A generalized covariance analysis namelist section entitled GENRAL, that must appear only if a generalized covariance analysis is to be performed.

Most namelist variables are preset by the program; these preset values are the quantities enclosed in parentheses in the namelist definitions. Unless otherwise indicated, input units correspond to the internal units defined by the variables ALNGTH and TM. Unspecified angular units are assumed to be radians.

7.1.1 Namelist ERRAN

1. Nominal trajectory variables

IM0	Month of final computation (integer)
IDAY	Day of final computation (integer)
IHR	Hour of final computation (integer)
IMIN	Minute of final computation (integer)
SECI	Second of final computation (floating)
IYR	Year of final computation (integer)
ALNGTH	Length units per AU (ALNGTH = 149597893. kilometers)
TG	Initial control covariance time (TG = 0)
TM	Time units per day. (TM = 86400. seconds)
TRTM1	Initial trajectory time. (TRTM1 = 0)

All other trajectory and state transition matrix data are contained on the file generated by NOMNAL.

2. Parameter Augmentation Variables

IAUGIN(24)	Array of augmented parameter codes; unspecified elements are assumed to be zeros. Up to 15 solve-for parameters may be augmented; up to 15 measurement-consider parameters; and up to 15 ignore parameters.

IAUGIN(I) = 0 - neglected parameter (preset value)
= 1 - consider parameter
= 2 - solve-for parameter
= 3 - ignore parameter (generalized covariance only)

I		
1	Radius error of station 1	measurement parameters
2	Latitude error of station 1	
3	Longitude error of station 1	
4	Radius error of station 2	
5	Latitude error of station 2	
6	Longitude error of station 2	
7	Radius error of station 3	
8	Latitude error of station 3	
9	Longitude error of station 3	
10-17	Undefined (no dynamic parameters are currently included in STEAP-L)	
18	Range bias of station 1	measurement parameters
19	Range-rate bias of station 1	
20	Star-planet angle 1 bias	
21	Star-planet angle 2 bias	
22	Star-planet angle 3 bias	
23	Apparent planet diameter bias	
24	Undefined	

3. Measurement Variables

NENT	Number of entries (cards in measurement schedule [NENT = 0])
NST	Number of tracking stations (at most 3) on the rotating earth (NST = 3). If no tracking station information is read in, the following three stations will be assumed:

		Altitude	Latitude	Longitude
1.	Goldstone	1.031 km	35.384 N	116.833 W
2.	Madrid	.050 km	40.417 N	3.667 W
3.	Canberra	.050 km	35.311 S	149.136 E

If different tracking stations are desired, their locations must be specified by the following three arrays.

SAL(3)	Array of altitudes of each tracking station (spherical Earth)
SLAT(3)	Array of latitudes of each tracking station in degrees north
SLON(3)	Array of longitudes of each tracking station in degrees east
UST(3) VST(3) WST(3)	Direction cosine arrays of three reference stars. If not specified, the three stars and their direction cosines are as follows:

	Canopus	Betelgeuse	Rigel
UST	-.061351	.028986	.201963
VST	.237886	.960388	.831343
WST	-.969355	-.277141	-.517784

4. Eigenvector and Prediction Event Variables

NEV1	Number of eigenvector events (NEV1 = 0)
T1(20)	Array of times at which eigenvector events occur; specified only if NEV1 is nonzero. Chronological order required.
NEV2	Number of prediction events (NEV2 = 0)
T2(20)	Array times at which prediction events occur; specified only if NEV2 is nonzero. Chronological order is required. Exactly NEV2 entries must be input.
TPT2(20)	Array of times to which one wishes to predict. The elements of the TPT2 array must correspond to the elements of the T2 array.
IPUNE	Flag controlling the punched output for eigenvector events (IPUNE = 0). = 0 - Do not punch. = 1 - Punch the P, PS, CXXS, CXU, CXSU matrices
IPUNP	Flag controlling the punched output for prediction events (IPUNP = 0). = 0 - Do not punch. = 1 - Punch the P, PS, CXXS, CXV, CXSV matrices at the time predicted to
FØP	A value to be used as an off-diagonal annihilation element in subroutine JACØBI for position eigenvalues and eigenvectors (FØP = 1. x 10^{-15})
FØV	A value to be used as an off-diagonal annihilation element in subroutine JACØBI for velocity eigenvalues and eigenvectors (FØV = 1. x 10^{-25})

5. Covariance Variables (filter, or assumed, covariances)

P(6,6)	Initial P (position and velocity) covariance matrix. Referenced to inertial frame (diag P = 1., 1., 1., 1. x 10^{-4}, 1. x 10^{-4}, 1. x 10^{-4}.)

The structure of the following ten parameter covariance matrix partitions must correspond to the structure of the solve-for and measurement-consider parameter vectors. The last five matrix partitions are at the time TG which may be different from TRTM1.

PS(15,15)	Initial P_S (solve-for parameter) covariance matrix (PS = identity matrix)
VO(15,15)	Initial V_o (measurement-consider parameter) covariance matrix (VO = 0)
CXXS(6,15)	Initial C_{xx_S} covariance matrix (CXXS = 0)
CXV(6,15)	Initial C_{xv} covariance matrix (CXV = 0)

CXSV(15,15)	Initial $C_{x_s v}$ covariance matrix (CXSV = 0)
PG(6,6)	Initial control (position and velocity) covariance matrix (diag PG = 1., 1., 1., 1. x 10^{-4}, 1. x 10^{-4}, 1. x 10^{-4})
PSG(15,15)	Initial solve-for control covariance matrix (PSG = identify matrix)
CXXSG(6,15)	Initial control C_{xx_s} covariance matrix (CXXSG = 0)
CXVG(6,15)	Initial control C_{xv} covariance matrix (CXVG = 0)
CXSVG(15,15)	Initial control $C_{x_s v}$ covariance matrix (CXSVG = 0)
IFCNRI	Flag for inputting the initial control covariances (IFCNRI = 0) = 0 control covariances not input (set equal to the initial covariances) = 1 control covariances input as PG, PSG, CXXSG, CXVG, CXSVG at time TG
IFPCØV	Covariance input code (IFPCØV = 0) = 0 P and PS are input in covariance form = 1 P and PS are input in standard deviation and correlation form (standard deviations on diagonal and correlations in lower left triangle)
IFGCØV	Control covariance input code (IFGCØV = 0) = 0 PG and PSG are input in covariance form = 1 PG and PSG are input in standard deviation and correlation form
IDNF	Dynamic noise flag (IDNF = 0) = 0 Dynamic noise is zero = 1 Dynamic noise is not zero
DNCN(3)	Array of constants used to calculate dynamic noise covariance matrix; must be specified if IDNF equals 1.
MNCN(12)	Array of variances for each type of measurement. If not specified, the following values are assumed: MNCN(1) = 1. x 10^{-6} Range (idealized station) (2) = 1. x 10^{-12} Range rate (idealized station) (3) = 1. x 10^{-6} Range (station 1) (4) = 1. x 10^{-12} Range rate (station 1) (5) = 1. x 10^{-6} Range (station 2) (6) = 1. x 10^{-12} Range rate (station 2) (7) = 1. x 10^{-6} Range (station 3) (8) = 1. x 10^{-12} Range rate (station 3) (9) = 2.5 x 10^{-9} Star-planet angle 1

MNCN(10) = 2.5×10^{-9} Star-planet angle 2
(11) = 2.5×10^{-9} Star-planet angle 3
(12) = 2.5×10^{-9} Apparent planet diameter

SIGRES	Variance of resolution execution error (SIGRES = $4. \times 10^{-8}$)
SIGPR0	Variance of proportionality execution error (SIGPR0 = .0001)
SIGALP	Variance of pointing angle alpha execution error (SIGALP = .0043625 radians^2)
SIGBET	Variance of pointing angle beta execution error (SIGBET = .0043625 radians^2)
IGEN	Code that indicates if a generalized covariance analysis is to be performed (IGEN = 0) = 0 No generalized covariance analysis = 1 Generalized covariance analysis

6. Print Codes

IPRINT	Measurement print interval; measurement information printed every IPRINT measurements (IPRINT = 1)
KPRINT	Correlation matrix print code (KPRINT = 1) = 0 Print out P and P_S correlation matrices and standard deviations at a measurement = 1 Print out all correlation matrices and standard deviations at a measurement
IERPR	Namelist print code (IERPR = 0) = 0 Do not print namelist ERRAN = 1 Print namelist ERRAN
IPR0B	Problem number

7. Guidance Event Variables

NEV3	Number of guidance events (NEV3 = 0)
T3(20)	Array of times at which guidance events occur; specified only if NEV3 is nonzero. Chronological order required
ICDT3(20)	Array of codes specifying the guidance policy (ICDT3 = 20*1) = 1 Fixed time of arrival (FTA) = 2 Variable time of arrival (VTA)

IFVMRI	Flag to indicate whether the targeting matrix η(ADA) is to be calculated or input (IFVMRI = 0) = 0 ADA is calculated = 1 ADA is input via the matrix RADA
RADA(3,6)	ADA matrix if it is to be input NOTE: Only one ADA matrix may be read, so this option should not be used with multiple guidance events.
SKALE	Scale factor used in calculating the S matrix (ΔV covariance) (SKALE = 0)
IPUNG	Flag controlling the punched output for guidance events (IPUNG = 0) = 0 Do not punch = 1 Punch the P^+, PS^+, $CXXS^+$, CXV^+, $CXSV^+$ matrices

8. Insertion Event Variables

NEV4	Number of insertion events, should be either 0 or 1 (NEV4 = 0)
T4(20)	Time of the insertion event; specified only if NEV4 is nonzero (days).
BRNTIM	Duration of the finite insertion burn, if less than one second burn is assumed to be impulsive (BRNTIM = 0) < 1. sec Impulsive insertion maneuver ≥ 1. sec Finite insertion burn of duration BRNTIM seconds
REXV(3)	Insertion ΔV vector for an impulsive insertion maneuver
UO(3,3)	Covariance matrix of execution errors for finite burn, diagonal elements are the variances of the right ascension (α) and declination (β) both in radians^2 and of the thrust level (T) in newtons^2 (UO = Identity)

7.1.2 Measurement Schedule

The measurement schedule must appear immediately after the namelist ERRAN section. It appears on NENT cards.

Each card defines an entry in the measurement schedule according to the following format:

> From DAY1 (F10.0) to DAY2 (F10.0), every X (F10.0) days, measurement code ITRK (I10).

The measurement codes are defined as follows:

ITRK = 1 Range rate (idealized station)
2 Range and range rate (idealized station)
3 Range rate (station 1)
4 Range and range rate (station 1)
5 Range rate (station 2)
6 Range and range rate (station 2)
7 Range rate (station 3)
8 Range and range rate (station 3)
9 Three star-planet angles
10 Apparent planet diameter
11 Star-planet angle 1
12 Star-planet angle 2
13 Star-planet angle 3

The total number of measurements must not exceed 1000, and measurement times must not coincide.

7.1.3 Namelist GENRAL

GP(6,6)	Actual spacecraft position/velocity covariance matrix P'_o (GP = P)
GPS(15,15)	Actual solve-for parameter covariance matrix P'_s (GPS = PS)
GV(15,15)	Actual measurement-consider parameter covariance matrix V'_o (GV = VO)
GW(15,15)	Actual ignore parameter covariance matrix W'_o (GW = identity matrix)
GCXXS(6,15)	Actual state/solve-for parameter covariance matrix C'_{xx_s} (GCXXS = CXXS)
GCXV(6,15)	Actual state/measurement-consider parameter covariance matrix C'_{xv} (GCXV = CXV)
GCXW(6,15)	Actual state/ignore parameter covariance matrix C'_{xw} (GCXW = 0)
GCXSV(15,15)	Actual solve-for parameter/measurement-consider parameter covariance matrix C'_{x_sv} (GCXSV = CXSV)
GCXSW(15,15)	Actual solve-for parameter/ignore parameter covariance matrix C'_{x_sw} (GCXSW = 0)
GCVW(15,15)	Actual measurement-consider parameter/ignore parameter covariance matrix C'_{vw} (GCVW = 0)
EXI(6)	Actual spacecraft position/velocity deviation mean $\overline{x}'_o$ (EXI = 0)
EXSI(15)	Actual solve-for parameter deviation mean $\overline{x}'_{s_o}$ (EXSI = 0)

EV(15)	Actual measurement-consider parameter deviation mean $\overline{v}'_o$ (EV = 0)
EW(15)	Actual ignore parameter deviation mean $\overline{w}'_o$ (EW = 0)
IGRPR	Namelist print code (IGRPR = 0) = 0 Do not print namelist GENRAL = 1 Print namelist GENRAL
IGDNF	Actual dynamic noise flag (IGDNF = IDNF) = 0 Actual dynamic noise is zero = 1 Actual dynamic noise is not zero
GDNCN(3)	Array of constants used to calculate actual dynamic noise covariance matrix; must be specified if IGDNF equals 1
GMNCN(12)	Actual measurement noise variance for each type of measurement. GMNCN(1) refers to same measurement type as MNCN(I) (GMNCN = MNCN)
EVK	Actual proportionality execution error mean (EVK = 0)
EVS	Actual resolution execution error mean (EVS = 0)
EVA	Actual pointing angle alpha execution error mean (EVA = 0)
EVB	Actual pointing angle beta execution error mean (EVB = 0)
VARK	Actual proportionality execution error variance (VARK = SIGPR0)
VARS	Actual resolution execution error variance (VARS = SIGRES)
VARA	Actual pointing angle alpha execution error variance (VARA = SIGALP)
VARB	Actual pointing angle beta execution error variance (VARB = SIGBET)

7.2 ERRAN Output Description

The printed output of the error analysis mode is described in this section according to the following groups: input data, measurement output, eigenvector event output, prediction event output, guidance event output, and final insertion event output.

7.2.1 Input Data

The initial output consists of the following input data:

(1) Namelist ERRAN (if IERPR $\neq$ 0).

(2) Calendar date and Julian date at launch.

(3) Final calendar date and Julian date.

(4) Initial trajectory time in days (TRTM1).

(5) Definition of inertial frame (geocentric ecliptic).

(6) Initial spacecraft position/velocity state vector components and magnitudes in inertial, heliocentric, and rotating geocentric coordinates. (In the last, the geocentric ecliptic x- and y-axes are rotating so that the x'-axis is along the sun-earth line.)

(7) Lists of solve-for and measurement consider parameters augmented to the position/velocity state vector. Definitions of names appearing in this list are given below:

RADIUS 1	Radius error of station 1
LAT 1	Latitude error of station 1
LONG 1	Longitude error of station 1
RADIUS 2	Radius error of station 2
LAT 2	Latitude error of station 2
LONG 2	Longitude error of station 2
RADIUS 3	Radius error of station 3
LAT 3	Latitude error of station 3
LONG 3	Longitude error of station 3
RANGE	Range bias of station 1
R-RATE	Range-rate bias of station 1
ST ANG 1	Star-planet angle 1 bias
ST ANG 2	Star-planet angle 2 bias
ST ANG 3	Star-planet angle 3 bias
APP DIAM	Apparent planet diameter bias

(8) Measurement schedule; measurement codes defined in section dealing with input description.

(9) Schedule of eigenvector, prediction, and guidance events.

(10) Initial P, C_{XX_S}, C_{XV}, P_S, and V_o covariance matrix partitions; defined in section dealing with input description.

(11) Definition of structure of augmented state transition, observation, and covariance matrices and their dimensions.

(12) Dynamic noise constants used to compute the dynamic noise covariance matrix if dynamic noise is nonzero.

(13) Measurement noise for range, range-rate, star-planet angle, and apparent planet diameter measurements.

(14) Tracking station locations.

7.2.2 Measurement Output

Measurement information is printed every IPRINT measurements. At such a time the following information is printed:

(1) Measurement number and corresponding trajectory time.

(2) Type of measurement.

(3) Trajectory time t_{k-1} at most recent measurement or event (initial trajectory time).

(4) Trajectory time t_k at present measurement (final trajectory time).

(5) Initial and final spacecraft position/velocity components and magnitudes in inertial, heliocentric and rotating geocentric coordinates.

(6) State transition matrix over the time interval $[t_{k-1}, t_k]$, relating deviations in spacecraft position and velocity at time t_{k-1} to spacecraft position and velocity deviations at time t_k. Note that transposed matrices are printed.

(7) Diagonal of dynamic noise covariance matrix Q; represents unmodeled accelerations over the time interval $[t_{k-1}, t_k]$.

(8) Observation matrix partitions H, M, and L, relating deviations in spacecraft position and velocity, solve-for parameters, and measurement consider parameters at time t_k to deviations in the observables at time t_k. Note that transposed matrices are printed.

(9) Measurement noise (covariance matrix R).

(10) Kalman gain matrix partitions. The K matrix is used in the filtering equations to compute the P, C_{xx_s}, and C_{xv} covariance matrix partitions. The S matrix is used in the filtering equations to compute the P_s and $C_{x_s v}$ covariance matrix partitions.

(11) Correlation matrix partitions and standard deviations at time t_k, must before the measurement. The first group of correlation matrix partitions represents the correlation between spacecraft position and velocity and the variables listed in the left hand column; they are obtained by converting P, C_{xx_s}, and C_{xv} into the corresponding correlation matrices and standard deviations. The second group represents the correlation between the solve-for parameters and the variables listed in the left hand column; they are obtained by converting P_s and $C_{x_s v}$ into the corresponding correlation matrices and standard deviations.

(12) Correlation matrix partitions and standard deviations at time t_k, just after processing the measurement. See (11) above for definitions of the two groups of matrix partitions.

7.2.3 Eigenvector Event Output

At an eigenvector event the following information is printed:

(1) Name of event and event time t_{ev}.

(2) Spacecraft position/velocity state vector at event time t_{ev} in inertial, heliocentric, and rotating geocentric coordinates.

(3) State transition matrix Φ, over the time interval $[t_{k-1}, t_{ev}]$, where t_{k-1} is the time of the most recent measurement or event.

(4) Diagonal of dynamic noise covariance matrix Q; represents unmodeled accelerations over the time interval $[t_{k-1}, t_{ev}]$.

(5) Propagated covariance matrix components and the total covariance matrix at t_{ev}.

(6) Correlation matrix partitions and standard deviations at event time t_{ev} propagated forward from time t_{k-1}. See article (11) under measurement output for definitions of the two groups of matrix partitions.

(7) Spacecraft position and velocity eigenvalues, square roots of eigenvalues, and eigenvectors at event time.

7.2.4 Prediction Event Output

At a prediction event the following information is printed:

(1) Name of event, event time t_{ev}, and time t_p to which prediction is being made.

(2) Articles (2) through (6) under eigenvector event output.

(3) State transition matrix partitions Φ, over the time interval $[t_{ev}, t_p]$.

(4) Diagonal of dynamic noise covariance matrix Q; represents unmodeled accelerations over the time interval $[t_{ev}, t_p]$.

(5) Propagated covariance matrix components and total covariance matrix at t_p.

(6) Correlation matrix partitions and standard deviations at time t_p based on prediction from time t_{ev}. See article (11) under measurement output for definitions of the two groups of matrix partitions.

(7) Spacecraft position and velocity eigenvalues, square root of eigenvalues, and eigenvectors at time t_p.

7.2.5 Output Preceding All Types of Guidance Events

At any guidance event the following information is printed:

(1) Articles (1) through (7) under eigenvector event output.

(2) State transition matrix partitions over the time interval $[t_g, t_{ev}]$, where t_g is the time of the previous guidance event ($t_g = t_o$ if no guidance event has occurred previously).

(3) Diagonal of dynamic noise covariance matrix Q; represents unmodeled accelerations over the time interval $[t_g, t_{ev}]$.

(4) Propagated control covariance matrix components and total control covariance matrix at t_{ev}, based on conditions just after the event at t_g.

(5) Control correlation matrix partitions and standard deviations at time t_{ev}, just before the guidance correction is applied. See article (11) under measurement output for definitions of the two groups of matrix partitions. Eigenvalues and eigenvectors are also printed.

7.2.6 Linear Midcourse Guidance Event Output

Two midcourse guidance policies are available: fixed-time-of-arrival (FTA) and variable-time-of-arrival (VTA).

(1) State transition matrix over the time interval $[t_{ev}, t_F]$ where t_F is the final time.

(2) Guidance policy and variation matrix η relating position/velocity deviations at time t_{ev} to target condition deviations.

(3) Target condition correlation matrix and standard deviations (covariance matrix W^-) immediately prior to guidance correction, together with eigenvalues and eigenvectors.

(4) Guidance matrix Γ used to compute the velocity correction required to null out target condition deviations.

(5) Velocity correction correlation matrix and standard deviations (covariance matrix S).

(6) The ΔV statistics: the eigenvalues of S, the trace of S and its square root, the eigenvalue ratios, the eigenvectors of S, the mean and standard deviation of the ΔV maneuver, and the values of required ΔV corresponding to 90, 99, 99.9, and 99.99 percentiles.

(7) Expected value of the effective velocity correction (a vector).

(8) The execution error model: σ^2_{pro}, σ^2_{res}, σ^2_α, σ^2_β.

(9) The execution error correlation matrix and standard deviations (covariance matrix $\tilde{Q}$).

(10) Control (and knowledge) correlation matrix partitions and standard deviations just after the guidance correction at time t_{ev}, together with eigenvalues and eigenvectors.

(11) Target condition correlation matrix and standard deviations (covariance matrix W^+) just after guidance correction is applied, together with eigenvalues and eigenvectors.

7.2.7 Final Insertion Guidance Event Output

(1) Final insertion type: impulsive or finite burn.

(2) If impulsive:

  (a) Final insertion ΔV in coordinates (from input).

  (b) Execution error model: σ^2_{pro}, σ^2_{res}, σ^2_{α}, σ^2_{β}.

  (c) Execution error correlation matrix and standard deviations, its eigenvalues and eigenvectors.

(3) If finite burn: execution error standard deviations and correlation matrix from the covariance matrix $\tilde{Q} = \theta U_o \theta^T$ where θ is the control-to-state transition matrix, and U_o is the diagonal input covariance matrix of thrust control parameters, with diagonal elements σ^2_{α}, σ^2_{β}, σ^2_{T}.

(4) The control correlation matrix partitions and standard deviations just after final insertion. The position and velocity partition eigenvalues and eigenvectors.

(5) The knowledge correlation matrix partitions and standard deviations just after final insertion. The position and velocity partition eigenvalues and eigenvectors.

7.2.8 Additional Generalized Covariance Output

The generalized covariance mode of ERRAN generates additional data which are output in conjunction with the normal output data at measurement and event times. The additional input data are also listed in the input data block. For each of the output data blocks described in sections 7.2.1 through 7.2.7 the additional generalized covariance output is listed below:

(1) Input data output:

  (a) Namelist GENRAL (if IGRPR $\neq$ 0)

  (b) Ignore parameters are listed with the other augmentation parameters

  (c) Initial position/velocity, solve-for, measurement-consider, and ignore parameter deviation means

  (d) Initial actual covariance matrix partitions

  (e) Definition of structure of augmented actual covariance matrix

  (f) Actual dynamic noise and measurement variances

(2) Measurement output:

  (a) Observation matrix N, relating deviations in the ignore parameters to the observables

  (b) Actual dynamic and measurement noises

  (c) Actual measurement residual mean and second moment matrix

  (d) Actual estimate error means and correlation matrix partitions just before and just after processing the measurement

(3) Guidance event output: Generalized covariance analysis information relating to the execution of the guidance event is printed immediately after the standard ERRAN guidance event information has been printed. This standard guidance event output, which is described in the ERRAN output description, comprises the assumed guidance data in contrast to the actual guidance data generated by the generalized covariance analysis. The generalized covariance analysis guidance event output for a midcourse guidance event follows.

(a) Actual propagated control covariance matrix components and the total actual control covariance matrix at t_{ev}.

(b) Actual position/velocity and solve-for parameter deviation means just before the guidance correction.

(c) Actual control correlation matrix partitions and standard deviations just before the guidance correction.

(d) Eigenvalues and eigenvectors of the position and velocity partitions of the actual position/velocity control covariance matrix.

(e) Actual target state deviation mean, $E[\delta\tau']$, just before the guidance correction.

(f) Actual target condition correlation matrix and standard deviations just before the guidance correction (2nd moment matrix W'^{-}).

(g) Eigenvalues and eigenvectors of actual target condition covariance matrix.

(h) Actual velocity correlation 2nd moment matrix S'.

(i) Actual velocity correction second moment matrix S', the expected mean velocity correction, and the ΔV statistics as described in section 7.2.6 articles (6) and (7).

(j) Actual statistical, or effective, velocity correction, "$E[\Delta V']$".

(k) Actual execution error mean, $E[\delta\Delta V']$.

(l) Actual execution error correlation matrix and standard deviation (2nd moment matrix Q').

(m) Actual position/velocity deviation means just after the guidance correction.

(n) Actual position/velocity estimation error means just after the guidance correction.

(o) Actual control (and knowledge) correlation matrix partitions and standard deviations just after the guidance correction.

(p) Eigenvalues and eigenvectors of the position and velocity partitions of the actual position/velocity control (and knowledge) covariance matrix.

(q) Actual target state deviation mean, $E[\delta\tau'^{+}]$, just after the guidance correction.

(r) Actual target condition correlation matrix and standard deviations just after the guidance correction (2nd moment matrix W'^{+}).

(s) Eigenvalues and eigenvectors of actual target condition covariance matrix.

7.3 ERRAN Sample Case Description

Two error analysis cases performed by the error analysis program ERRAN will be described in this section to illustrate the operation and versatility of ERRAN. The two cases to be discussed are:

Case E-1. Short (36 day) transfer time mission to the L_1 point with finite burn insertion.

Case E-2. Long (118 day) transfer time mission to the L_2 point with impulsive insertion and generalized covariance analysis.

7.3.1 Thirty-Six Day Mission to L_1

a) Input Data

Table 7.1 is a copy of the input data for this case. The trajectory and state transition matrix information for this case is all contained on the trajectory file generated by the corresponding NOMNAL case.

The IAUGIN array defines the parameter augmentation for this run, and indicates that there are nine consider parameters - the three station location parameters for each of the three tracking stations. The errors for these quantities are input in the VO array and are in a spherical coordinate system corresponding to the station location parameters (radius, latitude, longitude). The actual values used are consistent with a set of station location errors in the cylindrical co-ordinate system (radius from Earth spin-axis (r_s), longitude (λ) and z-height (z)). The uncertainties are $\sigma_{r_s} = 4.05$ meters, $\sigma_\lambda = 3.70$ meters, $\sigma = 10.0$ meters, and a correlation between station longitudes of $\rho_{\lambda\lambda} = .9$.

The number of entries in the measurement schedule, given in Table 7.1, is specified by NENT.

The first row of the measurement schedule indicates that range-rate measurements from Station 1 will be taken once a day beginning at .042 days and ending at 1.0 days (so only the single measurement at .042 days is made). The other rows are interpreted in similar fashion. The measurements are seen to divide into three groups. The first group is eleven measurements, once an hour from one hour through eleven hours after injection prepatory to a midcourse maneuver at 12 hours. The second and third groups are similarly prepatory to midcourses at 5 and 31 days respectively.

The variables NEV1 and T1 indicate that an eigenvector event will occur at 26 days, while NEV2, T2 and TPT2 indicate that a prediction event

```
&ERRAN
 P(1,1)=.284,.174,-.115,2.27D-4,2.002D-4,-1.313D-4,
 P(2,2)=2.9,.072,-1.5439D-3,4.1711D-3,5.98D-5,
 P(3,3)=2.283,-2.865D-4, 1.727D-4, 2.5351D-3,
 P(4,4)=1.96450D-3, -1.1801D-3, -1.788D-4,
 P(5,5)=7.881D-4,-2.847D-4,
 P(6,6)=2.65030D-3,
 V0(1,1)=4.4432984D-5,  V0(1,2)=6.1946257D-9,  V0(2,1)=6.1946257D-9,
 V0(2,2)=1.7730911D-12,  V0(3,3)=5.0741364D-13,  V0(3,6)=4.8902881D-13,
 V0(3,9)=4.5625977D-13,  V0(4,4)=5.1542894D-5,  V0(4,5)=6.4769909D-9,
 V0(5,4)=6.4769909D-9,  V0(5,5)=1.5979264D-12,  V0(6,6)=5.8186433D-13,
 V0(6,9)=4.8858708D-13,  V0(6,3)=4.8902881D-13,  V0(7,7)=4.4332462D-5,
 V0(7,8)=-6.1890988D-9,  V0(8,7)=-6.1890988D-9,  V0(8,8)=1.7755676D-12,
 V0(9,9)=5.0649737D-13,  V0(9,3)=4.5625977D-13,  V0(9,6)=4.8858708D-13,
 NENT=21,
 MNCN(4)=1.66666667D-14,
 MNCN(6)=1.66666667D-14,
 MNCN(8)=1.66666667D-14,
 IYR=1974,  IMO=8,  IDAY=14,  IHR=16,  IMIN= 8,  SECI=34,
 NEV1=1,  T1=26.,
 NEV2=1,  T2=1.5,  TPT2=5.,
 NEV3=3,  T3=.5,5.,31.,
 SIGRES=1.D-10,  SIGPRO=1.D-4,  SIGALP=3.43D-4,  SIGBET=3.43D-4,
 ICDT3=1,1,1,
 NEV4=1,  T4=34.54719013,  BRNTIM=1.45280987, IPRINT=10,
 IAUGIN=9*1,
 U0(1,1)=3.43D-4, U0(2,2)=3.43D-4, U0(3,3)=1.D-4,
&END
.042     1.        1.                  3
.083     1.        1.                  3
.125     1.        1.                  3
.167     1.        1.                  3
.208     1.        1.                  3
.25      1.        1.                  7
.292     1.        1.                  7
.333     1.        1.                  7
.375     1.        1.                  7
.417     1.        1.                  7
.458     1.        1.                  7
.6       4.6       1.                  7
.8       4.6       1.                  5
1.0      4.6       1.                  3
1.2      4.6       1.                  3
1.4      4.6       1.                  7
25.0     30.5      1.                  3
25.2     30.5      1.                  3
25.4     30.5      1.                  7
25.6     30.5      1.                  5
25.8     30.5      1.                  5
```

Table 7-1.   ERRAN Input Data Case E-1

will occur at 1.5 days and predict to 5.0 days. Three guidance events are scheduled at 0.5, 5.0 and 31.0 days as indicated by NEV3 and T3. The ICDT3 array specifies that all three maneuvers are fixed time of arrival (FTA). The values of NEV4, T4 and BRNTIM indicate that there is a finite burn insertion maneuver, when it begins and its duration.

The spacecraft injection covariance matrix is given by P and is similar to a typical Delta TE-364-4 injection covariance for a RAE-B mission. No initial correlations are assumed so that the initial value of CXV is zero. The measurement noise statistics for this case are given by the MNCN array. The values of SIGRES, SIGPR0, SIGALP, SIGBET and VO specify the execution error statistics for the impulsive midcourse maneuvers and finite burn insertion maneuver respectively. The code IPRINT indicates that every tenth measurement will be printed out. All other variables take on their internally specified values.

b) Discussion

The mission analyzed here is a 36 day transfer from Earth parking orbit to insertion at the Earth-Sun L_1 point using a finite burn. Given the large injection errors inherent in a Delta TE-364-4 launch, the first midcourse maneuver must be performed almost as early as possible. The first maneuver is scheduled for 12 hours after injection. The expected value of the maneuver is about 27 meters/sec but fuel for a maneuver of about 85 meters/sec must be loaded to allow for all but the worst one per cent of possible maneuvers. Due to the assumed execution errors (1% proportionality and 1.5 deg pointing) and the size of the first maneuver, sizable execution errors occur which are removed by the second midcourse planned at five days. The expected value of this maneuver is less the one meter/sec, with the 99 percentile value about 2.7 meters/sec. The third midcourse is scheduled five days before arrival at the L_1 point and is much less than one meter/sec in size.

The final insertion burn is modeled as a finite burn and is about 1.453 days long. Given the length of the burn and its size (effective ΔV = 374 meters/sec) the uncertainties in spacecraft control and knowledge after insertion, are totally dominated by the execution errors, with resulting RSS position errors of 582 kilometers and RSS velocity errors of 9.53 meters/sec.

7.3.2 One hundred and Eighteen Day Mission to L_2

a) Input Data

Table 7.2 is a copy of the input data for this case. Many variables are quite similar to the corresponding ones in the previous case and so will not be discussed. Again three midcourses are planned at 0.5, 5.0 and 113.0 days, the last one being arrival minus 5 days. For this case the ICDT3 array specifies that the first maneuver is to be fixed time of arrival (FTA), while the last two will be variable time of arrival (VTA). The values of NEV4 and T4 with the absence of a value for BRNTIM (default value = 0.) indicate that the final insertion event is to be impulsive with value of the ΔV given by REXV.

```
&ERRAN
 IPROB=118,
 P(1,1)=2.9,.174,.073,4.1711D-3,-1.5439D-3,5.98D-5,
 P(2,2)=.284,-.115,2.002D-4,2.27D-4,-1.313D-4,
 P(3,3)=2.283,1.727D-4,-2.865D-4,2.5351D-3,
 P(4,4)=7.881D-4,-1.1801D-3,-2.847D-4,
 P(5,5)=1.9645D-3,-1.788D-4.
 P(6,6)=2.6503D-3,
 V0(1,1)=4.4432984D-5,  V0(1,2)=6.1946257D-9,  V0(2,1)=6.1946257D-9,
 V0(2,2)=1.77309110-12,  V0(3,3)=5.0741364D-13,  V0(3,6)=4.8902881D-13,
 V0(3,9)=4.5625977D-13,  V0(4,4)=5.1542894D-5,  V0(4,5)=6.4769909D-9,
 V0(5,4)=6.4769909D-9,  V0(5,5)=1.5979264D-12,  V0(6,6)=5.8186433D-13,
 V0(6,9)=4.8858708D-13,  V0(6,3)=4.8902881D-13,  V0(7,7)=4.4332462D-5,
 V0(7,8)=-6.1890988D-9,  V0(8,7)=-6.1890988D-9,  V0(8,8)=1.7755676D-12,
 V0(9,9)=5.0649737D-13,  V0(9,3)=4.5625977D-13,  V0(9,6)=4.8858708D-13,
 NENT=21,
 MNCN(4)=1.66666667D-14,
 MNCN(6)=1.66666667D-14,
 MNCN(8)=1.66666667D-14,
 IYR=1974,  IMO=11,  IDAY=4,  IHR=22,  IMIN=21,  SECI=3.,
 NEV1=1,  T1=108.,
 NEV2=1,  T2=1.5,  TPT2=5.,
 NEV3=3,  T3=.5,5.,113.,
 SIGRES=1.D-10,  SIGPRO=1.D-4,  SIGALP=3.43D-4,  SIGBET=3.43D-4,
 ICOT3=1,2,2,
 REXV(1)=.015965, -.285378, -.037971,
 NEV4=1,  T4=118., IPRINT=10,
 IGEN=1,
 IAUGIN=9*1,
&END
.042      1.       1.                5
.083      1.       1.                5
.125      1.       1.                5
.167      1.       1.                5
.208      1.       1.                5
.25       1.       1.                5
.292      1.       1.                5
.333      1.       1.                3
.375      1.       1.                3
.417      1.       1.                3
.458      1.       1.                3
.6        4.6      1.                3
.8        4.6      1.                7
1.0       4.6      1.                5
1.2       4.6      1.                5
1.4       4.6      1.                3
107.      112.5    1.                7
107.2     112.5    1.                5
107.4     112.5    1.                5
107.6     112.5    1.                3
107.8     112.5    1.                7
&GENRAL
 GV(1,1)=4.4432984D-3,  GV(1,2)=6.1946257D-7,  GV(2,1)=6.1946257D-7,
 GV(2,2)=1.77309110-10,  GV(3,3)=5.0741364D-11,  GV(3,6)=4.8902881D-11,
 GV(3,9)=4.5625977D-11,  GV(4,4)=5.1542894D-3,  GV(4,5)=6.4769909D-7,
 GV(5,4)=6.4769909D-7,  GV(5,5)=1.5979264D-10,  GV(6,6)=5.8186433D-11,
 GV(6,9)=4.8858708D-11,  GV(6,3)=4.8902881D-11,  GV(7,7)=4.4332462D-3,
 GV(7,8)=-6.1890988D-7,  GV(8,7)=-6.1890988D-7,  GV(8,8)=1.7755676D-10,
 GV(9,9)=5.0649737D-11,  GV(9,3)=4.5625977D-11,  GV(9,6)=4.8858708D-11,
&END
```

Table 7-2. ERRAN Input Data Case E-2

The flag IGEN indicates that this is to be a generalized covariance run with the GENRAL namelist indicating that all actual parameters will have the same values as the assumed parameters with the exception of the station location errors whose actual standard deviations are ten times the size of the assumed ones.

b) Discussion

The mission considered here is a 118 day transfer from Earth park-int orbit to insertion at the Earth-Sun L_2 point using an impulsive burn. The first midcourse in this case is far larger than the corresponding one for the previous case, primarily it is believed, due to an unrealistically oriented injection covariance. For this reason the subsequent maneuvers are also larger although this is due also to the longer propagation arcs involved.

Of greatest interest in this run however is the use of the generalized covariance option. The actual station location errors are taken to be ten times larger than the assumed errors, which lead to actual knowledge uncertainties larger by a factor of two or three than the assumed knowledge. As soon as the guidance maneuver is performed, however, the execution errors are dominant and must be tracked out. At the second guidance event the difference between actual and assumed is a factor of six to ten, indicating that now the dominant limiting factor in the knowledge is the station location errors. At the third guidance event the significant error source for knowledge is seen to be the station location errors, which however is dominated by execution errors. The execution errors of the final insertion ΔV amount to about 8.1 meters/sec and thus are the dominant final error source.

8. REFERENCES

[1] Lee, B.G., et al: Interplanetary Trajectory Error Analysis, Final Report for Contract NAS8-21120, MMC Report MCR-67-441, December, 1967.

[2] Lee, B.G., et al: Space Trajectories Error Analyses Programs, Final Report for Contract NAS1-8745, NASA CR-66818, August, 1969.

[3] Vogt, E. D., et al: Space Trajectories Error Analyses Programs Version II, Final Report for Contracts NAS5-11795 and -11873, MCR-71-4, December, 1971.

[4] Hong, P., et al: Low Thrust Orbit Determination Program, Final Report for Contract NAS1-11686, NASA CR-112256, December, 1972.

[5] Hong, P., et al: Mission Analysis Program for Solar Electric Propulsion, Final Report for Contract NAS8-29666, MMC Report MCR-74-82, March, 1974.

[6] Lee, G. and Boain, R.: Propellant Requirements for Midcourse Velocity Corrections, Journal of Spacecraft and Rockets, Vol. 10, No. 12, December, 1973.

[7] Hoffman, L. and Young, G.: Approximation to the Statistics of Midcourse Velocity Corrections, NASA TN D-5381.

[8] Pu, C. L. and Edelbaum, T. N.: Four-Body Trajectory Optimization, Final Report on NGR 22-009-207, Draper Laboratory, Inc., R-778, December, 1973.

[9] Farquhar, R. W.: Future Missions for Libration-Point Satellites, Astronautics and Aeronautics, May, 1969.

[10] Battin, R. H.: Astronautical Guidance, McGraw-Hill Publishing Co., 1964.

[11] Lancaster, E. R. and Blanchard, R. C.: A Unified Form of Lambert's Theorem, NASA Technical Note D-5368.

APPENDIX A

Selected Sample Output from NOMNAL

CASE N-1

Short (36 day) Transfer Time Mission to the L_1 Point with Finite Burn Insertion

```
*******************************************************************************************************************************
                                                  INITIAL CONDITIONS (FROM TABLE)
                                                         TRAJECTORY DATA
*******************************************************************************************************************************

       INJECTION DATE       2442238.172 -  7/ 9/1974 16. 8. 0
       FLIGHT DURATION           36.000
       ARRIVAL DATE         2442274.172 -  8/14/1974 16. 8. 0
       LIBRATION POINT                1
       STATE AT L-POINT    -0.11812405D+07   0.95175934D+06   0.48683577D+01
                           -0.95730175D-01   0.96600899D-01   0.43646213D-06
       CENTRAL BODY        EARTH
       NO. OF BODIES       2
       BODY NO 1           EARTH
       BODY NO 2           SUN
```

```
****************************************************************************************************
                                         L1-LIBRATION POINT TRAJECTORY TARGETING
                                                   ITERATION NUMBER    1
                                           NEWTON-RAPHSON TARGETING ALGORITHM
****************************************************************************************************

      TARGETING EVENT AT JULIAN DATE          2442274.172223

      DESIGNATED TARGET TIME AT JULIAN DATE          2442239.172223

      SPACECRAFT STATE VECTOR AT INITIAL JULIAN DATE
           X-COMP              Y-COMP              Z-COMP              VX-COMP             VY-COMP             VZ-COMP

  GEO-EC -0.118124051819D+07  0.951759335586D+06  0.486835767916D+01 -0.957301745178D-01  0.966008989948D-01  0.436462125923D-06

  GEO-EQ -0.118124051819D+07  0.873198318462D+06  0.378643010676D+06 -0.957301745178D-01  0.886271993807D-01  0.384311490425D-01

      SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
           X-COMP              Y-COMP              Z-COMP              VX-COMP             VY-COMP             VZ-COMP

  GEO-EC -0.892117634421D+05  0.132928602602D+06  0.738279422106D+00 -0.150947323513D+01  0.145290360784D+01  0.843275107926D-05

  GEO-EQ -0.892117634421D+05  0.121956261252D+06  0.528836811471D+05 -0.150947323513D+01  0.133297626911D+01  0.578016573921D+00

  CONTROL VARIABLES     TARGET VARIABLES          ACTUAL TARGET VALUES          TARGET ERROR          TARGET TOLERANCES
        VX                    RCA              0.628476866058D+04 (  KM)     0.275231339418D+03     0.100000000000D+01
        VY                    ICA              0.234428903691D+02 ( DEG)     0.487510963093D+01     0.100000000000D-02
        VZ                    TCA              0.244223756519D+07 ( DAY)     0.607031926047D+00     0.100000000000D-04


  DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
    0.259270688670D+00  0.245118272295D+00  0.106289884410D+00 -0.234924557420D+05 -0.146887207376D+05 -0.636941905288D+04
    0.827904855782D-09 -0.484363263038D-03  0.111700253744D-02 -0.489303388918D-04  0.286264707280D+02 -0.660159927207D+02
    0.104549101473D-05 -0.458554218745D-05 -0.198841896050D-05 -0.356370026655D-02  0.189688981134D+00  0.822544017140D-01

  STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT LIBRATION POINT)
    0.470727472358D+01 -0.402337713884D+01 -0.224524573942D-04 -0.756633560466D+07  0.587402418692D+07  0.323447888962D+02
   -0.479810023691D+01  0.410129070966D+01  0.228578551154D-04  0.671895270621D+07 -0.715000365310D+07 -0.333727146090D+02
   -0.269793167601D-04  0.230388247469D-04 -0.110976452132D-01  0.378781442262D+02 -0.341879436952D+02 -0.103562856270D+07
   -0.285308440991D-04  0.252645108204D-04  0.140511790488D-09  0.399105738428D+02 -0.440943634149D+02 -0.242141671310D-03
    0.418231830969D-04 -0.348872213430D-04 -0.199379586379D-09 -0.646113836799D+02  0.539927231782D+02  0.334283687332D-03
    0.235872530691D-09 -0.202086444704D-09  0.893745733473D-06 -0.364055622254D-03  0.342916067041D-03 -0.670515111417D+01

  TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
   -0.697708348511D+05 -0.215865485341D+06 -0.981140903491D+00
   -0.764598965472D-02  0.102070756144D-01 -0.778404019097D+03
   -0.549935020567D+02  0.531980884856D+02  0.290636817341D-03

  TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
   -0.341388169390D-05 -0.869242455792D-09 -0.138527388807D-01
   -0.352909879463D-05  0.612001826994D-06  0.447740478271D-02
   -0.127430921448D-10 -0.128467990324D-02  0.194782020180D-06

  PREDICTED CONTROL CHANGES
       CONTROL VARIABLE                 CHANGE
             VX                  -0.934866623266D-02
             VY                   0.174664889652D-02
             VZ                  -0.626284063736D-02


  UPDATED INITIAL EC-STATE VECTOR
    X-COMP              Y-COMP              Z-COMP              VX-COMP             VY-COMP             VZ-COMP
```

```
 -0.118124051819D+07  0.951759335586D+06  0.486835767916D+01 -0.105078840750D+00  0.983475378913D-01 -0.626240417523D-02

TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  1 ITERATIONS
     CONTROLS VARIABLES                   TOTAL CHANGE
             VX                       -0.934866623266D-02
             VY                        0.174663889652D-02
             VZ                       -0.626284063736D-02
```

```
*******************************************************************************************************************************
                                                L1-LIBRATION POINT TRAJECTORY TARGETING
                                                       ITERATION NUMBER   2
                                                NEWTON-RAPHSON TARGETING ALGORITHM
*******************************************************************************************************************************

     SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
             X-COMP                Y-COMP                Z-COMP                VX-COMP               VY-COMP               VZ-COMP

  GEO-EC  0.791864818589D+04  0.831197652174D+04  0.112061267054D+04 -0.884522276085D+00  0.825322561806D+01  0.642113881668D+00

  GEO-EQ  0.791864818589D+04  0.718008493817D+04  0.433487101722D+04 -0.884522276085D+00  0.731654470440D+01  0.387249488977D+01

  CONTROL VARIABLES      TARGET VARIABLES          ACTUAL TARGET VALUES          TARGET ERROR           TARGET TOLERANCES
        VX                     RCA                0.665090986846D+04 (  KM)   -0.909098684587D+02     0.100000000000D+01
        VY                     ICA                0.283727692584D+02 ( DEG)   -0.542692583524D-01     0.100000000000D-02
        VZ                     ICA                0.244223815722D+07 ( DAY)    0.150006935000D-01     0.100000000000D-04


  DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
    0.128236136680D+01 -0.104691915632D+00  0.218405102839D-01 -0.143304798190D+04  0.507027995149D+03  0.184898837244D+03
   -0.714980675998D-04 -0.630619388088D-03  0.117513719890D-02 -0.296352557136D+00 -0.261385643740D+01  0.487083064465D+01
   -0.467406350896D-06 -0.827289851750D-06 -0.472390458294D-06 -0.709026675485D-03  0.225276997052D-02  0.116577556476D-02

  STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT LIBRATION POINT)
    0.271085576972D+01 -0.235705540691D+01 -0.175494244571D-01 -0.414794161358D+07  0.363910005397D+07  0.602233769677D+05
   -0.259833237848D+02  0.222540599782D+02  0.152948355192D+00  0.377307034193D+08 -0.366881922441D+08 -0.722243713532D+06
   -0.202040850782D+01  0.173126962641D+01 -0.120639023844D-01  0.293532586844D+07 -0.285045757040D+07 -0.236013039279D+06
    0.653604372230D-02 -0.560373212618D-02 -0.380831612498D-04 -0.954984477362D+04  0.916970299178D+04  0.183100147399D+03
    0.689658536647D-02 -0.589860630977D-02 -0.386819921974D-04 -0.996823377169D+04  0.977849439297D+04  0.209945304365D+03
    0.930317768938D-03 -0.795556950434D-03 -0.133861787553D-04 -0.134333293492D+04  0.132137650717D+04 -0.751129309253D+02

  TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
   -0.760797343132D+05 -0.219033057296D+00 -0.211115139614D+05
    0.261757316456D+02  0.862639420730D+02 -0.802438220688D+03
   -0.527832770399D+02  0.518106413174D+02  0.106882688600D+01

  TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
   -0.331589181406D-05  0.684149351697D-04 -0.141320710389D-01
   -0.336843906586D-05  0.951507285240D-04  0.490232140989D-02
   -0.470280100096D-06 -0.123374122339D-02  0.660191272687D-04

  PREDICTED CONTROL CHANGES
       CONTROL VARIABLE                  CHANGE
            VX                     0.857435946732D-04
            VY                     0.374598813829D-03
            VZ                     0.110697655924D-03


  UPDATED INITIAL EC-STATE VECTOR
    X-COMP              Y-COMP                Z-COMP              VX-COMP               VY-COMP               VZ-COMP
   -0.118124051819D+07  0.951759335586D+06  0.486835767916D+01 -0.104993097156D+00  0.987221367051D-01 -0.615170651931D-02

  TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  2 ITERATIONS
       CONTROLS VARIABLES                  TOTAL CHANGE
            VX                       -0.926292263798D-02
            VY                        0.212123771035D-02
            VZ                       -0.615214298144D-02
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*************************************************************************************************************************
                                        L1-LIBRATION POINT TRAJECTORY TARGETING
                                                  ITERATION NUMBER    3
                                          NEWTON-RAPHSON TARGETING ALGORITHM
*************************************************************************************************************************

      SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
             X-COMP                Y-COMP                Z-COMP                VX-COMP               VY-COMP               VZ-COMP

   GEO-EC  0.538524739561D+04 -0.374653513324D+04 -0.230082443867D+02  0.630330340638D+01  0.902546457783D+01  0.108155264060D+01

   GEO-EQ  0.538524739561D+04 -0.342813934622D+04 -0.151159369765D+04  0.630330340638D+01  0.785022029878D+01  0.458288208671D+01

   CONTROL VARIABLES      TARGET VARIABLES          ACTUAL TARGET VALUES          TARGET ERROR           TARGET TOLERANCES
          VX                    RCA              0.656031711498D+04 (  KM)    -0.317114981210D+00      0.100000000000D+01
          VY                    ICA              0.283176243412D+02 ( DEG)     0.375658849034D-03      0.100000000000D-02
          VZ                    TCA              0.244223817220D+07 ( DAY)     0.201119109988D-04      0.100000000000D-04


   DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
     0.819214399750D+00 -0.524637440873D+00 -0.231629114090D+00 -0.142351283830D+01  0.911641580387D+00  0.402492391913D+00
     0.225330937447D-03  0.200501719886D-02 -0.374440181066D-02 -0.239855923407D+00 -0.213426196492D+01  0.398576940717D+01
    -0.119630763619D-05 -0.149468465273D-05 -0.872351000907D-06 -0.102007583291D-02  0.657200752197D-03  0.290525417552D-03

   STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT LIBRATION POINT)
    -0.199286579995D+02  0.170070835709D+02  0.109591660595D+00  0.286778468229D+08 -0.283358688066D+08 -0.588440055685D+06
    -0.284324849667D+02  0.243202652493D+02  0.161143364213D+00  0.411948059634D+08 -0.401931080682D+08 -0.806357285381D+06
    -0.341051634820D+01  0.291581351126D+01  0.139304488609D-01  0.493115647318D+07 -0.483062913332D+07 -0.942362567515D+05
     0.243044510525D-01 -0.207535067602D-01 -0.133213938629D-03 -0.350566730580D+05  0.344818903906D+05  0.716460735619D+03
    -0.168489020943D-01  0.144199215719D-01  0.977452653658D-04  0.244661161171D+05 -0.237678546412D+05 -0.456290460265D+03
    -0.940892866951D-04  0.855060888503D-04 -0.209737866416D-04  0.161519927811D+03 -0.109997334229D+03 -0.175345403046D+03

   TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
    -0.756139075803D+05 -0.217555907471D+06 -0.207450791013D+05
     0.261253189274D+02  0.858395653853D+02 -0.807812933839D+03
    -0.527683940406D+02  0.517056351522D+02  0.104935552711D+01

   TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
    -0.333404973486D-05  0.972523153814D-04 -0.141399505981D-01
    -0.339307220783D-05  0.935119591750D-04  0.490836385686D-02
    -0.468379423545D-06 -0.122579862787D-02  0.642736701054D-04

   PREDICTED CONTROL CHANGES
         CONTROL VARIABLE                 CHANGE
                VX                   0.798159619060D-06
                VY                   0.120983920142D-05
                VZ                  -0.310659303265D-06


   UPDATED INITIAL EC-STATE VECTOR
     X-COMP                Y-COMP                Z-COMP                VX-COMP               VY-COMP               VZ-COMP
    -0.118124051819D+07  0.951759335586D+06  0.486835767916D+01 -0.104992298996D+00  0.987233465443D-01 -0.615201717861D-02

   TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  3 ITERATIONS
         CONTROLS VARIABLES                  TOTAL CHANGE
                VX                      -0.926212447836D-02
                VY                       0.212244754955D-02
                VZ                      -0.615245364074D-02
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*******************************************************************************************************************
                                             L1-LIBRATION POINT TRAJECTORY TARGETING
                                                       ITERATION NUMBER    4
                                               NEWTON-RAPHSON TARGETING ALGORITHM
*******************************************************************************************************************

       SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
             X-COMP             Y-COMP             Z-COMP              VX-COMP            VY-COMP            VZ-COMP

   GEO-EC  0.537403264589D+04 -0.376201463218D+04 -0.248864041699D+02  0.631679723246D+01  0.901636415155D+01  0.108160065071D+01

   GEO-EO  0.537403264589D+04 -0.344159396469D+04 -0.151947504356D+04  0.631679723246D+01  0.784185193008D+01  0.457930571022D+01

   CONTROL VARIABLES     TARGET VARIABLES        ACTUAL TARGET VALUES        TARGET ERROR          TARGET TOLERANCES
          VX                    RCA             0.656000002324D+04 (  KM)    -0.232361007075D-04     0.100000000000D+01
          VY                    ICA             0.283180000153D+02 ( DEG)    -0.153150239157D-07     0.100000000000D-02
          VZ                    ICA             0.244223817222D+07 ( DAY)     0.121071934700D-07     0.100000000000D-04


   CONVERGENCE HAS OCCURRED AFTER  4 ITERATIONS.
   THE TOTAL CHANGE TO THE CONTROL VARIABLES IS COMPUTED TO BE
        DELTA-  VX = -0.926212447836D-02
        DELTA-  VY =  0.212244754955D-02
        DELTA-  VZ = -0.615245364074D-02
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*************************************************************************************************************************************
                                                L1-LIBRATION POINT TRAJECTORY TARGETING
                                                         ITERATION NUMBER    1
                                                  NEWTON-RAPHSON TARGETING ALGORITHM
*************************************************************************************************************************************

      TARGETING EVENT AT JULIAN DATE          2442274.172223

      DESIGNATED TARGET TIME AT JULIAN DATE          2442238.172223

      SPACECRAFT STATE VECTOR AT INITIAL JULIAN DATE
              X-COMP               Y-COMP                Z-COMP               VX-COMP              VY-COMP              VZ-COMP

  GEO-EC -0.118124051819D+07  0.951759335586D+06  0.486835767916D+01 -0.182358565566D+00 -0.231188428946D+00 -0.957062046813D-05

  GEO-EQ -0.118124051819D+07  0.873199318462D+06  0.378643010676D+06 -0.182358565566D+00 -0.212102118477D+00 -0.919825043547D-01

      SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
              X-COMP               Y-COMP                Z-COMP               VX-COMP              VY-COMP              VZ-COMP

  GEO-EC -0.652294992003D+05  0.114222421417D+06  0.578180762622D+04 -0.160791054166D+01  0.169997304641D+01  0.514950956009D-01

  GEO-EQ -0.652294992003D+05  0.102494221965D+06  0.507456932069D+05 -0.160791054166D+01  0.153916942575D+01  0.723545148731D+00

  CONTROL VARIABLES     TARGET VARIABLES          ACTUAL TARGET VALUES          TARGET ERROR          TARGET TOLERANCES
      ALPH                   RCA                0.666085250572D+04 (  KM)     -0.100852505723D+03     0.100000000000D+01
      BETA                   ICA                0.282632241412D+02 ( DEG)      0.547758587951D-01     0.100000000000D-02
      TBRN                   ICA                0.244223771610D+07 ( DAY)      0.456123800483D+00     0.100000000000D-04


  NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY
      CONTROL VARIABLES       CONTROL VALUES
          ALPH               0.256802278574D+03
          BETA               0.103846980557D+01
          TBRN               0.125231790367D+06


  DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
    0.311966789392D+00  0.250255782058D+00  0.152784169940D+00 -0.207309700007D+05 -0.101935875199D+05 -0.671505823372D+04
   -0.749907625091D-04 -0.653539655181D-04  0.122359995710D-02  0.323535231351D+01  0.281958726560D+02 -0.527900872914D+02
    0.480877427666D-06 -0.418236387276D-05 -0.220437999051D-05  0.126564836006D-01  0.126901248684D+00  0.685551813755D-01

  STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT THRUST INITIATION)
    0.462318345746D+01 -0.408329585600D+01 -0.303902608798D-01 -0.722761424588D+07  0.591622604878D+07  0.947597047536D+05
   -0.511095564009D+01  0.453464696824D+01  0.335902845815D-01  0.704354457648D+07 -0.764193658139D+07 -0.108869512990D+06
   -0.152777657735D+00  0.135202914339D+00  0.113677761122D-02  0.220108424783D+06 -0.210108547196D+06 -0.943713896667D+06
   -0.344322636517D-04  0.316092537180D-04  0.245882923691D-06  0.463695334563D+02 -0.544868332724D+02 -0.109208658497D+01
    0.593985261740D-04 -0.516169651427D-04 -0.404595833660D-06 -0.888014351519D+02  0.793790518514D+02  0.171527344822D+01
    0.299872963401D-05 -0.266076261177D-05  0.104469111944D-05 -0.434799185411D+01  0.427709705274D+01 -0.822227922161D+01

  PARTIALS OF STATE VECTOR COMPONENTS AT THE END OF THE THRUST PHASE WRT THRUST CONTROLS
    0.370288061027D+03  0.157184508825D+01  0.0
   -0.869314580071D+02  0.671034721075D+01  0.0
   -0.175419812712D-04  0.380164765512D+03  0.0
   -0.576080672754D-02 -0.244185318476D-04  0.570686630453D-06
    0.135402424728D-02 -0.104369313469D-03  0.243357018309D-05
    0.821766297697D-09 -0.591174224745D-02 -0.453093124039D-07

  PARTIALS OF STATE VECTOR COMPONENTS AT THE TARGET TIME WRT THRUST CONTROLS
    0.517144788731D+05 -0.103286638349D+04  0.102685549915D+02
   -0.532105958258D+05  0.130436442419D+04 -0.145725994820D+02
   -0.162082006639D+04  0.559664675116D+04 -0.342941932631D+00
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 -0.356400109255D+00  0.112620747614D-01 -0.106085578327D-03
  0.645530770511D+00 -0.166634065396D-01  0.142418984081D-03
  0.321809248217D-01  0.486517829911D-01  0.829982085520D-05

TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
  0.175121141501D+03  0.148291407566D+03 -0.572709120324D+00
 -0.471409822252D-01  0.472149653704D+01  0.254606129424D-03
  0.364941858665D+00 -0.103004862066D-01  0.929837665881D-04

TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
  0.409571204304D-03 -0.731654585456D-02  0.254268040781D+01
  0.902335115950D-04  0.208927640134D+00 -0.163114787763D-01
 -0.159748559306D+01  0.518603439665D+02  0.773269060376D+03

PREDICTED CONTROL CHANGES
      CONTROL VARIABLE                 CHANGE
           ALPH                 0.111806999872D+01
           BETA                -0.509613852094D-02
           TBRN                 0.516657542408D+03


UPDATED THRUST CONTROLS FOR NEXT TRAJECTORY TARGETING ITERATION
      CONTROL VARIABLES       CONTROL VALUES
           ALPH             0.257920348573D+03
           BETA             0.103337366705D+01
           TBRN             0.125748447910D+06

TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  1 ITERATIONS
      CONTROLS VARIABLES                 TOTAL CHANGE
           ALPH                     0.111806999872D+01
           BETA                    -0.509613852094D-02
           TBRN                     0.516657542408D+03
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****************************************************************************************************
                                       L1-LIBRATION POINT TRAJECTORY TARGETING
                                                 ITERATION NUMBER    2
                                          NEWTON-RAPHSON TARGETING ALGORITHM
****************************************************************************************************

      SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
              X-COMP                Y-COMP                Z-COMP               VX-COMP               VY-COMP               VZ-COMP

   GEO-EC  0.445771128781D+04 -0.487046668035D+04 -0.155285224041D+03  0.731338030271D+01  0.817839385186D+01  0.108203447391D+01

   GEO-EQ  0.445771128781D+04 -0.440667679365D+04 -0.208008625338D+04  0.731338030271D+01  0.707287587238D+01  0.424633388852D+01

   CONTROL VARIABLES     TARGET VARIABLES          ACTUAL TARGET VALUES          TARGET ERROR          TARGET TOLERANCES
        ALPH                   RCA              0.653572011677D+04 (  KM)     0.242798832254D+02     0.100000000000D+01
        BETA                   ICA              0.283317269815D+02 ( DEG)    -0.137269814991D-01     0.100000000000D-02
        TBRN                   ICA              0.244223817363D+07 ( DAY)    -0.140697881579D-02     0.100000000000D-04

   NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY
        CONTROL VARIABLES        CONTROL VALUES
             ALPH               0.257920348573D+03
             BETA               0.103337366795D+01
             TBRN               0.125748447910D+06


   DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
     0.824537430864D+00 -0.550010771212D+00 -0.242797974553D+00  0.991270583745D+02 -0.657106842282D+02 -0.289685846490D+02
     0.281348181767D-03  0.240138720866D-04 -0.448441324361D-02 -0.215803697106D+00 -0.184194625769D+01  0.343969930049D+01
    -0.151126159521D-05 -0.118721249779D-05 -0.730563074319D-06 -0.117134735035D-02  0.501423052756D-03  0.195020889681D-03

   STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT THRUST INITIATION)
    -0.213368097623D+02  0.188398469664D+02  0.134423922506D+00  0.299598027212D+08 -0.307743394325D+08 -0.659608445785D+06
    -0.237816678205D+02  0.210395830803D+02  0.153425805294D+00  0.336344590275D+08 -0.340940977922D+08 -0.706049057379D+06
    -0.315039018700D+01  0.278552175145D+01  0.171504953567D-01  0.444228402412D+07 -0.452898611247D+07 -0.699174677268D+05
     0.182188381703D-01 -0.160830691030D-01 -0.113321131342D-03 -0.255836638924D+05  0.262689943245D+05  0.571104671733D+03
    -0.198409021526D-01  0.175493450164D-01  0.129045005085D-03  0.280593779509D+05 -0.284402298248D+05 -0.572419352613D+03
    -0.624991491708D-03  0.556694784077D-03 -0.143526378890D-04  0.906416820436D+03 -0.874800294851D+03 -0.192837508090D+03

   PARTIALS OF STATE VECTOR COMPONENTS AT THE END OF THE THRUST PHASE WRT THRUST CONTROLS
     0.375161099193D+03  0.144601682744D+01  0.0
    -0.803890549930D+02  0.676535648320D+01  0.0
    -0.177441793661D-04  0.383486987381D+03  0.0
    -0.581193499015D-02 -0.223656388903D-04  0.523093136146D-06
     0.124701088160D-02 -0.104781020063D-03  0.244424645534D-05
     0.827981844171D-09 -0.593819823296D-02 -0.450869877565D-07

   PARTIALS OF STATE VECTOR COMPONENTS AT THE TARGET TIME WRT THRUST CONTROLS
    -0.222019620926D+06  0.661953697576D+04 -0.595185631517D+02
    -0.248610309671D+06  0.717960583264D+04 -0.657085893962D+02
    -0.328717902857D+05  0.811247569907D+03 -0.874307760185D+01
     0.189576215679D+03 -0.569754991429D+01  0.507995078942D-01
    -0.207398866980D+03  0.589109434229D+01 -0.548114542634D-01
    -0.663814594330D+01  0.121385566633D+01 -0.165539264020D-02

   TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
     0.220576430349D+03  0.150082855974D+03 -0.564045918251D+00
    -0.666961311158D-01  0.481470042426D+01  0.259214646158D-03
     0.351658959625D+00 -0.102552556063D-01  0.934098277836D-04

   TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
     0.423188870826D-03 -0.770308816171D-02  0.257676000719D+01
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  0.910974076041D-04  0.204818605919D+00 -0.182942371065D-01
 -0.158317314515D+01  0.514863075930D+02  0.100280288288D+04

PREDICTED CONTROL CHANGES
     CONTROL VARIABLE                CHANGE
          ALPH                  0.675526977114D-02
          BETA                 -0.573967191308D-03
          TBRN                 -0.405569330942D+02


UPDATED THRUST CONTROLS FOR NEXT TRAJECTORY TARGETING ITERATION
     CONTROL VARIABLES      CONTROL VALUES
          ALPH             0.257927103843D+03
          BETA             0.103279969986D+01
          TBRN             0.125707890977D+06


TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  2 ITERATIONS
     CONTROLS VARIABLES                TOTAL CHANGE
          ALPH                    0.112482526849D+01
          BETA                   -0.567010571225D-02
          TBRN                    0.476100609314D+03
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*******************************************************************************************************
                                        L1-LIBRATION POINT TRAJECTORY TARGETING
                                                    ITERATION NUMBER    3
                                          NEWTON-RAPHSON TARGETING ALGORITHM
*******************************************************************************************************

     SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
            X-COMP                Y-COMP                Z-COMP               VX-COMP               VY-COMP               VZ-COMP

  GEO-EC  0.569166874494D+04 -0.330265367143D+04  0.426619736473D+02  0.598108889474D+01  0.922057102682D+01  0.109083735626D+01

  GEO-EQ  0.569166874494D+04 -0.304702185524D+04 -0.127475453759D+04  0.598108889474D+01  0.802552874452D+01  0.466901965028D+01

  CONTROL VARIABLES      TARGET VARIABLES          ACTUAL TARGET VALUES            TARGET ERROR            TARGET TOLERANCES
       ALPH                    RCA              0.656404744066D+04 (   KM)      -0.404744066025D+01        0.100000000000D-01
       BETA                    ICA              0.283161889400D+02 ( DEG)        0.181105996579D-02        0.100000000000D-02
       TBRN                    ICA              0.244223817153D+07 ( DAY)        0.692628789693D-03        0.100000000000D-04


  NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY
       CONTROL VARIABLES       CONTROL VALUES
            ALPH              0.257027103843D+03
            BETA              0.103279969986D+01
            TBRN              0.125707890977D+06


  DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
    0.814804565315D+00 -0.538475654422D+00 -0.237223196423D+00 -0.485839806906D+02  0.321321931742D+02  0.141580457257D+02
    0.217662428163D-03  0.186280654629D-04 -0.348978678178D-02 -0.261009400209D+00 -0.223378017526D+01  0.417397844054D+01
   -0.104406567159D-05 -0.157221306192D-05 -0.906686343622D-06 -0.944254954436D-03  0.761008879429D-03  0.348221038827D-03

  STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT THRUST INITIATION)
   -0.174546634559D+02  0.154140003006D+02  0.109905897630D+00  0.244943658774D+08 -0.251950666841D+08 -0.538802203002D+06
   -0.268131998814D+02  0.237266094527D+02  0.173109569152D+00  0.379219845532D+08 -0.384492387855D+08 -0.791442729256D+06
   -0.317484128481D+01  0.280843010889D+01  0.140381566480D-01  0.448055980029D+07 -0.456169357328D+07 -0.102392176958D+06
    0.234848903005D-01 -0.207530449436D-01 -0.147795916841D-03 -0.330688685155D+05  0.337950692586D+05  0.720980896554D+03
   -0.135777271968D-01  0.120232371732D-01  0.895967004053D-04  0.192729818565D+05 -0.194049195781D+05 -0.377365682478D+03
    0.184309641418D-03 -0.158856072209D-03 -0.182421860073D-04 -0.234433445588D+03  0.288925654399D+03 -0.169932402774D+03

  PARTIALS OF STATE VECTOR COMPONENTS AT THE END OF THE THRUST PHASE WRT THRUST CONTROLS
    0.374914851048D+03  0.144343308713D+01  0.0
   -0.802900082118D+02  0.675716141018D+01  0.0
   -0.176983060855D-04  0.383225732270D+03  0.0
   -0.581004608590D-02 -0.223330845231D-04  0.522805046142D-06
    0.124588746857D-02 -0.104688824147D-03  0.244430855347D-05
    0.826095660848D-09 -0.593612254093D-02 -0.450619477842D-07

  PARTIALS OF STATE VECTOR COMPONENTS AT THE TARGET TIME WRT THRUST CONTROLS
   -0.181485215651D+06  0.561011453789D+04 -0.487544594419D+02
   -0.280189579866D+06  0.806435324778D+04 -0.741203364031D+02
   -0.331313998975D+05  0.100508025269D+04 -0.880311335543D+01
    0.244707600268D+03 -0.724223918381D+01  0.652845167204D-01
   -0.142209096624D+03  0.393712218910D+01 -0.373385939027D-01
    0.180389281215D+01  0.975929648895D+00  0.591317945088D-03

  TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
    0.221188998386D+03  0.149951042207D+03 -0.565257620930D+00
   -0.663508070788D-01  0.480202067764D+01  0.257911399118D-03
    0.351516878685D+00 -0.102480204984D-01  0.934919863974D-04

  TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
    0.422769963419D-03 -0.770138493990D-02  0.257733553474D+01
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  0.906810358390D-04  0.205374959242D+00 -0.182945786684D-01
 -0.157961641975D+01  0.514680855339D+02  0.100367505553D+04

PREDICTED CONTROL CHANGES
     CONTROL VARIABLE                CHANGE
          ALPH                 0.600527817279D-04
          BETA                -0.775109679142D-05
          TBRN                 0.718178975309D+01


UPDATED THRUST CONTROLS FOR NEXT TRAJECTORY TARGETING ITERATION
     CONTROL VARIABLES       CONTROL VALUES
          ALPH              0.257927163895D+03
          BETA              0.103279194676D+01
          TBRN              0.125715072766D+06


TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  3 ITERATIONS
     CONTROLS VARIABLES                TOTAL CHANGE
          ALPH                    0.112488532127D+01
          BETA                   -0.567785680904D-02
          TBRN                    0.483282399067D+03
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************************************************************************************************************************************
                                              LI-LIBRATION POINT TRAJECTORY TARGETING
                                                         ITERATION NUMBER    4
                                                 NEWTON-RAPHSON TARGETING ALGORITHM
************************************************************************************************************************************

         SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
                 X-COMP              Y-COMP              Z-COMP              VX-COMP             VY-COMP             VZ-COMP

    GEO-EC  0.524716556519D+04 -0.393664026113D+04 -0.341896900941D+02  0.653215643703D+01  0.886055414206D+01  0.109212515994D+01

    GEO-EQ  0.524716556519D+04 -0.359810470808D+04 -0.159748176520D+04  0.653215643703D+01  0.769471565343D+01  0.452697559991D+01

    CONTROL VARIABLES     TARGET VARIABLES         ACTUAL TARGET VALUES         TARGET ERROR          TARGET TOLERANCES
         ALPH                  RCA               0.655928822081D+04 (  KM)      0.711779194192D+00     0.100000000000D+01
         BETA                  ICA               0.283183263116D+02 ( DEG)     -0.326311576920D-03     0.100000000000D-02
         TBRN                  ICA               0.244223817235D+07 ( DAY)     -0.122247729450D-03     0.100000000000D-04


    NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY
         CONTROL VARIABLES      CONTROL VALUES
              ALPH             0.257927163895D+03
              BETA             0.103279194876D+01
              TBRN             0.125715072766D+06


    DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
      0.810541668149D+00 -0.536204619918D+00 -0.236274944823D+00  0.856022510652D+01 -0.566289283051D+01 -0.249531364989D+01
      0.243293900052D-03  0.208137293336D-02 -0.388886626030D-02 -0.244807326268D+00 -0.209432023914D+01  0.391305807750D+01
     -0.125712697621D-05 -0.145279182547D-05 -0.856201207975D-06 -0.102396763613D-02  0.653256507143D-03  0.285570392127D-03

    STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT THRUST INITIATION)
     -0.190600190053D+02  0.168319664702D+02  0.120085490835D+00  0.267544693692D+08 -0.275041395061D+08 -0.588280482156D+06
     -0.257663653177D+02  0.227991840298D+02  0.166242581258D+00  0.364382825246D+08 -0.369492946728D+08 -0.762128941434D+06
     -0.317905046140D+01  0.281177899854D+01  0.152927984308D-01  0.448479868371D+07 -0.456911503683D+07 -0.901627597332D+05
      0.218667589920D-01 -0.193171318223D-01 -0.137057236533D-03 -0.307598200281D+05  0.314908145477D+05  0.675862931817D+03
     -0.163510056739D-01  0.144723794521D-01  0.107119158266D-03  0.231685378659D+05 -0.234035347149D+05 -0.462639988889D+03
     -0.133752217559D-03  0.122488972805D-03 -0.167847234046D-04  0.214411892607D+03 -0.168089444938D+03 -0.179693892759D+03

    PARTIALS OF STATE VECTOR COMPONENTS AT THE END OF THE THRUST PHASE WRT THRUST CONTROLS
      0.374960219527D+03  0.144358925495D+01  0.0
     -0.802993250025D+02  0.675792817757D+01  0.0
     -0.177044399853D-04  0.383272001088D+03  0.0
     -0.581040794329D-02 -0.223341847080D-04  0.522802485491D-06
      0.124595907671D-02 -0.104694552464D-03  0.244430910740D-05
      0.826335873453D-09 -0.593649029786D-02 -0.450616096338D-07

    PARTIALS OF STATE VECTOR COMPONENTS AT THE TARGET TIME WRT THRUST CONTROLS
     -0.198221758551D+06  0.590657547882D+04 -0.532148067363D+02
     -0.269250717013D+06  0.775953693069D+04 -0.712311300529D+02
     -0.331692417379D+05  0.933721339036D+03 -0.881960271942D+01
      0.227713686803D+03 -0.677368234356D+01  0.608615189626D-01
     -0.171071602318D+03  0.479448493333D+01 -0.450720565648D-01
     -0.151524082445D+01  0.107376195924D+01 -0.290670194696D-03

    TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
      0.221136677717D+03  0.149960580489D+03 -0.565051231518D+00
     -0.664266549062D-01  0.480417241631D+01  0.258101933168D-03
      0.351526468603D+00 -0.102482025002D-01  0.934789664488D-04

    TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
      0.422652333372D-03 -0.770137818962D-02  0.257727466908D+01
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  0.907413090242D-04  0.205280917396D+00 -0.182919567229D-01
 -0.158018277044D+01  0.514661091370D+02  0.100377957573D+04

PREDICTED CONTROL CHANGES
     CONTROL VARIABLE                  CHANGE
          ALPH                   -0.115754344947D-04
          BETA                   -0.161613873295D-06
          THRN                   -0.126424498025D+01


UPDATED THRUST CONTROLS FOR NEXT TRAJECTORY TARGETING ITERATION
     CONTROL VARIABLES       CONTROL VALUES
          ALPH              0.257927152340D+03
          BETA              0.103279178715D+01
          THRN              0.125713808521D+06


TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  4 ITERATIONS
     CONTROLS VARIABLES                  TOTAL CHANGE
          ALPH                       0.112487374583D+01
          BETA                      -0.567801842292D-02
          THRN                       0.482018154087D+03
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************************************************************************************************************************
                                             L1-LIBRATION POINT TRAJECTORY TARGETING
                                                      ITERATION NUMBER    5
                                               NEWTON-RAPHSON TARGETING ALGORITHM
************************************************************************************************************************

      SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
              X-COMP               Y-COMP                Z-COMP                VX-COMP               VY-COMP               VZ-COMP

   GEO-EC  0.532840019939D+04 -0.382664111115D+04 -0.206232593799D+02  0.643785515145D+01  0.892891296886D+01  0.109245730544D+01

   GEO-EQ  0.532840019939D+04 -0.350258212284D+04 -0.154127414342D+04  0.643785515145D+01  0.775729994307D+01  0.455447553106D+01

   CONTROL VARIABLES      TARGET VARIABLES         ACTUAL TARGET VALUES         TARGET ERROR           TARGET TOLERANCES
        ALPH                  RCA              0.656012543005D+04 (  KM)     -0.125430051208D+00      0.100000000000D+01
        BETA                  ICA              0.283179426799D+02 ( DEG)      0.573200852081D-04      0.100000000000D-02
        TBRN                  ICA              0.244223817220D+07 ( DAY)      0.215277541429D-04      0.100000000000D-04


   NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY
        CONTROL VARIABLES        CONTROL VALUES
             ALPH               0.257927152320D+03
             BETA               0.103279178715D+01
             TBRN               0.125713808521D+06


   DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
     0.810417314400D+00 -0.536120777415D+00 -0.236237746146D+00 -0.150736817341D+01  0.997181579805D+00  0.439400557298D+00
     0.238873417297D-03  0.204369552751D-02 -0.381852696721D-02 -0.247797311545D+00 -0.212004441307D+01  0.396118135648D+01
    -0.122169204242D-05 -0.147709585964D-05 -0.866973856120D-06 -0.100882998708D-02  0.671628123293D-03  0.296350051400D-03

   STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT THRUST INITIATION)
    -0.187852631576D+02  0.165893189024D+02  0.118360403158D+00  0.263678077788D+08 -0.271088359813D+08 -0.579786864496D+06
    -0.259651746858D+02  0.229752732224D+02  0.167543076919D+00  0.367198811447D+08 -0.372342765625D+08 -0.767734190902D+06
    -0.317993591550D+01  0.281262819981D+01  0.150788749844D-01  0.448634818031D+07 -0.457014506257D+07 -0.923703373638D+05
     0.222001178352D-01 -0.196127594862D-01 -0.139253880950D-03 -0.312345002891D+05  0.319663417945D+05  0.685293945003D+03
    -0.158898000196D-01  0.140651924496D-01  0.104213514356D-03  0.225212648285D+05 -0.227381036555D+05 -0.448377360660D+03
    -0.772804674811D-04  0.725464099291D-04 -0.170522031457D-04  0.134772395296D+03 -0.869035123402D+02 -0.178046064875D+03

   PARTIALS OF STATE VECTOR COMPONENTS AT THE END OF THE THRUST PHASE WRT THRUST CONTROLS
     0.374952231650D+03  0.144355974909D+01  0.0
    -0.802976914899D+02  0.675778318697D+01  0.0
    -0.177033352490D-04  0.383263856124D+03  0.0
    -0.581034422460D-02 -0.223339598766D-04  0.522802979340D-06
     0.124594657355D-02 -0.104693389009D-03  0.244430900190D-05
     0.826292408344D-09 -0.593642556243D-02 -0.450616025832D-07

   PARTIALS OF STATE VECTOR COMPONENTS AT THE TARGET TIME WRT THRUST CONTROLS
    -0.195357861782D+06  0.582143254828D+04 -0.524510772294D+02
    -0.271327630871D+06  0.781767196426D+04 -0.717802187845D+02
    -0.331795555164D+05  0.946811578388D+03 -0.882120816597D+01
     0.231210395995D+03 -0.687113363253D+01  0.617752467534D-01
    -0.166274082199D+03  0.465135185042D+01 -0.437845624980D-01
    -0.926153081880D+00  0.105688863357D+01 -0.133936586699D-03

   TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
     0.221145886834D+03  0.149958677353D+03 -0.565087547539D+00
    -0.664135235728D-01  0.480379346160D+01  0.258067906083D-03
     0.351524793618D+00 -0.102481553661D-01  0.934812573678D-04

   TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
     0.422837831251D-03 -0.770136813415D-02  0.257728528478D+01
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  0.907305665746D-04  0.205297482250D+00 -0.182922017111D-01
 -0.158008315871D+01  0.514663645328D+02  0.100376121899D+04

PREDICTED CONTROL CHANGES
     CONTROL VARIABLE                CHANGE
          ALPH                  0.200512006250D-05
          BETA                 -0.646045719844D-08
          TRRN                  0.222748693797D+00


UPDATED THRUST CONTROLS FOR NEXT TRAJECTORY TARGETING ITERATION
     CONTROL VARIABLES       CONTROL VALUES
          ALPH             0.257927154325D+03
          BETA             0.103279178059D+01
          TRRN             0.125714031270D+06


TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  5 ITERATIONS
     CONTROLS VARIABLES                TOTAL CHANGE
          ALPH                     0.112487575098D+01
          BETA                    -0.567802488337D-02
          TRRN                     0.482240902781D+03
```

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*************************************************************************************************************************************
                                               L1-LIBRATION POINT TRAJECTORY TARGETING
                                                          ITERATION NUMBER   6
                                                  NEWTON-RAPHSON TARGETING ALGORITHM
*************************************************************************************************************************************

         SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
                 X-COMP               Y-COMP              Z-COMP             VX-COMP             VY-COMP              VZ-COMP

    GEO-EC  0.531418102838D+04 -0.384607166752D+04 -0.230123032696D+02  0.645456186729D+01  0.891701992907D+01  0.109241628534D+01

    GEO-EQ  0.531418102838D+04 -0.351945842977D+04 -0.155119605430D+04  0.645456186729D+01  0.774640488461D+01  0.454970648718D+01

    CONTROL VARIABLES     TARGET VARIABLES          ACTUAL TARGET VALUES          TARGET ERROR           TARGET TOLERANCES
         ALPH                    RCA              0.655997792037D+04 (  KM)     0.220796308140D-01     0.100000000000D+01
         BETA                    ICA              0.283180100979D+02 ( DEG)    -0.100978788886D-04     0.100000000000D-02
         TBRN                    ICA              0.244223817223D+07 ( DAY)    -0.378955155611D-05     0.100000000000D-04

    NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY
         CONTROL VARIABLES       CONTROL VALUES
              ALPH              0.257927154325D+03
              BETA              0.103279178069D+01
              TBRN              0.125714031270D+06

    CONVERGENCE HAS OCCURRED AFTER  6 ITERATIONS.
    THE TOTAL CHANGE TO THE CONTROL VARIABLES IS COMPUTED TO BE
         DELTA-ALPH =  0.112487575098D+01
         DELTA-BETA = -0.567802488337D-02
         DELTA-TBRN =  0.482240902781D+03
```

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**********************************************************************************************************************
                                            LAUNCH PROFILE FOR TARGETING
                                                  TRAJECTORY DATA
**********************************************************************************************************************

      INJECTION DATE        2442238.171 -   7/ 9/1974 16. 6.24
      AZIMUTH              0.89750069D+02
      LS LONGITUDE         0.27945700D+03
      LS LATITUDE          0.28317000D+02
      BURN1 ANGLE          0.17000000D+02
      BURN2 ANGLE          0.80000000D+01
      LAUNCH TOD          -0.34401473D+00
      BURN1 DUR-SEC        0.50000000D+03
      COAST TIME-SEC       0.70729444D+03
      BURN2 DUR-SEC        0.10000000D+03
      INJECTION TOD       -0.32888401D+00
      INJECTION GHA        0.24163925D+06
      INJ DV (IN)         -0.24977997D+05
      STATE (ECL)          0.53141810D+04  -0.38460717D+04  -0.23012303D+02
                           0.64545619D+01   0.84170199D+01   0.10924163D+01
      ELEMENTS (ECL)       0.61894344D+06   0.98940132D+00   0.56709498D+01
                          -0.33970160D+02  -0.20028181D+01  -0.31634958D-01
      STATE (ECQ)          0.53141810D+04  -0.35194584D+04  -0.15511961D+04
                           0.64545619D+01   0.77464049D+01   0.45497065D+01
      ELEMENTS (ECQ)       0.61894344D+06   0.98940133D+00   0.28318010D+02
                          -0.66667366D+01  -0.29868150D+02  -0.31634958D-01
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****************************************************************************************************
                                LI-LIBRATION POINT TRAJECTORY TARGETING
                                         ITERATION NUMBER    1
                                    NEWTON-RAPHSON TARGETING ALGORITHM
****************************************************************************************************

     TARGETING EVENT AT JULIAN DATE        2442274.171116

     DESIGNATED TARGET TIME AT JULIAN DATE        2442238.171116

     SPACECRAFT STATE VECTOR AT INITIAL JULIAN DATE
             X-COMP             Y-COMP             Z-COMP               VX-COMP              VY-COMP              VZ-COMP

  GEO-EC -0.118122307017D+07  0.951781455220D+06  0.486927281792D+01 -0.182358565566D+00 -0.231188428946D+00 -0.957062046813D-05

  GEO-EQ -0.118122307017D+07  0.873218611958D+06  0.378651811373D+06 -0.182358565566D+00 -0.212102118477D+00 -0.919825043547D-01

     SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
             X-COMP             Y-COMP             Z-COMP               VX-COMP              VY-COMP              VZ-COMP

  GEO-EC   0.533464252349D+04 -0.381878805219D+04 -0.196176391704D+02  0.643077481944D+01  0.893350142472D+01  0.109240709440D+01

  GEO-EQ   0.533464252349D+04 -0.349577732952D+04 -0.153722734451D+04  0.643077481944D+01  0.776152963907D+01  0.455625489049D+01

  CONTROL VARIABLES     TARGET VARIABLES        ACTUAL TARGET VALUES         TARGET ERROR          TARGET TOLERANCES
     ALPH                  RCA              0.656059957937D+04 (  KM)    -0.599579370138D+00     0.100000000000D+01
     BETA                  ICA              0.283177235548D+02 ( DEG)     0.276445235123D-03     0.100000000000D-02
     TBRN                  TCA              0.244223817108D+07 ( DAY)     0.322021078318D-04     0.100000000000D-04

  NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY
     CONTROL VARIABLES       CONTROL VALUES
        ALPH                0.257927154325D+03
        BETA                0.103279178069D+01
        TBRN                0.125714031270D+06


  DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
    0.810410727115D+00 -0.536138704736D+00 -0.236245554944D+00 -0.225474812487D+01  0.149166290703D+01  0.657289942865D+00
    0.238536164760D-03  0.204080863204D-02 -0.381316792942D-02 -0.248022064849D+00 -0.212196573142D+01  0.396480757987D+01
   -0.121909122957D-05 -0.147887609288D-05 -0.867756049368D-06 -0.100783591120D-02  0.673106805320D-03  0.297200807528D-03

  STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT THRUST INITIATION)
   -0.187643055253D+02  0.165714832935D+04  0.118231390116D+00  0.263381559498D+08 -0.270797934447D+08 -0.579151339876D+06
   -0.259780581232D+02  0.229876227476D+02  0.167631349592D+00  0.367379429655D+08 -0.372542695206D+08 -0.768109762872D+06
   -0.317972767361D+01  0.281256335325D+01  0.150614094361D-01  0.448605149437D+07 -0.457001578949D+07 -0.925277757475D+05
    0.222205880966D-01 -0.196317239747D-01 -0.139392985623D-03 -0.312635345025D+05  0.319968019463D+05  0.685877736490D+03
   -0.158531864115D-01  0.140334315476D-01  0.103984436395D-03  0.224697243121D+05 -0.227686242826D+05 -0.467261134881D+03
   -0.730773261303D-06  0.688313688301D-04 -0.170708018749D-04  0.128841624580D+03 -0.808688252429D+02 -0.177911214329D+03

  PARTIALS OF STATE VECTOR COMPONENTS AT THE END OF THE THRUST PHASE WRT THRUST CONTROLS
    0.374953634784D+03  0.144356487314D+01  0.0
   -0.802979811705D+02  0.675780857831D+01  0.0
   -0.177034623879D-04  0.383265291269D+03  0.0
   -0.581035531694D-02 -0.223339978675D-04  0.522802893799D-06
    0.124594883150D-02 -0.104693592824D-03  0.244430902020D-05
    0.826294885806D-09 -0.593643697087D-02 -0.450616023013D-07

  PARTIALS OF STATE VECTOR COMPONENTS AT THE TARGET TIME WRT THRUST CONTROLS
   -0.195140483156D+06  0.581515338341D+04 -0.523956217468D+02
   -0.271463843475D+06  0.782170559835D+04 -0.718196318790D+02
   -0.331776526700D+05  0.947734353589D+03 -0.882104066389D+01
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  0.231426700567D+03 -0.687730545981D+01  0.618344985618D-01
 -0.165894046330D+03  0.464020679743D+01 -0.436847967789D-01
 -0.882301812456D+00  0.105556462107D+01 -0.122292660437D-03

TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
  0.221182182252D+03  0.149960180690D+03 -0.565106059388D+00
 -0.664188628908D-01  0.480358645750D+01  0.258047957790D-03
  0.351520487324D+00 -0.102483504915D-01  0.934847975768D-04

TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
  0.422838152167D-03 -0.770176424587D-02  0.257727280489D+01
  0.907242204287D-04  0.205306496596D+00 -0.182929793324D-01
 -0.158000555736D+01  0.514669869431D+02  0.100388873087D+04

PREDICTED CONTROL CHANGES
     CONTROL VARIABLE               CHANGE
          ALPH                -0.172660532199D-03
          BETA                 0.177055928978D-05
          THRN                 0.993893873364D+00


UPDATED THRUST CONTROLS FOR NEXT TRAJECTORY TARGETING ITERATION
     CONTROL VARIABLES      CONTROL VALUES
          ALPH             0.257026981965D+03
          BETA             0.103279355125D+01
          THRN             0.125715025194D+06


TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  1 ITERATIONS
     CONTROLS VARIABLES                TOTAL CHANGE
          ALPH                   -0.172660532199D-03
          BETA                    0.177055928978D-05
          THRN                    0.993893873364D+00
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**************************************************************************************************************************************
                                                    L1-LIBRATION POINT TRAJECTORY TARGETING
                                                            ITERATION NUMBER    2
                                                      NEWTON-RAPHSON TARGETING ALGORITHM
**************************************************************************************************************************************

      SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
              X-COMP                  Y-COMP                  Z-COMP                  VX-COMP                 VY-COMP                 VZ-COMP

  GEO-EC  0.530671826563D+04 -0.385624037545D+04 -0.242518098487D+02  0.646337757305D+01  0.891070431176D+01  0.109240284837D+01

  GEO-EQ  0.530671826563D+04 -0.352829469024D+04 -0.155637866932D+04  0.646337757305D+01  0.774061590973D+01  0.454718161643D+01

  CONTROL VARIABLES      TARGET VARIABLES          ACTUAL TARGET VALUES           TARGET ERROR              TARGET TOLERANCES
       ALPH                    RCA               0.655990141841D+04 (  KM)     0.985815864260D-01         0.100000000000D+01
       BETA                    ICA               0.283180450701D+02 ( DEG)    -0.450700812991D-04         0.100000000000D-02
       TBRN                    !CA               0.244223817113D+07 ( DAY)    -0.169232953340D-04         0.100000000000D-04


  NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY
       CONTROL VARIABLES          CONTROL VALUES
            ALPH                 0.257926981665D+03
            BETA                 0.103279355125D+01
            TBRN                 0.125715025164D+06


  DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
    0.810405055835D+00 -0.536133375236D+00 -0.236243217168D+00  0.118496087907D+01 -0.783923113886D+00 -0.345430285961D+00
    0.240075750303D-03  0.205386591784D-02 -0.383751626092D-02 -0.247010352503D+00 -0.211319194080D+01  0.394836402047D+01
   -0.123130805783D-05 -0.147070007768D-05 -0.864159741846D-06 -0.101282096605D-02  0.666702558286D-03  0.293461592494D-03

  STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT THRUST INITIATION)
   -0.188592900444D+02  0.166553256813D+02  0.118828680421D+00  0.264719277404D+08 -0.272162833697D+08 -0.582089226700D+06
   -0.259117609323D+02  0.229288277938D+02  0.167198286420D+00  0.366441390545D+08 -0.371590191358D+08 -0.766248786773D+06
   -0.317974303204D+01  0.281254598758D+01  0.151368141480D-01  0.448598502071D+07 -0.457009307259D+07 -0.917838133193D+05
    0.221121867129D-01 -0.195355124870D-01 -0.138677881185D-03 -0.311091863896D+05  0.318420473588D+05  0.682828648948D+03
   -0.160146276262D-01  0.141759387879D-01  0.105003131206D-03  0.226964257099D+05 -0.229189956450D+05 -0.452246852494D+03
   -0.923870405007D-04  0.859099793537D-04 -0.169808926520D-04  0.156079223026D+03 -0.108624467290D+03 -0.178490579754D+03

  PARTIALS OF STATE VECTOR COMPONENTS AT THE END OF THE THRUST PHASE WRT THRUST CONTROLS
    0.374959660278D+03  0.144361181012D+01  0.0
   -0.803004545134D+02  0.675792872420D+01  0.0
   -0.177043854414D-04  0.383271694292D+03  0.0
   -0.581040147638D-02 -0.223345424541D-04  0.522810259418D-06
    0.124597708310D-02 -0.104694602809D-03  0.244430744336D-05
    0.826331599501D-09 -0.593648786010D-02 -0.450616795440D-07

  PARTIALS OF STATE VECTOR COMPONENTS AT THE TARGET TIME WRT THRUST CONTROLS
   -0.196132297078D+06  0.584459889030D+04 -0.526589386938D+02
   -0.270773506942D+06  0.780237252066D+04 -0.716356067592D+02
   -0.331777293877D+05  0.943363332793D+03 -0.882125758898D+01
    0.230291212931D+03 -0.684573453531D+01  0.615367821587D-01
   -0.167575063082D+03  0.469026463915D+01 -0.441347689223D-01
   -0.108376671571D+01  0.106143250427D+01 -0.175868689543D-03

  TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
    0.221166786474D+03  0.149961616930D+03 -0.565076347479D+00
   -0.664265476790D-01  0.480389606740D+01  0.258076698445D-03
    0.351524057264D+00 -0.102484059653D-01  0.934827758293D-04

  TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
    0.422848431797D-03 -0.770171594134D-02  0.257725852343D+01
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  0.907333677203D-04  0.205292952463D+00 -0.182926463689D-01
 -0.158009347343D+01  0.514668494979D+02  0.100386574883D+04

PREDICTED CONTROL CHANGES
     CONTROL VARIABLE                CHANGE
          ALPH                  -0.158354095607D-05
          BETA                   0.164113095740D-08
          THRN                  -0.175076452946D+00

UPDATED THRUST CONTROLS FOR NEXT TRAJECTORY TARGETING ITERATION
     CONTROL VARIABLES       CONTROL VALUES
          ALPH              0.257926980081D+03
          BETA              0.103279355289D+01
          THRN              0.125714850087D+06

TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  2 ITERATIONS
     CONTROLS VARIABLES                 TOTAL CHANGE
          ALPH                     -0.172440531550D-03
          BETA                      0.177220042074D-05
          THRN                      0.818174204180D+00
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****************************************************************************************************
                                   L1-LIBRATION POINT TRAJECTORY TARGETING
                                           ITERATION NUMBER   3
                                     NEWTON-RAPHSON TARGETING ALGORITHM
****************************************************************************************************

       SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
             X-COMP         Y-COMP         Z-COMP         VX-COMP        VY-COMP        VZ-COMP

   GEO-EC  0.531791470564D+04 -0.384097831092D+04 -0.223737061372D+02  0.645026503736D+01  0.892008460151D+01  0.109243877343D+01

   GEO-EQ  0.531791470564D+04 -0.351503953665D+04 -0.154858387682D+04  0.645026503736D+01  0.774920764977D+01  0.455094633813D+01

   CONTROL VARIABLES    TARGET VARIABLES        ACTUAL TARGET VALUES        TARGET ERROR          TARGET TOLERANCES
       ALPH                  RCA             0.656001735909D+04 (  KM)    -0.173590853155D-01     0.100000000000D+01
       BETA                  ICA             0.283179920629D+02 ( DEG)     0.793714686864D-05     0.100000000000D-02
       TBRN                  TCA             0.244223817111D+07 ( DAY)     0.297953374684D-05     0.100000000000D-04

   NOMINAL THRUST CONTROLS FOR THE CURRENT TRAJECTORY
       CONTROL VARIABLES     CONTROL VALUES
           ALPH             0.257926980081D+03
           BETA             0.103279355289D+01
           TBRN             0.125714850087D+06

   CONVERGENCE HAS OCCURRED AFTER  3 ITERATIONS.
   THE TOTAL CHANGE TO THE CONTROL VARIABLES IS COMPUTED TO BE
       DELTA-ALPH = -0.174244053155D-03
       DELTA-BETA =  0.177220042074D-05
       DELTA-TBRN =  0.818817420418D+00
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************************************************************************************************************************
                                               PROJECTED LAUNCH PROFILE
                                                   TRAJECTORY DATA
************************************************************************************************************************

    INJECTION DATE       2442238.171 -  7/ 9/1974 16. 6.25
    AZIMUTH             0.89752307D+02
    LS LONGITUDE        0.27945700D+03
    LS LATITUDE         0.28317000D+02
    BURN1 ANGLE         0.17000000D+02
    BURN2 ANGLE         0.80000000D+01
    LAUNCH TOD         -0.34400231D+00
    BURN1 DUR-SEC       0.50000000D+03
    COAST TIME-SEC      0.70752982D+03
    BURN2 DUR-SEC       0.10000000D+03
    INJECTION TOD      -0.32886886D+00
    INJECTION GHA       0.24163925D+06
    INJ DV (IN)        -0.24978056D+05
    STATE (ECL)         0.53179147D+04  -0.38409783D+04  -0.22373706D+02
                        0.64502650D+01   0.89200846D+01   0.10924388D+01
    ELEMENTS (ECL)      0.61894363D+06   0.98940127D+00   0.56709853D+01
                       -0.33871230D+02  -0.20029204D+01   0.24870842D-01
    STATE (ECQ)         0.53179147D+04  -0.35150395D+04  -0.15485839D+04
                        0.64502650D+01   0.77492076D+01   0.45509463D+01
    ELEMENTS (ECQ)      0.61894363D+06   0.98940127D+00   0.28317992D+02
                       -0.66669687D+01  -0.29869013D+02   0.24870842D-01
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****************************************************************************************************
                                                   TRAJECTORY DATA
****************************************************************************************************

      DATF                    2442238.171 -  7/ 9/1974 16. 6.24
      DAYS FROM INJECTION          0.0

      DATA WITH RESPECT TO EARTH
      STATE (ECL)             0.53179147D+04  -0.38409783D+04  -0.22373706D+02
                              0.64502650D+01   0.89200846D+01   0.10924388D+01
      R-MAG                   0.65600177D+04
      V-MAG                   0.11061973D+02
      RA (ECL)                    324.160
      DEC (ECL)                    -0.195
      STATE (ECQ)             0.53179147D+04  -0.35150395D+04  -0.15485839D+04
                              0.64502650D+01   0.77492076D+01   0.45509463D+01
      RA (ECQ)                    326.536
      DEC (ECQ)                   -13.654
      STATE PARTIALS          0.10000000D+01   0.50600713D-18   0.0             -0.21778547D-14   0.32384456D-16  -0.22137812D-18
                              0.10120143D-17   0.10000000D+01   0.39531807D-20   0.24289342D-16  -0.38861347D-14   0.18975267D-18
                             -0.59297710D-20   0.19765903D-20   0.10000000D+01  -0.72738524D-18   0.12650178D-18  -0.39023270D-14
                              0.72459697D-19  -0.82811082D-19   0.59641771D-21   0.10000000D+01  -0.39749319D-17   0.20702771D-19
                             -0.85398928D-19  -0.12939232D-19  -0.37402466D-21  -0.46374206D-17   0.10000000D+01  -0.12939232D-19
                              0.57620016D-21  -0.34369834D-21  -0.59520465D-19   0.20702771D-19  -0.15527078D-19   0.10000000D+01

      DATA WITH RFSPECT TO SUN
      STATE (ECL)             0.43760617D+08  -0.14566158D+09  -0.65890970D+03
                              0.34489671D+02   0.17374276D+02   0.10922083D+01
      R-MAG                   0.15209302D+09
      V-MAG                   0.38634127D+02
      RA (ECL)                    286.722
      DEC (ECL)                    -0.000
```

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*****************************************************************************************************
                                          SPECIAL PRINT POINT   1
                                            TRAJECTORY DATA
*****************************************************************************************************

     DATE                    2442238.671 -  7/10/1974  4. 6.24
     DAYS FROM INJECTION           0.500

     DATA WITH RESPECT TO EARTH
     STATE (ECL)            -0.71478193D+05   0.12049949D+06   0.59788853D+04
                            -0.15652217D+01   0.16285125D+01   0.47621452D-01
     R-MAG                   0.14023197D+06
     V-MAG                   0.22592565D+01
     RA (ECL)                    120.676
     DEC (ECL)                     2.444
     STATE (ECQ)            -0.71478193D+05   0.10817477D+06   0.53423711D+05
                            -0.15652217D+01   0.14751483D+01   0.69156208D+00
     RA (ECQ)                    123.455
     DEC (ECQ)                    22.394
     STATE PARTIALS          0.24484157D+02   0.46026660D+01   0.28188253D+01   0.26314726D+05  -0.66413413D+03   0.11209188D+04
                             0.11509272D+03  -0.69571751D+02   0.22489387D+01   0.10170769D+06   0.11839401D+06   0.14972230D+05
                             0.11928524D+02  -0.38659330D+01  -0.19250902D+02   0.95612668D+04   0.93064131D+04   0.63681750D+04
                            -0.23103542D-03   0.47407918D-03   0.45048542D-04  -0.92356424D-01  -0.63341214D+00  -0.59363938D-01
                             0.33426378D-02  -0.21275561D-02   0.37513219D-04   0.29285143D+01   0.35707993D+01   0.45346218D+00
                             0.28154690D-03  -0.12123791D-03  -0.33318190D-03   0.23430231D+00   0.25631718D+00   0.70754109D-01


     DATA WITH RESPECT TO SUN
     STATE (ECL)             0.44893594D+08  -0.14516690D+09   0.53349983D+04
                             0.26403155D+02   0.10319474D+02   0.47510947D-01
     R-MAG                   0.15195020D+09
     V-MAG                   0.28348190D+02
     RA (ECL)                    287.184
     DEC (ECL)                     0.002
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************************************************************************************************************************************
                                                            SPECIAL PRINT POINT   2
                                                                TRAJECTORY DATA
************************************************************************************************************************************

       DATE                    2442243.171 -  7/14/1974 16. 6.24
       DAYS FROM INJECTION           5.000

       DATA WITH RESPECT TO EARTH
       STATE (ECL)            -0.43530532D+06   0.42674412D+06   0.10934513D+05
                              -0.66781868D+00   0.49565007D+00   0.29681588D-02
       R-MAG                   0.60968913D+06
       V-MAG                   0.83166074D+00
       RA (ECL)                    135.569
       DEC (ECL)                     1.028
       STATE (ECQ)            -0.43530532D+06   0.38717020D+06   0.17980364D+06
                              -0.66781869D+00   0.45355784D+00   0.19990770D+00
       RA (ECQ)                    138.349
       DEC (ECQ)                    17.152
       STATE PARTIALS         -0.90955179D+03   0.73608230D+03   0.15403885D+02  -0.74538496D+06  -0.11617208D+07  -0.13748338D+06
                               0.19871207D+04  -0.13541732D+04   0.59054111D+01   0.17144874D+07   0.22365776D+07   0.27861514D+06
                               0.11816659D+03  -0.63086549D+02  -0.90222355D+02   0.99311930D+05   0.11898357D+06   0.23440418D+05
                              -0.38786436D-02   0.28905166D-02   0.30469904D-04  -0.32567027D+01  -0.46510237D+01  -0.56370792D+00
                               0.58150972D-02  -0.40753107D-02  -0.36984106D-05   0.49818502D+01   0.66825682D+01   0.82664943D+00
                               0.26863758D-03  -0.16361345D-03  -0.12338203D-03   0.22789136D+00   0.29005244D+00   0.36687998D-01


       DATA WITH RESPECT TO SUN
       STATE (ECL)             0.55267657D+08  -0.14107039D+09   0.10448231D+05
                               0.26573181D+02   0.11294836D+02   0.38199295D-02
       R-MAG                   0.15151029D+09
       V-MAG                   0.28873990D+02
       RA (ECL)                    291.394
       DEC (ECL)                     0.004
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*******************************************************************************************************************************************
                                                                      TRAJECTORY DATA
*******************************************************************************************************************************************

        DATE                    2442268.171 -  8/ 8/1974 16. 6.24
        DAYS FROM INJECTION           30.000

        DATA WITH RESPECT TO EARTH
        STATE (ECL)            -0.11122019D+07   0.91442626D+06   0.27983974D+04
                               -0.14110442D+00   0.12156482D+00  -0.60363280D-02
        R-MAG                   0.14398529D+07
        V-MAG                   0.18634618D+00
        RA (ECL)                    140.574
        DEC (ECL)                     0.111
        STATE (ECQ)            -0.11122019D+07   0.83783540D+06   0.36635374D+06
                               -0.14110442D+00   0.11393218D+00   0.42824064D-01
        RA (ECQ)                    143.009
        DEC (ECQ)                    14.740
        STATE PARTIALS         -0.23286149D+05   0.16926951D+05   0.11473681D+03  -0.19719777D+08  -0.27447901D+08  -0.33541526D+07
                                0.24832481D+05  -0.17725500D+05  -0.69111010D+02   0.21153900D+08   0.28905296D+08   0.35538671D+07
                                0.62214402D+03  -0.40439761D+03  -0.18269177D+03   0.52806563D+06   0.69307025D+06   0.85163641D+05
                               -0.18135279D-01   0.13060800D-01   0.70332526D-04  -0.15401742D+02  -0.21236520D+02  -0.26028957D+01
                                0.16531262D-01  -0.11914050D-01  -0.65260908D-04   0.14040463D+02   0.19373494D+02   0.23746914D+01
                                0.17521763D-03  -0.12789414D-03   0.53048448D-05   0.14935480D+00   0.20754838D+00   0.19976621D-01


        DATA WITH RESPECT TO SUN
        STATE (ECL)             0.10685127D+09  -0.10561976D+09   0.18672469D+04
                                0.20298839D+02   0.21209201D+02  -0.55912773D-02
        R-MAG                   0.15024224D+09
        V-MAG                   0.29357675D+02
        RA (ECL)                    315.332
        DEC (ECL)                     0.001
```

```
*********************************************************************************************************************************
                                                       SPECIAL PRINT FOR BURN POINT
                                                             TRAJECTORY DATA
*********************************************************************************************************************************

       DATE                   2442272.716 -  8/13/1974  5.11. 9
       DAYS FROM INJECTION        34.545

       DATA WITH RESPECT TO EARTH
       STATE (ECL)           -0.11625325D+07   0.95907743D+06   0.40195317D+03
                             -0.11697807D+00   0.10618469D+00  -0.61413652D-02
       R-MAG                  0.15070871D+07
       V-MAG                  0.15810368D+00
       RA (ECL)                   140.478
       DEC (ECL)                    0.015
       STATE (ECQ)           -0.11625325D+07   0.87975440D+06   0.38191868D+06
                             -0.11697807D+00   0.99863330D-01   0.36609018D-01
       RA (ECQ)                   142.883
       DEC (ECQ)                   14.680
       STATE PARTIALS        -0.31173754D+05   0.22606002D+05   0.14505052D+03  -0.26418162D+08  -0.36682781D+08  -0.44861582D+07
                              0.31906705D+05  -0.22826052D+05  -0.97382925D+02   0.27161318D+08   0.37198122D+08   0.45701936D+07
                              0.68410912D+03  -0.45025611D+03  -0.17826087D+03   0.58090867D+06   0.76701729D+06   0.92088543D+05
                             -0.22157521D-01   0.15950205D-01   0.84567324D-04  -0.18821087D+02  -0.25939040D+02  -0.31798363D+01
                              0.19575720D-01  -0.14119057D-01  -0.78993925D-04   0.16621585D+02   0.22952991D+02   0.28126376D+01
                              0.13897686D-03  -0.10459709D-03   0.17017785D-04   0.11858876D+00   0.16737680D+00   0.15107064D-01


       DATA WITH RESPECT TO SUN
       STATE (ECL)            0.11450487D+09  -0.96988514D+08  -0.21021846D+03
                              0.18659055D+02   0.22732170D+02  -0.51196345D-02
       R-MAG                  0.15006045D+09
       V-MAG                  0.29409384D+02
       RA (ECL)                   319.735
       DEC (ECL)                   -0.000
```

```
**************************************************************************************************************************
                                                               TRAJECTORY DATA
**************************************************************************************************************************

      DATE                        2442274.171 -  8/14/1974 16. 6.24
      DAYS FROM INJECTION               36.000

      DATA WITH RESPECT TO EARTH
      STATE (ECL)               -0.11812231D+07   0.95178146D+06   0.48693573D+01
                                -0.18235857D+00  -0.23118843D+00  -0.95706081D-05
      R-MAG                      0.15169627D+07
      V-MAG                      0.29445329D+00
      RA (ECL)                          141.140
      DEC (ECL)                           0.000
      STATE (ECQ)               -0.11812231D+07   0.87321862D+06   0.37865181D+06
                                -0.18235857D+00  -0.21210212D+00  -0.91982504D-01
      RA (ECQ)                          143.526
      DEC (ECQ)                          14.455
      STATE PARTIALS             0.10009690D+01  -0.18157324D-02  -0.29371102D-06   0.12575565D+06  -0.75797315D+02  -0.75667761D-02
                                -0.18157204D-02   0.10002651D+01   0.24197695D-06  -0.75797035D+02   0.12572559D+06   0.62228152D-02
                                -0.29354860D-06   0.24184462D-06   0.99876744D+00  -0.75638538D-02   0.62204368D-02   0.12566335D+06
                                 0.15530812D-07  -0.28795108D-07  -0.31721397D-11   0.10009821D+01  -0.18034775D-02  -0.10477429D-06
                                -0.28794576D-07   0.40749489D-08   0.26109194D-11  -0.18034628D-02   0.10002461D+01   0.86012497D-07
                                -0.31665868D-11   0.26064105D-11  -0.19557611D-07  -0.10465760D-06   0.85917973D-07   0.99877337D+00


      DATA WITH RESPECT TO SUN
      STATE (ECL)                0.11681156D+09  -0.94121885D+08  -0.48152085D+03
                                 0.18033911D+02   0.22461954D+02   0.94654491D-03
      R-MAG                      0.15001290D+09
      V-MAG                      0.29118566D+02
      RA (ECL)                          321.140
      DEC (ECL)                          -0.000


      THRUST MAG                 0.10000000D+01
      SPECIFIC IMPULSE           0.21500000D+03
      INITIAL S/C MASS           0.40000000D+03
      MASS RATE (KG/SEC)         0.47431031D-03
      FINAL MASS                 0.33504240D+03
      EEC INSRT DELTA V          0.37361083D+00
```

CASE N-2

Long (118 day) Transfer Time Mission to the L_2 Point with Impulsive Insertion

```
***************************************************************************************************************************
                                                         INITIAL CONDITIONS (FROM TABLE)
                                                                TRAJECTORY DATA
***************************************************************************************************************************

        INJECTION DATE        2442238.428 -  7/ 9/1974 22.16. 0
        FLIGHT DURATION           118.000
        ARRIVAL DATE          2442356.428 - 11/ 4/1974 22.16. 0
        LIBRATION POINT                  2
        STATE AT L-POINT       0.11149880D+07   0.99584291D+06  -0.53469755D+01
                              -0.21786462D+00   0.49868693D+00  -0.19464244D-05
        CENTRAL BODY          EARTH
        NO. OF BODIES         2
        BODY NO 1             EARTH
        BODY NO 2             SUN
```

```
************************************************************************************************************************************
                                                        L2-LIBRATION POINT TRAJECTORY TARGETING
                                                                   ITERATION NUMBER    1
                                                           NEWTON-RAPHSON TARGETING ALGORITHM
************************************************************************************************************************************

         TARGETING EVENT AT JULIAN DATE          2442356.427779

         DESIGNATED TARGET TIME AT JULIAN DATE          2442238.427779

         SPACECRAFT STATE VECTOR AT INITIAL JULIAN DATE
                 X-COMP              Y-COMP              Z-COMP             VX-COMP             VY-COMP             VZ-COMP

    GEO-EC  0.111498802062D+07  0.995842908471D+06 -0.534697546581D+01 -0.217864615110D+00  0.498686925314D+00 -0.194642442848D-05

    GEO-EQ  0.111498802062D+07  0.913647358793D+06  0.396171177838D+06 -0.217864615110D+00  0.457525678628D+00  0.198390783252D+00

         SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
                 X-COMP              Y-COMP              Z-COMP             VX-COMP             VY-COMP             VZ-COMP

    GEO-EC  0.479781001497D+06 -0.728865428784D+06  0.233414399079D+00 -0.190764250635D+00  0.510684285747D+00  0.308867293681D-05

    GEO-EQ  0.479781001497D+06 -0.668704381284D+06 -0.289964245603D+06 -0.190764250635D+00  0.468530764141D+00  0.203168311434D+00

    CONTROL VARIABLES     TARGET VARIABLES        ACTUAL TARGET VALUES         TARGET ERROR          TARGET TOLERANCES
          VX                    RCA             0.140704829898D+05 (  KM)   -0.751048298976D+04    0.100000000000D+01
          VY                    ICA            -0.234434088924D+02 ( DEG)    0.517614088924D+02    0.100000000000D-02
          VZ                    ICA             0.244224814161D+07 ( DAY)   -0.971383362170D+01    0.100000000000D-04


    DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
      0.136979699633D+00  0.471970840408D-01  0.204698107757D-01  0.195806292178D+06  0.117956839300D+06  0.511554058279D+05
      0.230726726613D-08  0.410381114486D-04 -0.946366952110D-04  0.580261160721D-02  0.103207437892D+03 -0.237991494506D+03
      0.105294928856D-04 -0.954302769296D-05 -0.413796718945D-05  0.709977272599D+01 -0.452866103503D+01 -0.196362895120D+01

    STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT LIBRATION POINT)
     -0.146897544490D+02 -0.858849179251D+01  0.463650362870D-04  0.331620187891D+08 -0.425174048222D+07 -0.758613615344D+02
      0.328091585119D+02  0.174593324381D+02 -0.112467175244D-03 -0.713101428607D+08  0.392887468792D+07  0.160558512341D+03
      0.558526213202D-04  0.332367455160D-04 -0.681730401526D+00 -0.137599280403D+03  0.221624109764D+02 -0.147458749901D+07
     -0.198545449524D-04 -0.103812292992D-04  0.695369862045D-10  0.435484851784D+02 -0.307831158312D+01 -0.101764067976D-03
      0.233893128675D-04  0.129959041951D-04 -0.790955680063D-10 -0.513757606313D+02  0.399554287144D+01  0.112986958160D-03
      0.545878588486D-10  0.270345088429D-10  0.505609235821D-06 -0.116641725250D-03  0.456311731811D-05 -0.373219294457D+00

    TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
      0.279557675389D+07 -0.469320454850D+06 -0.154702131231D+02
     -0.167984716592D+00  0.857984114308D-02  0.248921410532D+03
      0.165369271435D+04 -0.127212560248D+03 -0.390801534696D-02

    TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
     -0.302541761127D-06 -0.127924582038D-08  0.111615579984D-02
     -0.393287506298D-05 -0.140043368901D-06  0.664854720775D-02
     -0.686118108034D-10  0.401733221281D-02  0.524075597012D-06

    PREDICTED CONTROL CHANGES
         CONTROL VARIABLE                 CHANGE
                VX                 -0.203035925289D-02
                VY                 -0.830443177364D-02
                VZ                  0.492637194518D-01


    UPDATED INITIAL EC-STATE VECTOR
      X-COMP              Y-COMP              Z-COMP             VX-COMP             VY-COMP             VZ-COMP
```

```
  0.111498802062D+07  0.995842908471D+06 -0.534697546581D+01 -0.219894974363D+00  0.490382493540D+00  0.492617730273D-01

TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  1 ITERATIONS
     CONTROLS VARIABLES                TOTAL CHANGE
             VX                     -0.203035925289D-02
             VY                     -0.830443177364D-02
             VZ                      0.492637194518D-01
```

```
****************************************************************************************************************************
                                                L2-LIBRATION POINT TRAJECTORY TARGETING
                                                         ITERATION NUMBER    6
                                                  NEWTON-RAPHSON TARGETING ALGORITHM
****************************************************************************************************************************

        SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
              X-COMP                Y-COMP                Z-COMP                VX-COMP               VY-COMP               VZ-COMP

     GEO-EC -0.305319204475D+04  0.580612361030D+04 -0.233959628233D+02 -0.836045590986D+01 -0.437304675233D+01  0.577155712924D+01

     GEO-EQ -0.305319204475D+04  0.533618909809D+04  0.228838472696D+04 -0.836045590986D+01 -0.630818993479D+01  0.355543940193D+01

     CONTROL VARIABLES     TARGET VARIABLES        ACTUAL TARGET VALUES         TARGET ERROR            TARGET TOLERANCES
           VX                    RCA              0.656000003090D+04 (  KM)    -0.309020842906D-04      0.100000000000D+01
           VY                    ICA              0.283179998693D+02 ( DEG)     0.130653187824D-06      0.100000000000D-02
           VZ                    TCA              0.244223842778D+07 ( DAY)     0.113621354103D-06      0.100000000000D-04

     CONVERGENCE HAS OCCURRED AFTER  6 ITERATIONS.
     THE.TOTAL CHANGE TO THE CONTROL VARIABLES IS COMPUTED TO BE
          DELTA-  VX = -0.319948655939D-02
          DELTA-  VY =  0.874254539096D-02
          DELTA-  VZ =  0.365279060118D-01
```

```
****************************************************************************************************************************************
                                                                  LAUNCH PROFILE FOR TARGETING
                                                                        TRAJECTORY DATA
****************************************************************************************************************************************

          INJECTION DATE       2442238.431 -  7/ 9/1974 22.21. 2
          AZIMUTH             0.89751335D+02
          LS LONGITUDE        0.27945700D+03
          LS LATITUDE         0.28317000D+02
          BURN1 ANGLE         0.17000000D+02
          BURN2 ANGLE         0.80000000D+01
          LAUNCH TOD         -0.11476601D+00
          BURN1 DUR-SEC       0.50000000D+03
          COAST TIME-SEC      0.33787153D+04
          BURN2 DUR-SEC       0.10000000D+03
          INJECTION TOD      -0.68716066D-01
          INJECTION GHA       0.24165302D+06
          INJ DV (IN)        -0.24977991D+05
          STATE (ECL)        -0.30531920D+04   0.58061236D+04  -0.23395963D+02
                             -0.83604559D+01  -0.43730468D+01   0.57715571D+01
          ELEMENTS (ECL)      0.58659701D+06   0.98881685D+00   0.31455465D+02
                              0.11807200D+03  -0.39253508D+00   0.94715891D-03
          STATE (ECQ)        -0.30531920D+04   0.53361891D+04   0.22883847D+04
                             -0.83604559D+01  -0.63081899D+01   0.35554394D+01
          ELEMENTS (ECQ)      0.58659701D+06   0.98881685D+00   0.28318000D+02
                              0.76085710D+02   0.47338516D+02   0.94715891D-03
```

```
******************************************************************************************
                                     L2-LIBRATION POINT TRAJECTORY TARGETING
                                               ITERATION NUMBER    1
                                        NEWTON-RAPHSON TARGETING ALGORITHM
******************************************************************************************

      TARGETING EVENT AT JULIAN DATE          2442356.431284

      DESIGNATED TARGET TIME AT JULIAN DATE          2442238.431284

      SPACECRAFT STATE VECTOR AT INITIAL JULIAN DATE
               X-COMP              Y-COMP              Z-COMP              VX-COMP             VY-COMP             VZ-COMP

   GEO-EC  0.111492601002D+07  0.995910399632D+06 -0.534375797999D+01 -0.221064101669D+00  0.507429470705D+00  0.365259595874D-01

   GEO-EQ  0.111492601002D+07  0.913709277900D+06  0.396198030792D+06 -0.221064101669D+00  0.451014714120D+00  0.235381692387D+00

      SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
               X-COMP              Y-COMP              Z-COMP              VX-COMP             VY-COMP             VZ-COMP

   GEO-EC  0.335728717743D+05 -0.114020658988D+05 -0.148402465817D+05 -0.327444011023D+01  0.295718432818D+01  0.917071421128D+00

   GEO-EQ  0.335728717743D+05 -0.455703638776D+04 -0.181514033817D+05 -0.327444011023D+01  0.234825751797D+01  0.201783194829D+01

   CONTROL VARIABLES      TARGET VARIABLES          ACTUAL TARGET VALUES           TARGET ERROR           TARGET TOLERANCES
         VX                    RCA               0.656928213261D+04 (  KM)     -0.928213261295D+01      0.100000000000D+01
         VY                    ICA               0.283213332420D+02 ( DEG)     -0.333324204598D-02      0.100000000000D-02
         VZ                    TCA               0.244223851136D+07 ( DAY)     -0.800791711061D-01      0.100000000000D-04


   DIFFERENTIAL TRANSFORMATION MATRIX - (PARTIALS OF TARGET VARIABLES WRT FINAL EQ-STATE VECTOR)
     0.392399665860D+00  0.697119413102D+00 -0.114608022720D+00  0.146219124387D+04  0.664506833862D+04  0.990788964100D+02
    -0.541012880705D-03  0.134468633699D-03 -0.103441773651D-02  0.133543257207D+01 -0.331921594423D+00  0.255334982889D+01
     0.250466765583D-05  0.107709555058D-05 -0.116995464193D-05  0.124691878912D-01  0.558696628553D-02 -0.579525949322D-02

   STATE TRANSITION MATRIX - (PARTIALS OF EARTH INJECTION EC-STATE WRT EC-STATE AT LIBRATION POINT)
    -0.341580530576D+03 -0.183253205930D+03  0.783257560536D+01  0.751197671711D+09 -0.595305178476D+08 -0.305428909076D+08
     0.308270240422D+03  0.165292129807D+03 -0.705844487472D+01 -0.677584413677D+09  0.530305457636D+08  0.275669321810D+08
     0.957606662100D+02  0.513693100522D+02 -0.224410968517D+01 -0.210564442975D+09  0.166041899402D+08  0.813861963064D+07
    -0.248883828038D-01 -0.133462997834D-01  0.572126850095D-03  0.547155265146D+05 -0.430021411525D+04 -0.221203490285D+04
     0.845108055298D-02  0.453820730494D-02 -0.195169806670D-03 -0.185964496438D+05  0.149421616258D+04  0.748926057255D+03
     0.109855888120D-01  0.589244796316D-02 -0.246991350137D-03 -0.241549957470D+05  0.190786829819D+04  0.100334914465D+04

   TARGET SENSITIVITY MATRIX - (PARTIALS OF TARGET VARIABLES WRT CONTROL VARIABLES)
     0.390117172608D+06 -0.200734516119D+06  0.761484731794D+05
     0.450906325554D+01  0.321092701958D+03  0.482982961242D+03
     0.265546761757D+04 -0.210110723465D+03 -0.107347427781D+03

   TARGETING MATRIX - (INVERSE OF THE SENSITIVITY MATRIX)
    -0.226079647404D-06  0.126677298208D-03  0.409579973667D-03
    -0.432861853237D-05  0.823490961145D-03  0.634522989157D-03
     0.287982670064D-05  0.152181738339D-02 -0.425662061709D-03

   PREDICTED CONTROL CHANGES
        CONTROL VARIABLE                CHANGE
               VX                  -0.311225696221D-04
               VY                  -0.133781584686D-04
               VZ                   0.228314604761D-05


   UPDATED INITIAL EC-STATE VECTOR
     X-COMP              Y-COMP              Z-COMP              VX-COMP             VY-COMP             VZ-COMP
```

```
  0.111492601002D+07  0.995910399632D+06 -0.534375797999D+01 -0.221095224239D+00  0.507416092547D+00  0.365282427334D-01

TOTAL CHANGE TO THE CONTROL VARIABLES AFTER  1 ITERATIONS
     CONTROLS VARIABLES                TOTAL CHANGE
            VX                     -0.311225696221D-04
            VY                     -0.133781584686D-04
            VZ                      0.220314604761D-05
```

```
************************************************************************************************************************************
                                                   L2-LIBRATION POINT TRAJECTORY TARGETING
                                                              ITERATION NUMBER    3
                                                      NEWTON-RAPHSON TARGETING ALGORITHM
************************************************************************************************************************************

        SPACECRAFT STATE VECTOR AT TARGET JULIAN DATE
                X-COMP                  Y-COMP                  Z-COMP                  VX-COMP                 VY-COMP                 VZ-COMP

    GEO-EC -0.305344798306D+04  0.580598872396D+04 -0.234618872012D+02 -0.836006750295D+01 -0.437336029540D+01  0.577188218888D+01

    GEO-EQ -0.305344798306D+04  0.533609157207D+04  0.228827058222D+04 -0.836006750295D+01 -0.630860691620D+01  0.355561289408D+01

    CONTROL VARIABLES      TARGET VARIABLES           ACTUAL TARGET VALUES            TARGET ERROR            TARGET TOLERANCES
           VX                     RCA              0.656000000824D+04 (  KM)      -0.824017024570D-05       0.100000000000D+01
           VY                     ICA              0.283179999653D+02 ( DEG)       0.346554891451D-07       0.100000000000D-02
           VZ                     ICA              0.244223843128D+07 ( DAY)      -0.130385160446D-07       0.100000000000D-04

    CONVERGENCE HAS OCCURRED AFTER  3 ITERATIONS.
    THE TOTAL CHANGE TO THE CONTROL VARIABLES IS COMPUTED TO BE
         DELTA-  VX = -0.309640348632D-04
         DELTA-  VY = -0.119977002852D-04
         DELTA-  VZ =  0.212867757584D-05
```

```
**********************************************************************************************************************************
                                                   PROJECTED LAUNCH PROFILE
                                                        TRAJECTORY DATA
**********************************************************************************************************************************

        INJECTION DATE       2442238.431 -  7/ 9/1974 22.21. 4
        AZIMUTH             0.89751323D+02
        LS LONGITUDE        0.27945700D+03
        LS LATITUDE         0.28317000D+02
        BURN1 ANGLE         0.17000000D+02
        BURN2 ANGLE         0.80000000D+01
        LAUNCH TOD         -0.11475048D+00
        BURN1 DUR-SEC       0.50000000D+03
        COAST TIME-SEC      0.33787248D+04
        BURN2 DUR-SEC       0.10000000D+03
        INJECTION TOD      -0.68700429D-01
        INJECTION GHA       0.24165302D+06
        INJ DV (IN)        -0.24977991D+05
        STATE (ECL)        -0.30534460D+04   0.58059887D+04  -0.23461887D+02
                           -0.83600675D+01  -0.43733603D+01   0.57718822D+01
        ELEMENTS (ECL)      0.58659691D+06   0.98881685D+00   0.31457441D+02
                            0.11807544D+03  -0.39256032D+00  -0.10888429D-03
        STATE (ECQ)        -0.30534480D+04   0.53360916D+04   0.22882706D+04
                           -0.83600675D+01  -0.63086069D+01   0.35556129D+01
        ELEMENTS (ECQ)      0.58659691D+06   0.98881685D+00   0.28318000D+02
                            0.76091340D+02   0.47336471D+02  -0.10888429D-03
```

```
*************************************************************************************************************************************
                                                                        TRAJECTORY DATA
*************************************************************************************************************************************

        DATE                      2442238.431 -  7/ 9/1974 22.21. 2
        DAYS FROM INJECTION             0.0

        DATA WITH RESPECT TO EARTH
        STATE (ECL)              -0.30534480D+04   0.58059887D+04  -0.23461887D+02
                                 -0.83600675D+01  -0.43733603D+01   0.57718822D+01
        R-MAG                     0.65600000D+04
        V-MAG                     0.11060363D+02
        RA (ECL)                     117.740
        DEC (ECL)                     -0.205
        STATE (ECQ)              -0.30534480D+04   0.53360916D+04   0.22882706D+04
                                 -0.83600675D+01  -0.63086069D+01   0.35556129D+01
        RA (ECQ)                     119.779
        DEC (ECQ)                     20.415
        STATE PARTIALS            0.10000000D+01  -0.50982423D-18   0.0               0.14552933D-13  -0.24471563D-16   0.0
                                  0.0              0.10000000D+01   0.0              -0.81571876D-17   0.14430065D-13   0.50982423D-18
                                 -0.31864014D-19  -0.31864014D-19   0.10000000D+01  -0.15294727D-17   0.0              0.13328845D-13
                                 -0.10390355D-19  -0.59744542D-19  -0.19481916D-20   0.10000000D+01  -0.26599309D-17  -0.13247703D-18
                                 -0.62342131D-19   0.54549364D-19   0.35716846D-20  -0.19949482D-17   0.10000000D+01   0.24936852D-18
                                 -0.21105409D-20   0.37340339D-20  -0.46756598D-19  -0.13507462D-18   0.24936852D-18   0.10000000D+01


        DATA WITH RESPECT TO SUN
        STATE (ECL)               0.44382118D+08  -0.14546051D+09  -0.70179004D+03
                                  0.19642620D+02   0.42040893D+01   0.57717162D+01
        R-MAG                     0.15208069D+09
        V-MAG                     0.20900230D+02
        RA (ECL)                     286.968
        DEC (ECL)                     -0.000
```

```
**************************************************************************************************************************************************
                                                               TRAJECTORY DATA
**************************************************************************************************************************************************

         DATE                     2442248.431 -  7/19/1974 22.21. 2
         DAYS FROM INJECTION           10.000

         DATA WITH RESPECT TO EARTH
         STATE (ECL)               0.35155679D+06    -0.81129316D+06     0.42625420D+05
                                   0.27481156D+00    -0.45462556D+00    -0.20100255D-01
         R-MAG                     0.88521506D+06
         V-MAG                     0.53161059D+00
         RA (ECL)                      293.428
         DEC (ECL)                       2.760
         STATE (ECQ)               0.35155679D+06    -0.76128604D+06    -0.28364959D+06
                                   0.27481156D+00    -0.40910392D+00    -0.19930481D+00
         RA (ECQ)                      294.787
         DEC (ECQ)                     -18.689
         STATE PARTIALS           -0.53537482D+03     0.11448389D+04    -0.11171514D+03    -0.10706663D+07    -0.70163169D+06     0.78363619D+06
                                   0.32533537D+04    -0.61454332D+04    -0.24969182D+02     0.62226780D+07     0.31991830D+07    -0.42780560D+07
                                  -0.71645773D+03     0.11087636D+04    -0.64366717D+02    -0.12052923D+07    -0.53791842D+06     0.81233227D+06
                                  -0.16130607D-02     0.31273806D-02    -0.68961805D-04    -0.31064445D+01    -0.16961466D+01     0.21632269D+01
                                   0.54661839D-02    -0.10352089D-01     0.81928947D-05     0.10456463D+02     0.54245980D+01    -0.72071792D+01
                                  -0.73482674D-03     0.12564376D-02    -0.38300580D-04    -0.13207189D+01    -0.63948381D+00     0.89325049D+00


         DATA WITH RESPECT TO SUN
         STATE (ECL)               0.68203007D+08    -0.13485216D+09     0.42535056D+05
                                   0.26456645D+02     0.12742692D+02    -0.19376750D-01
         R-MAG                     0.15290574D+09
         V-MAG                     0.29365467D+02
         RA (ECL)                      296.490
         DEC (ECL)                       0.016
```

```
*******************************************************************************************************************
                                                               TRAJECTORY DATA
*******************************************************************************************************************

       DATE                  2442356.431 - 11/ 4/1974 22.21. 2
       DAYS FROM INJECTION       118.000

       DATA WITH RESPECT TO EARTH
       STATE (ECL)           0.11149260D+07   0.99591040D+06  -0.53440844D+01
                            -0.22109506D+00   0.50741747D+00   0.36528088D-01
       R-MAG                 0.14949574D+07
       V-MAG                 0.55469796D+00
       RA (ECL)                  41.773
       DEC (ECL)                 -0.000
       STATE (ECQ)           0.11149260D+07   0.91370928D+06   0.39619803D+06
                            -0.22109506D+00   0.45100286D+00   0.23537887D+00
       RA (ECQ)                  39.335
       DEC (ECQ)                 15.368
       STATE PARTIALS       -0.10048613D+07   0.19111504D+07  -0.79883461D+04  -0.19249958D+10  -0.10074383D+10   0.13290806D+10
                             0.79361842D+05  -0.15110785D+06   0.77881366D+03   0.15208953D+09   0.79787170D+08  -0.10506744D+09
                             0.40737957D+05  -0.77182165D+05   0.40004023D+03   0.77849924D+08   0.40638767D+08  -0.53720073D+08
                            -0.45696910D+00   0.86906594D+00  -0.35970126D-02  -0.87539137D+03  -0.45808338D+03   0.60438436D+03
                            -0.24511950D+00   0.46618450D+00  -0.19405673D-02  -0.46957064D+03  -0.24573719D+03   0.32420720D+03
                             0.10489151D-01  -0.19965009D-01   0.79270874D-04   0.20108886D+02   0.10529297D+02  -0.13879024D+02


       DATA WITH RESPECT TO SUN
       STATE (ECL)           0.11174186D+09   0.99813817D+08  -0.53556790D+03
                            -0.20539722D+02   0.22620451D+02   0.37582064D-01
       R-MAG                 0.14983004D+09
       V-MAG                 0.30554319D+02
       RA (ECL)                  41.773
       DEC (ECL)                 -0.000


       IMP INSRT DELTA V     0.28735414D+00
```

APPENDIX B

Selected Sample Output from ERRAN

CASE E-1

Short (36 day) Transfer Time Mission to the L_1 Point with Finite Burn Insertion

```
INPUT DATA FOR PROBLEM....     0
  MODE TO BE EXECUTED. . .ERROR ANALYSIS

     LAUNCH DATE              7  9 16  6 24.421 1974     JULIAN DATE . . .2442238.17111595

      FINAL DATE              8 14 16  8 34.000 1974     JULIAN DATE . . .2442274.17261570

     INITIAL TRAJECTORY TIME =       0.0

  INERTIAL FRAME IS   GEOCENTRIC ECLIPTIC

        INITIAL STATE VECTOR
     AT TRAJECTORY TIME      0.0

STATE         X-COMP        Y-COMP        Z-COMP        RADIUS        X-DOT        Y-DOT        Z-DOT       VELOCITY

INERTIAL  0.5317915D+04 -0.3840978D+04 -0.2237371D+02  0.6560018D+04   6.45026504   8.92008460   1.09243877  11.06197319
HELIO-    0.4376053D+08 -0.1456616D+09 -0.9430564D+03  0.1520930D+09  34.48967577  17.37425886   1.09220739  38.63412381
ROT.GEO-  0.5208536D+04  0.3988043D+04 -0.2237371D+02  0.6560018D+04  -6.68646646   8.74283626   1.09243877  11.06071617

     THE FOLLOWING QUANTITIES ARE TO BE AUGMENTED TO THE STATE VECTOR

     MEASUREMENT CONSIDER PARAMETERS
       RADIUS 1
       LAT  1
       LONG 1
       RADIUS 2
       LAT  2
       LONG 2
       RADIUS 3
       LAT  3
       LONG 3
```

```
          MEASUREMENT NO    1 AT TRAJECTORY TIME      0.042                                                     PROBLEM. .      0

         RANGE-RATE WAS MEASURED FROM STATION 1 AT TRAJECTORY TIME       0.04200 DAYS

         INITIAL TRAJECTORY TIME       0.0
         FINAL   TRAJECTORY TIME       0.042
 INITIAL
      AT TRAJECTORY TIME       0.0

 STATE          X-COMP         Y-COMP         Z-COMP         RADIUS         X-DOT          Y-DOT          Z-DOT        VELOCITY

 INERTIAL  0.5317915D+04 -0.3840978D+04 -0.2237371D+02  0.6560018D+04   6.45026504     8.92008460     1.09243877   11.06197319
 HELIO-    0.4376053D+08 -0.1456616D+09 -0.6430564D+03  0.1520930D+09  34.48967577    17.37425886     1.09220739   38.63412381
 ROT.GEO-  0.5208536D+04  0.3988043D+04 -0.2237371D+02  0.6560018D+04  -6.68646646     8.74283626     1.09243877   11.06071617
 FINAL
      AT TRAJECTORY TIME       0.0420

 STATE          X-COMP         Y-COMP         Z-COMP         RADIUS         X-DOT          Y-DOT          Z-DOT        VELOCITY

 INERTIAL  0.3545082D+04  0.2344102D+05  0.2128900D+04  0.2380297D+05  -2.28098263     5.28705905     0.30967735    5.76643523
 HELIO-    0.4386050D+08 -0.1456036D+09  0.1507397D+04  0.1520663D+09  25.75253596    13.76113995     0.30945598   29.20030554
 ROT.GEO- -0.2142297D+05  0.1015409D+05  0.2128900D+04  0.2380297D+05  -5.71826884    -0.65535263     0.30967734    5.76402512




 STATE TRANSITION MATRIX PARTITIONS OVER(     0.0  ,     0.042)           --TRANSPOSES SHOWN

                             X(  0.042)          Y(  0.042)          Z(  0.042)          VX(  0.042)         VY(  0.042)         VZ(  0.042)
          X(   0.0   )    0.6979247918D+01    0.2670152575D+01    0.6980566930D+00    0.1703593169D-02    0.1654065920D-02    0.2723908701D-03
          Y(   0.0   )   -0.1117568594D+01   -0.1454369001D+01   -0.4523065427D-01   -0.2594772949D-03   -0.9327400756D-03   -0.2909528001D-04
          Z(   0.0   )    0.3857607350D+00    0.1643959847D+00   -0.1621040343D+01    0.1146200684D-03    0.7680735134D-04   -0.7413504762D-03
         VX(   0.0   )    0.5950172867D+04    0.2581976168D+04    0.4362129575D+03    0.1649157114D+01    0.1452875804D+01    0.1962256659D+00
         VY(   0.0   )    0.1359792328D+04    0.3749264891D+04    0.2248541258D+03    0.6604346366D+00    0.1439599540D+01    0.1331462234D+00
         VZ(   0.0   )    0.3354444422D+03    0.2924943454D+03    0.1957524935D+04    0.1308892497D+00    0.1770028816D+00    0.2898682690D+00

      SOLVE-FOR PARAMETERS

                  --NONE

      DYNAMIC CONSIDER PARAMETERS

                  --NONE
      IGNORE PARAMETERS

                  --NONE

 DIAGONAL OF DYNAMIC NOISE MATRIX
                  0.0               0.0               0.0               0.0               0.0               0.0



 OBSERVATION MATRIX PARTITIONS -- TRANSPOSES SHOWN
                                      RANGE-RATE(1)
                 X                 -0.7011364316D-04
                 Y                 -0.8635099560D-05
                 Z                  0.8346959682D-06
                VX                 -0.1206211130D+00
```

```
          VY              0.9883591651D+00
          VZ              0.9271843301D-01

      SOLVE-FOR PARAMETERS

                --NONE

      DYNAMIC CONSIDER PARAMETERS

                --NONE

      MEASUREMENT CONSIDER PARAMETERS
      RADIUS 1                0.6679560727D-05
      LAT  1                  0.1656888629D-01
      LONG 1                 -0.5253245287D-02
      RADIUS 2                0.0
      LAT  2                  0.0
      LONG 2                  0.0
      RADIUS 3                0.0
      LAT  3                  0.0
      LONG 3                  0.0

      IGNORE PARAMETERS

                --NONE
```

```
 MEASUREMENT NOISE MATRIX
                     0.16666667D-13



 GAIN MATRIX PARTITIONS
                 K-MATRIX
                               0.1816736423D+05
                               0.3797621063D+04
                              -0.2350679298D+04
                               0.4624703298D+01
                               0.2901815719D+01
                              -0.1794594021D-01

                 S-MATRIX

                      NOT DEFINED

 CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME    0.042 DAYS, JUST BEFORE  THE MEASUREMENT

                STD DEV               X            Y            Z            VX           VY           VZ
        X      0.22645444D+03    1.00000000
        Y      0.25429202D+02    0.55322390   1.00000000
        Z      0.98854806D+02    0.08565697  -0.49235532   1.00000000
       VX      0.55112515D-01    0.99962146   0.56997860   0.08603995   1.00000000
       VY      0.26215466D-01    0.97228975   0.72536722  -0.01699310   0.97751128   1.00000000
       VZ      0.14443271D-01    0.30602226  -0.33009576   0.97287967   0.30690698   0.20691705   1.00000000


  RSS POSITION ERRORS. . .  0.248395918784D+03
  RSS VELOCITY ERRORS. . .  0.627156124049D-01
```

```
          SOLVE-FOR PARAMETERS

                    --NONE

          DYNAMIC CONSIDER PARAMETERS

                    --NONE

          MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                                 0.0           0.0           0.0           0.0           0.0           0.0
LAT  1                                   0.0           0.0           0.0           0.0           0.0           0.0
LONG 1                                   0.0           0.0           0.0           0.0           0.0           0.0
RADIUS 2                                 0.0           0.0           0.0           0.0           0.0           0.0
LAT  2                                   0.0           0.0           0.0           0.0           0.0           0.0
LONG 2                                   0.0           0.0           0.0           0.0           0.0           0.0
RADIUS 3                                 0.0           0.0           0.0           0.0           0.0           0.0
LAT  3                                   0.0           0.0           0.0           0.0           0.0           0.0
LONG 3                                   0.0           0.0           0.0           0.0           0.0           0.0

          NO SOLVE-FOR PARAMETERS



CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME    0.042 DAYS, JUST AFTER   THE MEASUREMENT

                  STD DEV                X             Y             Z             VX            VY            VZ
        X         0.19769567D+03      1.00000000
        Y         0.10660283D+02      0.30175667    1.00000000
        Z         0.97816436D+02      0.18077640   -0.87054381    1.00000000
        VX        0.47401901D-01      0.99994170    0.29629135    0.18774898    1.00000000
        VY        0.19391910D-01      0.99740538    0.36900911    0.10968723    0.99686695    1.00000000
        VZ        0.14442859D-01      0.35476931   -0.77107876    0.98213175    0.36132038    0.28660602    1.00000000


 RSS POSITION ERRORS. . .  0.220828607331D+03
 RSS VELOCITY ERRORS. . .  0.532126171160D-01

          SOLVE-FOR PARAMETERS

                    --NONE

          DYNAMIC CONSIDER PARAMETERS

                    --NONE

          MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                             -0.00000551   -0.00002135    0.00000144   -0.00000585   -0.00000897    0.00000007
LAT  1                               -0.00000488   -0.00001893    0.00000128   -0.00000518   -0.00000795    0.00000007
LONG 1                                0.00000034    0.00000133   -0.00000009    0.00000037    0.00000056   -0.00000000
RADIUS 2                              0.0           0.0           0.0           0.0           0.0           0.0
LAT  2                                0.0           0.0           0.0           0.0           0.0           0.0
LONG 2                                0.00000031    0.00000120   -0.00000008    0.00000033    0.00000050   -0.00000000
RADIUS 3                              0.0           0.0           0.0           0.0           0.0           0.0
LAT  3                                0.0           0.0           0.0           0.0           0.0           0.0
LONG 3                                0.00000031    0.00000120   -0.00000008    0.00000033    0.00000050   -0.00000000

          NO SOLVE-FOR PARAMETERS
```

```
      ERROR ANALYSIS MODE-    GUIDANCE     EVENT AT TRAJECTORY TIME 0.50000000D+00 DAYS          PROBLEM. .          0
*****************************************************************************************************************************
      AT TRAJECTORY TIME        0.5000

STATE          X-COMP          Y-COMP          Z-COMP          RADIUS         X-DOT         Y-DOT          Z-DOT        VELOCITY

INERTIAL -0.7147819D+05  0.1204995D+06  0.5978885D+04  0.1402320D+06  -1.56522173    1.62851249     0.04762145    2.25925647
HELIO-     0.4489351D+08 -0.1451669D+09  0.5350811D+04  0.1519502D+09  26.40316035   10.31945751     0.04750999   28.34819812
ROT.GEO- -0.1362454D+06 -0.3265659D+05  0.5978885D+04  0.1402320D+06  -2.02476295   -0.98753505     0.04762156    2.25325504




STATE TRANSITION MATRIX PARTITIONS OVER(     0.458,     0.500)          --TRANSPOSES SHOWN

                          X(  0.500)          Y(  0.500)          Z(  0.500)         VX(  0.500)         VY(  0.500)         VZ(  0.500)
       X(  0.458)   0.9997340676D+00 -0.1410676340D-02 -0.7097306404D-04 -0.1386797771D-06 -0.7571166326D-06 -0.3796222532D-07
       Y(  0.458)  -0.1410686066D-02  0.1001345724D+01  0.1222712826D-03 -0.7571295861D-06  0.7171391872D-06  0.6505911133D-07
       Z(  0.458)  -0.7097386684D-04  0.1222718228D-03  0.9989213578D+00 -0.3796329454D-07  0.6505983074D-07 -0.5772367150D-06
      VX(  0.458)   0.3628495695D+04 -0.1660143475D+01 -0.8322835149D-01  0.9997620404D+00 -0.1336280537D-02 -0.6676125613D-04
      VY(  0.458)  -0.1660151396D+01  0.3630371269D+04  0.1425933334D+00 -0.1336289619D-02  0.1001255436D+01  0.1137746079D-03
      VZ(  0.458)  -0.8322900607D-01  0.1425937710D+00  0.3627533840D+04 -0.6676200577D-04  0.1137751124D-03  0.9989835939D+00

      SOLVE-FOR PARAMETERS

                    --NONE

      DYNAMIC CONSIDER PARAMETERS

                    --NONE
      IGNORE PARAMETERS

                    --NONE

         DIAGONAL OF DYNAMIC NOISE MATRIX

             0.0              0.0              0.0              0.0              0.0              0.0

MATRIX 1 = PHI*P*PHI(TRANSPOSE)
  0.255531521901D+00  0.263990617804D+00  0.738493502332D+00  0.883493908980D-05  0.721894536002D-05  0.667810523672D-06
  0.263990617804D+00  0.344299870913D+00  0.107235197976D+01  0.118265084674D-04  0.961103525813D-05  0.303449604790D-05
  0.738493502332D+00  0.107235197976D+01  0.351777547172D+01  0.372606896082D-04  0.301919660090D-04  0.128283721544D-04
  0.883493908980D-05  0.118265084674D-04  0.372606896082D-04  0.407486604442D-09  0.330791934064D-09  0.112718731006D-09
  0.721894536002D-05  0.961103525813D-05  0.301919660090D-04  0.330791934064D-09  0.268810350384D-09  0.884641822312D-10
  0.667810523672D-06  0.303449604790D-05  0.128283721544D-04  0.112718731006D-09  0.884641822312D-10  0.110414392615D-09

TOTAL COVARIANCE MATRIX AT K+1
  0.255531521901D+00  0.263990617804D+00  0.738493502332D+00  0.883493908980D-05  0.721894536002D-05  0.667810523672D-06
  0.263990617804D+00  0.344299870913D+00  0.107235197976D+01  0.118265084674D-04  0.961103525813D-05  0.303449604790D-05
  0.738493502332D+00  0.107235197976D+01  0.351777547172D+01  0.372606896082D-04  0.301919660090D-04  0.128283721544D-04
  0.883493908980D-05  0.118265084674D-04  0.372606896082D-04  0.407486604442D-09  0.330791934064D-09  0.112718731006D-09
  0.721894536002D-05  0.961103525813D-05  0.301919660090D-04  0.330791934064D-09  0.268810350384D-09  0.884641822312D-10
  0.667810523672D-06  0.303449604790D-05  0.128283721544D-04  0.112718731006D-09  0.884641822312D-10  0.110414392615D-09

   CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT EVENT TIME      0.500 DAYS
         BASED ON MEASUREMENTS UP TO TIME      0.458 DAYS

                STD DEV                    X              Y              Z              VX              VY              VZ
```

```
      X         0.50550126D+00      1.00000000
      Y         0.58677071D+00      0.89001602     1.00000000
      Z         0.18755734D+01      0.77891556     0.97439460     1.00000000
     VX         0.20186297D-04      0.86591409     0.99846179     0.98414743     1.00000000
     VY         0.16395437D-04      0.87102079     0.99903050     0.98182558     0.99048263     1.00000000
     VZ         0.10507825D-04      0.12572400     0.49215885     0.65091555     0.53140615     0.51348957     1.00000000


  RSS POSITION ERRORS. . .   0.202918872078D+01
  RSS VELOCITY ERRORS. . .   0.280483751301D-04


          SOLVE-FOR PARAMETERS

                 --NONE

          DYNAMIC CONSIDER PARAMETERS

                 --NONE

          MEASUREMENT CONSIDER PARAMETERS
  RADIUS 1                          0.12900213     0.29197701     0.40672654     0.30416983     0.30723953     0.54480013
  LAT  1                            0.08262037     0.19811883     0.27670151     0.20704865     0.20829930     0.38261640
  LONG 1                           -0.11657146    -0.06320152     0.01234723    -0.04023361    -0.04787184     0.00004483
  RADIUS 2                          0.0            0.0            0.0            0.0            0.0            0.0
  LAT  2                            0.0            0.0            0.0            0.0            0.0            0.0
  LONG 2                           -0.13599409    -0.07048879     0.01073642    -0.04571377    -0.05500952     0.03826021
  RADIUS 3                          0.01521947    -0.23605412    -0.25974806    -0.25057071    -0.26022651    -0.07004586
  LAT  3                           -0.01090619     0.16616126     0.18555710     0.17737487     0.18310772     0.06108290
  LONG 3                           -0.17052716    -0.08560814     0.01031854    -0.05627323    -0.06825937     0.08072670

          NO SOLVE-FOR PARAMETERS

               POSITION EIGENVALUES           SQUARE ROOTS OF EIGENVALUES
                  1      0.1059754779651D+00             1      0.3255387503D+00
                  2      0.1973886654969D-02             2      0.4442844421D-01
                  3      0.4009657499917D+01             3      0.2002412919D+01


               POSITION EIGENVECTORS
                  1      0.9108441033352D+00      0.2941058185436D+00     -0.2895941762507D+00
                  2     -0.3586428271623D+00      0.9112239168746D+00     -0.2025988544900D+00
                  3      0.2042996376515D+00      0.2883968460550D+00      0.9354618737506D+00


               VELOCITY EIGENVALUES           SQUARE ROOTS OF EIGENVALUES
                  1      0.7103434013791D-09             1      0.2665226822D-04
                  2      0.9623948925143D-13             2      0.3102249011D-06
                  3      0.7627170657230D-10             3      0.8733367425D-05


               VELOCITY EIGENVECTORS
                  1      0.7555191716486D+00      0.6125658697832D+00      0.2322796513862D+00
                  2     -0.6350332640831D+00      0.7719075076617D+00      0.2985888684210D-01
                  3     -0.1610078717929D+00     -0.1700642666532D+00      0.9721906245323D+00
```

```
STATE TRANSITION MATRIX PARTITIONS OVER(    0.0  ,    0.500)          --TRANSPOSES SHOWN

                        X(  0.500)          Y(  0.500)          Z(  0.500)          VX(  0.500)          VY(  0.500)          VZ(  0.500)
         X(  0.0  )   0.2448415680D+02  0.1150927196D+03  0.1192852377D+02 -0.2310354181D-03  0.3342637793D-02  0.2815469873D-03
         Y(  0.0  )   0.4602665962D+01 -0.6957175058D+02 -0.3865932965D+01  0.4740791794D-03 -0.2127556147D-02 -0.1212379067D-03
         Z(  0.0  )   0.2818825326D+01  0.2248938749D+01 -0.1925090176D+02  0.4504854218D-04  0.3751321874D-04 -0.3331818955D-03
        VX(  0.0  )   0.2631472643D+05  0.1017076928D+06  0.9561266845D+04 -0.9235642445D-01  0.2928514328D+01  0.2343023094D+00
        VY(  0.0  )  -0.6641341267D+03  0.1153940106D+06  0.9306413089D+04 -0.6334121358D+00  0.3570799292D+01  0.2563171843D+00
        VZ(  0.0  )   0.1120918786D+04  0.1497223024D+05  0.6368174992D+04 -0.5936393838D-01  0.4534621760D+00  0.7075410870D-01

     SOLVE-FOR PARAMETERS

                  --NONE

     DYNAMIC CONSIDER PARAMETERS

                  --NONE
     IGNORE PARAMETERS

                  --NONE


************************************************************************************************************************
                  * ASSUMED GUIDANCE EVENT *



       DIAGONAL OF DYNAMIC NOISE MATRIX
                 0.0                 0.0                 0.0                 0.0                 0.0                 0.0

MATRIX 1 = PHI*P*PHI(TRANSPOSE)
  0.139527651331D+07  0.152365993544D+07  0.193671931181D+06  0.154363452883D+02  0.386827374052D+02  0.397715938017D+01
  0.152365993544D+07  0.196668220390D+07  0.181395679357D+06  0.152639041950D+02  0.512793520663D+02  0.460226225742D+01
  0.193671931181D+06  0.181395679357D+06  0.900810416618D+05  0.230706730337D+01  0.456592749392D+01  0.975945230660D+00
  0.154363452883D+02  0.152639041950D+02  0.230706730337D+01  0.179158133466D-03  0.380433782090D-03  0.426780725078D-04
  0.386827374052D+02  0.512793520663D+02  0.456592749392D+01  0.380433782090D-03  0.134229495229D-02  0.118697324904D-03
  0.397715938017D+01  0.460226225742D+01  0.975945230660D+00  0.426780725078D-04  0.118697324904D-03  0.150038390528D-04

TOTAL COVARIANCE MATRIX AT K+1
  0.139527651331D+07  0.152365993544D+07  0.193671931181D+06  0.154363452883D+02  0.386827374052D+02  0.397715938017D+01
  0.152365993544D+07  0.196668220390D+07  0.181395679357D+06  0.152639041950D+02  0.512793520663D+02  0.460226225742D+01
  0.193671931181D+06  0.181395679357D+06  0.900810416618D+05  0.230706730337D+01  0.456592749392D+01  0.975945230660D+00
  0.154363452883D+02  0.152639041950D+02  0.230706730337D+01  0.179158133466D-03  0.380433782090D-03  0.426780725078D-04
  0.386827374052D+02  0.512793520663D+02  0.456592749392D+01  0.380433782090D-03  0.134229495229D-02  0.118697324904D-03
  0.397715938017D+01  0.460226225742D+01  0.975945230660D+00  0.426780725078D-04  0.118697324904D-03  0.150038390528D-04

 CONTROL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST BEFORE GUIDANCE CORRECTION AT TIME      0.5000000 DAYS

                STD DEV                X               Y               Z               VX              VY              VZ
       X        0.11812182D+04      1.00000000
       Y        0.14023845D+04      0.91979451      1.00000000
       Z        0.30013504D+03      0.54628571      0.43096613      1.00000000
      VX        0.13384997D-01      0.97632875      0.81316799      0.57428213      1.00000000
      VY        0.36637344D-01      0.89384678      0.99804806      0.41522963      0.77577688      1.00000000
      VZ        0.38734789D-02      0.86924391      0.84723340      0.83947458      0.82316204      0.83640333      1.00000000


RSS POSITION ERRORS. . .  0.1857966565600D+04
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RSS VELOCITY ERRORS. . .  0.391976647877D-01


         SOLVE-FOR PARAMETERS

                    --NONE

         DYNAMIC CONSIDER PARAMETERS

                    --NONE

         MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                      0.0           0.0           0.0           0.0           0.0           0.0
LAT   1                       0.0           0.0           0.0           0.0           0.0           0.0
LONG 1                        0.0           0.0           0.0           0.0           0.0           0.0
RADIUS 2                      0.0           0.0           0.0           0.0           0.0           0.0
LAT   2                       0.0           0.0           0.0           0.0           0.0           0.0
LONG 2                        0.0           0.0           0.0           0.0           0.0           0.0
RADIUS 3                      0.0           0.0           0.0           0.0           0.0           0.0
LAT   3                       0.0           0.0           0.0           0.0           0.0           0.0
LONG 3                        0.0           0.0           0.0           0.0           0.0           0.0

         NO SOLVE-FOR PARAMETERS

                    POSITION EIGENVALUES           SQUARE ROOTS OF EIGENVALUES
                       1       0.1449993325867D+06          1      0.3807877789D+03
                       2       0.3253109637551D+07          2      0.1803637890D+04
                       3       0.5393078873235D+05          3      0.2322300341D+03


                    POSITION EIGENVECTORS
                       1       0.6853440766809D+00     -0.6124524731348D+00      0.3939612477255D+00
                       2       0.6371088161320D+00      0.7662966895018D+00      0.8295625392543D-01
                       3      -0.3526979628027D+00      0.1941426068889D+00      0.9153757672263D+00


                    VELOCITY EIGENVALUES           SQUARE ROOTS OF EIGENVALUES
                       1       0.6655721451895D-04          1      0.8158260508D-02
                       2       0.1466600974081D-02          2      0.3829622663D-01
                       3       0.3298736204973D-05          3      0.1816242331D-02


                    VELOCITY EIGENVECTORS
                       1       0.9495723594204D+00     -0.2934464851706D+00      0.1104603755456D+00
                       2       0.2849559761683D+00      0.9546352498732D+00      0.8643859870153D-01
                       3      -0.1308144711821D+00     -0.5060335997248D-01      0.9901145762430D+00




STATE TRANSITION MATRIX PARTITIONS OVER(    0.500,    36.001)          --TRANSPOSES SHOWN

                         X( 36.001)          Y( 36.001)          Z( 36.001)         VX( 36.001)         VY( 36.001)         VZ( 36.001)
          X(   0.500)   0.4463082236D+02 -0.5184955186D+02 -0.9939336756D+00  0.3248716752D-04 -0.2956878076D-04 -0.2058419211D-06
          Y(   0.500)  -0.8213704822D+02  0.7272649981D+02  0.1508015134D+01 -0.5392774756D-04  0.4651882760D-04  0.3262794198D-06
          Z(   0.500)  -0.3934533672D+01  0.3843683852D+01 -0.7741704991D+01 -0.2666827322D-05  0.2349263867D-05 -0.9554389793D-06
         VX(   0.500)   0.7439505955D+07 -0.6054062852D+07 -0.9195751100D+05  0.4674947844D+01 -0.4108899938D+01 -0.2744136971D-01
         VY(   0.500)  -0.7139802867D+07  0.7728713549D+07  0.1040392896D+06 -0.5102103901D+01  0.4489165735D+01  0.2988072965D-01
```

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    VZ(  0.500)  -0.2157675964D+06  0.2047873982D+06  0.9762980906D+06 -0.1471221080D+00  0.1293338870D+00 -0.6167355214D-02

  SOLVE-FOR PARAMETERS

                  --NONE

  DYNAMIC CONSIDER PARAMETERS

                  --NONE
  IGNORE PARAMETERS

                  --NONE
 (VARIATION MATRIX HAS BEEN COMPUTED AND PUNCHED)

    VARIATION MATRIX
        0.4463082236D+02   -0.8213704822D+02   -0.3934533672D+01    0.7439505955D+07   -0.7139802867D+07   -0.2157675964D+06
       -0.5184955186D+02    0.7272649981D+02    0.3843683852D+01   -0.6054062852D+07    0.7728713549D+07    0.2047873982D+06
       -0.9939336756D+00    0.1508015134D+01   -0.7741704991D+01   -0.9195751100D+05    0.1040392896D+06    0.9762980906D+06


      TARGET CONDITION CORRELATION MATRIX AND STANDARD DEVIATIONS BEFORE GUIDANCE CORRECTION
 0.2652947711D+06      0.1000000000D+01     -0.9991859147D+00     -0.9901739327D+00
 0.2778750976D+06     -0.9991859147D+00      0.1000000000D+01      0.9945752177D+00
 0.6215439103D+04     -0.9901739327D+00      0.9945752177D+00      0.1000000000D+01

                             EIGENVALUES           SQUARE ROOTS OF EIGENVALUES
                      1       0.6040155433797D+08            1     0.7771843690D+04
                      2       0.1475740046352D+12            2     0.3841536211D+06
                      3       0.1109371882313D+06            3     0.3330723468D+03


                             EIGENVECTORS
                      1       0.7215445789452D+00      0.6869272566471D+00      0.8662773614772D-01
                      2      -0.6904412243571D+00      0.7232101732888D+00      0.1606116309328D-01
                      3      -0.5161720936878D-01     -0.7140020537063D-01      0.9961112760982D+00


    GUIDANCE MATRIX --   FIXED  TIME OF ARRIVAL GUIDANCE POLICY
        0.1774197888D-05    0.8089896893D-05    0.3230748631D-06   -0.1000000000D+01    0.0                 0.0
        0.8089896893D-05   -0.3060829981D-05   -0.4564607661D-06    0.0                -0.1000000000D+01    0.0
        0.3230748632D-06   -0.4564607661D-06    0.8008726106D-05    0.0                 0.0                -0.1000000000D+01


    VELOCITY CORRECTION CORRELATION MATRIX AND STANDARD DEVIATIONS
 0.7344980970D-02              0.1000000000D+01    -0.4973012394D+00     -0.3935299392D+00
 0.3267841155D-01             -0.4973012394D+00     0.1000000000D+01      0.9847377630D+00
 0.2561856246D-02             -0.3935299392D+00     0.9847377630D+00      0.1000000000D+01
```

```
DELTA-VEE STATISTICS ---

EIGENVALUES OF S ---            0.10880715D-02 KM2/SEC2      0.40201851D-04 KM2/SEC2      0.11711890D-06 KM2/SEC2

TRACE OF S ---                  0.11283904D-02 KM2/SEC2

SQUARE ROOT OF TRACE ---        0.33591523D-01 KM/SEC

EIGENVALUE RATIOS ---           1.00000000          0.03694780          0.00010764

EIGENVECTORS OF S ---           0.99238213D+00      0.11097166D+00      0.53507044D-01
(TRANSPOSE)                    -0.11486842D+00      0.99044730D+00      0.76284897D-01
                               -0.44530445D-01     -0.81850038D-01      0.99564934D+00

MEAN ---                        0.27388937D-01 KM/SEC

STANDARD DEVIATION ---          0.19448305D-01 KM/SEC

DELTA-VEE(90) =                 0.54643768D-01 KM/SEC
DELTA-VEE(99) =                 0.85225253D-01 KM/SEC
DELTA-VEE(99.9) =               0.10875402D+00 KM/SEC
DELTA-VEE(99.99) =              0.12852326D+00 KM/SEC



     EXPECTED VALUE OF VELOCITY CORRECTION
        -0.3146123813D-02    0.2712729904D-01    0.2089362263D-02

SIGPRO=    0.1000000000D-03    SIGRES=    0.1000000000D-09
SIGALP=    0.3430000000D-03    SIGBET=    0.3430000000D-03

EXECUTION ERROR CORRELATION MATRIX AND STANDARD DEVIATIONS
     0.5048750977D-03                0.1000000000D+01    0.1464575205D+00    0.6246660920D-02
     0.2803203964D-03                0.1464575205D+00    0.1000000000D+01   -0.9700808444D-01
     0.5062040727D-03                0.6246660920D-02   -0.9700808444D-01    0.1000000000D+01

                          EIGENVALUES               SQUARE ROOTS OF EIGENVALUES
                     1     0.2573027819011D-06            1    0.5072502163D-03
                     2     0.7511538830937D-07            2    0.2740718671D-03
                     3     0.2573027819011D-06            3    0.5072502163D-03


                          EIGENVECTORS
                     1     0.9932588719421D+00      0.1157178983607D+00     -0.6795682996148D-02
                     2    -0.1148684151529D+00      0.9904473038243D+00      0.7628489724291D-01
                     3     0.1555829388679D-01     -0.7499004164606D-01      0.9970629033041D+00

CONTROL (AND KNOWLEDGE) CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST AFTER GUIDANCE CORRECTION AT TIME   0.500 DAYS

                 STD DEV              X              Y              Z              VX             VY             VZ
         X     0.50550126D+00     1.00000000
         Y     0.58677071D+00     0.89001602     1.00000000
         Z     0.18755734D+01     0.77891556     0.97439460     1.00000000
        VX     0.50527849D-03     0.03429000     0.03988938     0.03931751     1.00000000
        VY     0.28079946D-03     0.05085753     0.05833181     0.05732725     0.14842239     1.00000000
        VZ     0.50631312D-03     0.00260923     0.01021407     0.01350885     0.00668093    -0.09619949     1.00000000


 RSS POSITION ERRORS. . .  0.202918872078D+01
 RSS VELOCITY ERRORS. . .  0.768444964496D-03
```

```
        SOLVE-FOR PARAMETERS

                  --NONE

        DYNAMIC CONSIDER PARAMETERS

                  --NONE

        MEASUREMENT CONSIDER PARAMETERS
 RADIUS 1                           0.12900213    0.29197701    0.40672654    0.01215184    0.01793923    0.01130657
 LAT   1                            0.08262037    0.19811883    0.27670151    0.00827177    0.01216227    0.00794067
 LONG 1                            -0.11657146   -0.06320152    0.01234723   -0.00160737   -0.00279516    0.00000093
 RADIUS 2                           0.0           0.0           0.0           0.0           0.0           0.0
 LAT   2                            0.0           0.0           0.0           0.0           0.0           0.0
 LONG 2                            -0.13599409   -0.07048879    0.01073642   -0.00182630   -0.00321192    0.00079404
 RADIUS 3                           0.01521947   -0.23605412   -0.25974806   -0.01001051   -0.01519422   -0.00145370
 LAT   3                           -0.01090619    0.16616126    0.18555710    0.00708627    0.01069137    0.00126769
 LONG 3                            -0.17052716   -0.08560814    0.01031854   -0.00224816   -0.00398556    0.00167537

        NO SOLVE-FOR PARAMETERS

                 POSITION EIGENVALUES           SQUARE ROOTS OF EIGENVALUES
                    1        0.1059754779651D+00             1     0.3255387503D+00
                    2        0.1973886654969D-02             2     0.4442844421D-01
                    3        0.4009657499917D+01             3     0.2002412919D+01


                 POSITION EIGENVECTORS
                    1        0.9108441033352D+00        0.2941058185436D+00       -0.2895941762507D+00
                    2       -0.3586428271623D+00        0.9112239168746D+00       -0.2025988544900D+00
                    3        0.2042996376515D+00        0.2883968460550D+00        0.9354618737506D+00


                 VELOCITY EIGENVALUES           SQUARE ROOTS OF EIGENVALUES
                    1        0.2578085832169D-06             1     0.5077485531D-03
                    2        0.7532066286046D-07             2     0.2744461019D-03
                    3        0.2573784073817D-06             3     0.5073247553D-03


                 VELOCITY EIGENVECTORS
                    1        0.9672061435015D+00        0.9583581073448D-01        0.2352185650706D+00
                    2       -0.1165838191722D+00        0.9902752325254D+00        0.7591559098031D-01
                    3       -0.2256556870106D+00       -0.1008487046398D+00        0.9689731934848D+00

       TARGET CONDITION CORRELATION MATRIX AND STANDARD DEVIATIONS AFTER  GUIDANCE CORRECTION
   0.3984468041D+04           0.1000000000D+01     -0.9895349199D+00     -0.7582339546D-01
   0.3472894984D+04          -0.9895349199D+00      0.1000000000D+01      0.6686719135D-01
   0.4938465471D+03          -0.7582339546D-01      0.6686719135D-01      0.1000000000D+01

                     EIGENVALUES              SQUARE ROOTS OF EIGENVALUES
                  1  0.2779482443547D+08            1     0.5272079707D+04
                  2  0.1421375255436D+06            2     0.3770113069D+03
                  3  0.2439075936753D+06            3     0.4938700170D+03


                     EIGENVECTORS
                  1  0.7542964813476D+00       -0.6564985450687D+00       -0.6817517828885D-02
                  2  0.6528770331751D+00        0.7489601116074D+00        0.1131827317818D+00
                  3 -0.6919824982767D-01       -0.8982433714609D-01        0.9935507992433D+00
```

```
       ERROR ANALYSIS MODE-   PREDICTION    EVENT AT TRAJECTORY TIME 0.15000000D+01 DAYS          PROBLEM. .        0
                                          PREDICTING TO TRAJECTORY TIME. . . 0.50000000D+01 DAYS
**********************************************************************************************************************
       AT TRAJECTORY TIME      1.5000

  STATE          X-COMP          Y-COMP          Z-COMP          RADIUS          X-DOT          Y-DOT          Z-DOT        VELOCITY

  INERTIAL -0.1825400D+06  0.2251049D+06  0.8450351D+04  0.2899387D+06   -1.10026065    0.96208888     0.01828918    1.46168499
  HELIO-    0.4719259D+08 -0.1442910D+09  0.7823107D+04  0.1518125D+09   26.72025286   10.12514743     0.01841908   28.57430424
  ROT.GEO- -0.2707671D+06 -0.1033355D+06  0.8450351D+04  0.2899387D+06   -1.27686062   -0.69366870     0.01828940    1.45323219




 STATE TRANSITION MATRIX PARTITIONS OVER(     1.400,     1.500)            --TRANSPOSES SHOWN

                           X(  1.500)         Y(  1.500)         Z(  1.500)         VX(  1.500)        VY(  1.500)        VZ(  1.500)
        X(  1.400)    0.1000116609D+01 -0.9892422037D-03 -0.3755736185D-04  0.2700381847D-07 -0.2241644015D-06 -0.8484375733D-08
        Y(  1.400)   -0.9892441348D-03  0.1000558614D+01  0.4680821691D-04 -0.2241655611D-06  0.1259909210D-06  0.1054700781D-07
        Z(  1.400)   -0.3755752386D-04  0.4680832706D-04  0.9993252260D+00 -0.8484473077D-08  0.1054707441D-07 -0.1527921318D-06
       VX(  1.400)    0.8640335430D+04 -0.2787320810D+01 -0.1054858084D+00  0.1000116386D+01 -0.9473276370D-03 -0.3573984181D-04
       VY(  1.400)   -0.2787341286D+01  0.8641565731D+04  0.1311163817D+00 -0.9473297118D-03  0.1000529536D+01  0.4430805578D-04
       VZ(  1.400)   -0.1054975190D+00  0.1311176026D+00  0.8638099595D+04 -0.3574001606D-04  0.4430817564D-04  0.9993545036D+00

    SOLVE-FOR PARAMETERS

                 --NONE

    DYNAMIC CONSIDER PARAMETERS

                 --NONE
    IGNORE PARAMETERS

                 --NONE

       DIAGONAL OF DYNAMIC NOISE MATRIX

          0.0             0.0             0.0             0.0             0.0             0.0

 MATRIX 1 = PHI*P*PHI(TRANSPOSE)
   0.1447702937310+00  0.1550819907870+00  0.3666635410590+00  0.1917366147480-05  0.1601241225760-05  0.2143907744850-05
   0.1550819907870+00  0.1735152573540+00  0.4012653979950+00  0.2203082528330-05  0.1834103084270-05  0.2203243157620-05
   0.3666635410590+00  0.4012653979950+00  0.1225133427430+01  0.5261498041530-05  0.4327131278150-05  0.7510796517910-05
  .0.1917366147480-05  0.2203082528330-05  0.5261498041530-05  0.2918187959090-10  0.2399982447640-10  0.2892384291550-10
   0.1601241225760-05  0.1834103084270-05  0.4327131278150-05  0.2399982447640-10  0.1983216662450-10  0.2355617647430-10
   0.2143907744850-05  0.2203243157620-05  0.7510796517910-05  0.2892384291550-10  0.2355617647430-10  0.5277151032230-10

 TOTAL COVARIANCE MATRIX AT K+1
   0.1447702937310+00  0.1550819907870+00  0.3666635410590+00  0.1917366147480-05  0.1601241225760-05  0.2143907744850-05
   0.1550819907870+00  0.1735152573540+00  0.4012653979950+00  0.2203082528330-05  0.1834103084270-05  0.2203243157620-05
   0.3666635410590+00  0.4012653979950+00  0.1225133427430+01  0.5261498041530-05  0.4327131278150-05  0.7510796517910-05
   0.1917366147480-05  0.2203082528330-05  0.5261498041530-05  0.2918187959090-10  0.2399982447640-10  0.2892384291550-10
   0.1601241225760-05  0.1834103084270-05  0.4327131278150-05  0.2399982447640-10  0.1983216662450-10  0.2355617647430-10
   0.2143907744850-05  0.2203243157620-05  0.7510796517910-05  0.2892384291550-10  0.2355617647430-10  0.5277151032230-10

    CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT EVENT TIME     1.500 DAYS
         BASED ON MEASUREMENTS UP TO TIME     1.400 DAYS
```

```
              STD DEV                   X              Y              Z              VX             VY             VZ
      X       0.38048692D+00        1.00000000
      Y       0.41655163D+00        0.97848192     1.00000000
      Z       0.11068575D+01        0.87063537     0.87030441     1.00000000
     VX       0.54020255D-05        0.93284330     0.97905097     0.87995627     1.00000000
     VY       0.44533321D-05        0.94500032     0.98871205     0.87785603     0.99762277     1.00000000
     VZ       0.72644002D-05        0.77565144     0.72810470     0.93410251     0.73705450     0.72814849     1.00000000


RSS POSITION ERRORS. . .   0.1242344146570+01
RSS VELOCITY ERRORS. . .   0.1008882819 1D-04


         SOLVE-FOR PARAMETERS

                  --NONE

         DYNAMIC CONSIDER PARAMETERS

                  --NONE

         MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                                0.61025411     0.57756642     0.79584488     0.53604555     0.55669897     0.77326488
LAT   1                                 0.42298119     0.40287960     0.55342683     0.37384709     0.38802596     0.54024015
LONG 1                                 -0.43077117    -0.33737097    -0.01790800    -0.18317114    -0.22152009    -0.01814879
RADIUS 2                               -0.01577910    -0.10150225     0.00257263    -0.13984156    -0.14471711     0.06055829
LAT   2                                -0.01139378    -0.07329277     0.00185765    -0.10097682    -0.10449737     0.04372794
LONG 2                                 -0.33950926    -0.23818893     0.04082400    -0.07709499    -0.11754895     0.02569300
RADIUS 3                               -0.17487514    -0.20658718    -0.10158684    -0.26947780    -0.25247323    -0.20159451
LAT   3                                 0.12668616     0.15060730     0.07552862     0.19388791     0.18229496     0.13517353
LONG 3                                 -0.29194903    -0.20392978     0.10506459    -0.03256852    -0.08146963     0.09533406

         NO SOLVE-FOR PARAMETERS

       TARGETED NOMINAL AT     5.000
         -0.4353053190+06   0.426744122D+06   0.109345126D+05  -0.667818680D+00   0.495650074D+00   0.296815880D-02




STATE TRANSITION MATRIX PARTITIONS OVER(     1.500,     5.000)          --TRANSPOSES SHOWN

                            X(  5.000)          Y(  5.000)          Z(  5.000)          VX(  5.000)         VY(  5.000)         VZ(  5.000)
       X(  1.500)    0.1126834210D+01 -0.5022262103D+00 -0.1677227612D-01  0.8050036412D-06 -0.2525757355D-05 -0.8004246469D-07
       Y(  1.500)   -0.5075455050D+00  0.1264484704D+01  0.1933931668D-01 -0.2582989726D-05  0.1377433787D-05  0.9068224159D-07
       Z(  1.500)   -0.1723995172D-01  0.1906988591D-01  0.6855224791D+00 -0.8514530773D-07  0.9432101281D-07 -0.1483676904D-05
      VX(  1.500)    0.3112947531D+06 -0.3249946930D+05 -0.1011042467D+04  0.1075949357D+01 -0.2393857912D+00 -0.7020344362D-02
      VY(  1.500)   -0.3264905165D+05  0.3172207377D+06  0.1109214044D+04 -0.2413029326D+00  0.1106194641D+01  0.7492104816D-02
      VZ(  1.500)   -0.1024409954D+04  0.1118741162D+04  0.2814702834D+06 -0.7194660862D-02  0.7617527078D-02  0.8494366445D+00

    SOLVE-FOR PARAMETERS

                  --NONE

    DYNAMIC CONSIDER PARAMETERS

                  --NONE
    IGNORE PARAMETERS
```

```
                    --NONE

          DIAGONAL OF DYNAMIC NOISE MATRIX

                0.0               0.0               0.0               0.0               0.0               0.0

   MATRIX 1 = PHI*P*PHI(TRANSPOSE)
     0.292655674894D+01  0.273189389706D+01  0.378352948031D+01  0.656207799190D-05  0.582849805638D-05  0.545894841654D-05
     0.273189389706D+01  0.257064676355D+01  0.344794051150D+01  0.611834786019D-05  0.549305919294D-05  0.487244918680D-05
     0.378352948031D+01  0.344794051150D+01  0.765855901971D+01  0.831033107696D-05  0.731366153750D-05  0.126117151520D-04
     0.656207799190D-05  0.611834786019D-05  0.831033107696D-05  0.148741664906D-10  0.131293068727D-10  0.118724376583D-10
     0.582849805638D-05  0.549305919294D-05  0.731366153750D-05  0.131293068727D-10  0.117855273703D-10  0.102538780234D-10
     0.545894841654D-05  0.487244918680D-05  0.126117151520D-04  0.118724376583D-10  0.102538780234D-10  0.218375455415D-10

   TOTAL COVARIANCE MATRIX AT K+1
     0.292655674894D+01  0.273189389706D+01  0.378352948031D+01  0.656207799190D-05  0.582849805638D-05  0.545894841654D-05
     0.273189389706D+01  0.257064676355D+01  0.344794051150D+01  0.611834786019D-05  0.549305919294D-05  0.487244918680D-05
     0.378352948031D+01  0.344794051150D+01  0.765855901971D+01  0.831033107696D-05  0.731366153750D-05  0.126117151520D-04
     0.656207799190D-05  0.611834786019D-05  0.831033107696D-05  0.148741664906D-10  0.131293068727D-10  0.118724376583D-10
     0.582849805638D-05  0.549305919294D-05  0.731366153750D-05  0.131293068727D-10  0.117855273703D-10  0.102538780234D-10
     0.545894841654D-05  0.487244918680D-05  0.126117151520D-04  0.118724376583D-10  0.102538780234D-10  0.218375455415D-10

       CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME    5.000 DAYS
            BASED ON PREDICTION FROM TIME    1.500 DAYS

                     STD DEV                 X              Y              Z              VX             VY             VZ
           X       0.17107182D+01        1.00000000
           Y       0.16033237D+01        0.99601104     1.00000000
           Z       0.27674103D+01        0.79918089     0.77707870     1.00000000
           VX      0.38567041D-05        0.99459574     0.98945636     0.77862519     1.00000000
           VY      0.34330056D-05        0.99243865     0.99797248     0.76981575     0.99163300     1.00000000
           VZ      0.46730660D-05        0.68285517     0.65031565     0.97521121     0.65875158     0.63916314     1.00000000


    RSS POSITION ERRORS. . .  0.362708745858D+01
    RSS VELOCITY ERRORS. . .  0.696399593642D-05


          SOLVE-FOR PARAMETERS

                    --NONE

          DYNAMIC CONSIDER PARAMETERS

                    --NONE

          MEASUREMENT CONSIDER PARAMETERS
    RADIUS 1                             0.54893797     0.56354687     0.78974660     0.51015007     0.55928986     0.74171228
    LAT  1                               0.38220545     0.39314853     0.55105087     0.35564723     0.39044741     0.51912143
    LONG 1                              -0.22721695    -0.23495144    -0.01834199    -0.15373567    -0.18551151    -0.01768645
    RADIUS 2                            -0.11686595    -0.14332072     0.04520771    -0.14424700    -0.16648089     0.07844537
    LAT  2                              -0.08438659    -0.10348906     0.03264359    -0.10415790    -0.12021256     0.05664385
    LONG 2                              -0.12201253    -0.13223166     0.03020822    -0.04529304    -0.08275172     0.01965442
    RADIUS 3                            -0.25972296    -0.24237356    -0.17691922    -0.28681350    -0.25269514    -0.23064571
    LAT  3                               0.18680389     0.17547884     0.12067118     0.20577565     0.18273583     0.15207013
    LONG 3                              -0.07464355    -0.09850605     0.09924331     0.00346432    -0.05226331     0.08890071

          NO SOLVE-FOR PARAMETERS

                    POSITION EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
                       1      0.1341514335903D+01          1     0.1158237599D+01
```

```
   2      0.9164545258142D-02          2    0.9573163144D-01
   3      0.1180508455104D+02          3    0.3435852814D+01

POSITION EIGENVECTORS
   1      0.5438763236769D+00     0.5555226645043D+00     -0.6269619334798D+00
   2     -0.7002051074877D+00     0.7135136456511D+00      0.2472013183172D-01
   3      0.4625055156359D+00     0.4269576638165D+00      0.7770429855005D+00

VELOCITY EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
   1      0.4005594083329D-10          1    0.6328976286D-05
   2      0.1058770239711D-12          2    0.3253874982D-06
   3      0.8335421545156D-11          3    0.2887113012D-05

VELOCITY EIGENVECTORS
   1      0.5687348479597D+00     0.5007944458217D+00      0.6524918357730D+00
   2     -0.6724719872073D+00     0.7398970078656D+00      0.1827140314823D-01
   3     -0.4736265397312D+00    -0.4491740651303D+00      0.7575754484383D+00
```

```
       ERROR ANALYSIS MODE-FINAL INSERTION  EVENT AT TRAJECTORY TIME 0.34547190D+02 DAYS          PROBLEM. .          0
***********************************************************************************************************************
       AT TRAJECTORY TIME     34.5472

 STATE          X-COMP          Y-COMP          Z-COMP          RADIUS          X-DOT          Y-DOT          Z-DOT        VELOCITY

 INERTIAL -0.1162555D+07  0.9590978D+06  0.4007736D+03  0.1507117D+07  -0.11696875    0.10617756  -0.00614138    0.15809200
 HELIO-    0.1145084D+09 -0.9698422D+08 -0.2005447D+03  0.1500604D+09  18.65823215   22.73287502  -0.00512210   29.40940768
 ROT.GEO- -0.1506994D+07 -0.1929650D+05  0.4007736D+03  0.1507117D+07  -0.16162185    0.29776686  -0.00613297    0.33885740




STATE TRANSITION MATRIX PARTITIONS OVER(   31.000,   34.547)          --TRANSPOSES SHOWN

                       X( 34.547)         Y( 34.547)         Z( 34.547)        VX( 34.547)        VY( 34.547)        VZ( 34.547)
      X( 31.000)   0.1005853692D+01 -0.1149116945D-01 -0.1551674641D-04  0.3818982608D-07 -0.7408296588D-07 -0.8080135068D-10
      Y( 31.000)  -0.1149160675D-01  0.1001964762D+01  0.1277238917D-04 -0.7409013956D-07  0.1249164078D-07  0.6653716717D-10
      Z( 31.000)  -0.1554449896D-04  0.1279534913D-04  0.9922412058D+00 -0.8124612562D-10  0.6690490158D-10 -0.4991436557D-07
     VX( 31.000)   0.3070710023D+06 -0.1157377603D+04 -0.1256582409D+01  0.1005796574D+01 -0.1118519416D-01 -0.9257166693D-05
     VY( 31.000)  -0.1157404444D+04  0.3066695734D+06  0.1034809484D+01 -0.1118563614D-01  0.1001819681D+01  0.7626799337D-05
     VZ( 31.000)  -0.1258426130D+01  0.1036331415D+01  0.3056947057D+06 -0.9283931377D-05  0.7648916153D-05  0.9924415927D+00

    SOLVE-FOR PARAMETERS

              --NONE

    DYNAMIC CONSIDER PARAMETERS

              --NONE
    IGNORE PARAMETERS

              --NONE

        DIAGONAL OF DYNAMIC NOISE MATRIX

           0.0              0.0              0.0              0.0              0.0              0.0

MATRIX 1 = PHI*P*PHI(TRANSPOSE)
  0.6770832427660D+01 -0.3129002087590D+01  0.2838224552580D+01  0.1870606594980D-04 -0.1448068216840D-04 -0.2504864620950D-08
 -0.3129002087590D+01  0.6669411540900D+01  0.3942320518350D+01 -0.1456842542150D-04  0.1658965325470D-04  0.4460448443400D-06
  0.2838224552580D+01  0.3942320518350D+01  0.1516211633510D+02 -0.1168090713730D-06  0.6749825356460D-06  0.3750783239300D-05
  0.1870606594980D-04 -0.1456842542150D-04 -0.1168090713730D-06  0.6156326351300D-10 -0.4803836875310D-10 -0.5131782208320D-12
 -0.1448068216840D-04  0.1658965325470D-04  0.6749825356460D-06 -0.4803836875310D-10  0.5407074065380D-10  0.5843329767360D-12
 -0.2504864620950D-08  0.4460448443400D-06  0.3750783239300D-05 -0.5131782208320D-12  0.5843329767360D-12  0.9825325467830D-11

TOTAL COVARIANCE MATRIX AT K+1
  0.6770832427660D+01 -0.3129002087590D+01  0.2838224552580D+01  0.1870606594980D-04 -0.1448068216840D-04 -0.2504864620950D-08
 -0.3129002087590D+01  0.6669411540900D+01  0.3942320518350D+01 -0.1456842542150D-04  0.1658965325470D-04  0.4460448443400D-06
  0.2838224552580D+01  0.3942320518350D+01  0.1516211633510D+02 -0.1168090713730D-06  0.6749825356460D-06  0.3750783239300D-05
  0.1870606594980D-04 -0.1456842542150D-04 -0.1168090713730D-06  0.6156326351300D-10 -0.4803836875310D-10 -0.5131782208320D-12
 -0.1448068216840D-04  0.1658965325470D-04  0.6749825356460D-06 -0.4803836875310D-10  0.5407074065380D-10  0.5843329767360D-12
 -0.2504864620950D-08  0.4460448443400D-06  0.3750783239300D-05 -0.5131782208320D-12  0.5843329767360D-12  0.9825325467830D-11

     CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT EVENT TIME    34.547 DAYS
         BASED ON MEASUREMENTS UP TO TIME    31.000 DAYS

              STD DEV                   X                Y                Z                VX               VY               VZ
```

```
      X        0.26020823D+01       1.00000000
      Y        0.25825204D+01      -0.46563012    1.00000000
      Z        0.38938562D+01       0.28012109    0.39203809    1.00000000
     VX        0.78462261D-05       0.91622178   -0.71896548   -0.00382328   1.00000000
     VY        0.73532809D-05      -0.75680994    0.87359953    0.02357390  -0.83261892   1.00000000
     VZ        0.31345375D-05      -0.00030711    0.05510123    0.30730426  -0.02086575   0.02535162   1.00000000


RSS POSITION ERRORS. . .  0.534811745417D+01
RSS VELOCITY ERRORS. . .  0.112008628969D-04


     SOLVE-FOR PARAMETERS

           --NONE

     DYNAMIC CONSIDER PARAMETERS

           --NONE

     MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                     0.23597136    0.37476411    0.81070816   -0.00213212    0.02343533    0.07687363
LAT  1                       0.16300269    0.25901837    0.56009351   -0.00155279    0.01610984    0.05217086
LONG 1                      -0.24475987   -0.26377406    0.03968606    0.00109735    0.00447030   -0.01324388
RADIUS 2                     0.16593449    0.16493759    0.43502515    0.00288103   -0.00082371   -0.00722827
LAT  2                       0.11740348    0.11665031    0.30767129    0.00202369   -0.00060590   -0.00535862
LONG 2                      -0.23383385   -0.22801733    0.07887893   -0.00070456    0.00774797    0.00279494
RADIUS 3                     0.07149135   -0.00067880    0.14559004    0.00003657   -0.01806919   -0.08357345
LAT  3                      -0.04932553    0.00040249   -0.10025590   -0.00003570    0.01244345    0.05791271
LONG 3                      -0.20007658   -0.22255347    0.12068100    0.00422405    0.00629113    0.01108882

     NO SOLVE-FOR PARAMETERS

           POSITION EIGENVALUES        SQUARE ROOTS OF EIGENVALUES
              1     0.9789002347399D+01            1     0.3128738140D+01
              2     0.1850379104491D+01            2     0.1360286405D+01
              3     0.1696297885173D+02            3     0.4118613705D+01


           POSITION EIGENVECTORS
              1     0.7531375304467D+00      -0.6528367459454D+00      0.8116676275430D-01
              2     0.6365181731153D+00       0.6919602475986D+00     -0.3406400314662D+00
              3     0.1662181564289D+00       0.3082129116158D+00      0.9366836849154D+00


           VELOCITY EIGENVALUES        SQUARE ROOTS OF EIGENVALUES
              1     0.1060074458171D-09            1     0.1029599174D-04
              2     0.9602840659546D-11            2     0.3098845053D-05
              3     0.9849043158003D-11            3     0.3138318524D-05


           VELOCITY EIGENVECTORS
              1     0.7349523232598D+00      -0.6790452962472D+00     -0.8041912797659D-02
              2     0.6343833081846D+00       0.6899020919463D+00     -0.3487017663060D+00
              3     0.2423324266655D+00       0.2508636864370D+00      0.9371992348554D+00
```

```
STATE TRANSITION MATRIX PARTITIONS OVER(    31.000,    34.547)          --TRANSPOSES SHOWN

                          X( 34.547)          Y( 34.547)          Z( 34.547)         VX( 34.547)         VY( 34.547)         VZ( 34.547)
          X( 31.000)   0.1005853692D+01 -0.1149116945D-01 -0.1551674641D-04  0.3818982608D-07 -0.7408296588D-07 -0.8080135068D-10
          Y( 31.000)  -0.1149160675D-01  0.1001964762D+01  0.1277238917D-04 -0.7409013956D-07  0.1249164078D-07  0.6653716717D-10
          Z( 31.000)  -0.1554449896D-04  0.1279534913D-04  0.9922412058D+00 -0.8124612562D-10  0.6690490158D-10 -0.4991436557D-07
         VX( 31.000)   0.3070710023D+06 -0.1157377603D+04 -0.1256582409D+01  0.1005796574D+01 -0.1118519416D-01 -0.9257166693D-05
         VY( 31.000)  -0.1157404444D+04  0.3066695734D+06  0.1034809484D+01 -0.1118563614D-01  0.1001819681D+01  0.7626799337D-05
         VZ( 31.000)  -0.1258426130D+01  0.1036331415D+01  0.3056947057D+06 -0.9283931377D-05  0.7648916153D-05  0.9924415927D+00

     SOLVE-FOR PARAMETERS

                     --NONE

     DYNAMIC CONSIDER PARAMETERS

                     --NONE
     IGNORE PARAMETERS

                     --NONE



*******************************************************************************************************************************************
                     * ASSUMED GUIDANCE EVENT *



      DIAGONAL OF DYNAMIC NOISE MATRIX
                 0.0                 0.0                 0.0                 0.0                 0.0                 0.0

MATRIX 1 = PHI*P*PHI(TRANSPOSE)
  0.67708324276 6D+01 -0.31290020875 9D+01  0.28382245525 8D+01  0.18706065949 8D-04 -0.14480682168 4D-04 -0.25048646209 5D-08
 -0.31290020875 9D+01  0.66694115409 0D+01  0.39423205183 5D+01 -0.14568425421 5D-04  0.16589653254 7D-04  0.44604484434 0D-06
  0.28382245525 8D+01  0.39423205183 5D+01  0.15162116335 1D+02 -0.11680907137 3D-06  0.67498253564 6D-06  0.37507832393 0D-05
  0.18706065949 8D-04 -0.14568425421 5D-04 -0.11680907137 3D-06  0.61563263513 0D-10 -0.48038368753 1D-10 -0.51317822083 2D-12
 -0.14480682168 4D-04  0.16589653254 7D-04  0.67498253564 6D-06 -0.48038368753 1D-10  0.54070740653 8D-10  0.58433297673 6D-12
 -0.25048646209 5D-08  0.44604484434 0D-06  0.37507832393 0D-05 -0.51317822083 2D-12  0.58433297673 6D-12  0.98253254678 3D-11

TOTAL COVARIANCE MATRIX AT K+1
  0.67708324276 6D+01 -0.31290020875 9D+01  0.28382245525 8D+01  0.18706065949 8D-04 -0.14480682168 4D-04 -0.25048646209 5D-08
 -0.31290020875 9D+01  0.66694115409 0D+01  0.39423205183 5D+01 -0.14568425421 5D-04  0.16589653254 7D-04  0.44604484434 0D-06
  0.28382245525 8D+01  0.39423205183 5D+01  0.15162116335 1D+02 -0.11680907137 3D-06  0.67498253564 6D-06  0.37507832393 0D-05
  0.18706065949 8D-04 -0.14568425421 5D-04 -0.11680907137 3D-06  0.61563263513 0D-10 -0.48038368753 1D-10 -0.51317822083 2D-12
 -0.14480682168 4D-04  0.16589653254 7D-04  0.67498253564 6D-06 -0.48038368753 1D-10  0.54070740653 8D-10  0.58433297673 6D-12
 -0.25048646209 5D-08  0.44604484434 0D-06  0.37507832393 0D-05 -0.51317822083 2D-12  0.58433297673 6D-12  0.98253254678 3D-11

  CONTROL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST BEFORE GUIDANCE CORRECTION AT TIME     34.5471901 DAYS

                 STD DEV                  X              Y              Z             VX             VY             VZ
        X        0.26020823D+01       1.00000000
        Y        0.25825204D+01      -0.46503012     1.00000000
        Z        0.38938562D+01       0.28012109     0.39203809     1.00000000
       VX        0.78462261D-05       0.91622178    -0.71896548    -0.00382328     1.00000000
       VY        0.73532809D-05      -0.75680994     0.87359953     0.02357390    -0.83261892     1.00000000
       VZ        0.31345375D-05      -0.00030711     0.05510123     0.30730426    -0.02086575     0.02535162     1.00000000


 RSS POSITION ERRORS. . .   0.5348117454 17D+01
```

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RSS VELOCITY ERRORS. . .  0.112008628969D-04


        SOLVE-FOR PARAMETERS

                 --NONE

        DYNAMIC CONSIDER PARAMETERS

                 --NONE

        MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                          0.23597136    0.37476411    0.81070816   -0.00213212    0.02343533    0.07687363
LAT  1                            0.16300269    0.25901837    0.56009351   -0.00155279    0.01610984    0.05217086
LONG 1                           -0.24475987   -0.26377406    0.03968606    0.00109735    0.00447030   -0.01324388
RADIUS 2                          0.16593449    0.16493759    0.43502515    0.00288103   -0.00082371   -0.00722827
LAT  2                            0.11740348    0.11665031    0.30767129    0.00202369   -0.00060590   -0.00535862
LONG 2                           -0.23383385   -0.22801733    0.07887893   -0.00070456    0.00774797    0.00279494
RADIUS 3                          0.07149135   -0.00067880    0.14559004    0.00003657   -0.01806919   -0.08357345
LAT  3                           -0.04932553    0.00040249   -0.10025590   -0.00003570    0.01244345    0.05791271
LONG 3                           -0.20007658   -0.22255347    0.12068100    0.00422405    0.00629113    0.01108882

        NO SOLVE-FOR PARAMETERS

                 POSITION EIGENVALUES           SQUARE ROOTS OF EIGENVALUES
                    1      0.9789002347399D+01            1     0.3128738140D+01
                    2      0.1850379104491D+01            2     0.1360286405D+01
                    3      0.1696297885173D+02            3     0.4118613705D+01


                 POSITION EIGENVECTORS
                    1      0.7531375304467D+00      -0.6528367459454D+00      0.8116676275430D-01
                    2      0.6365181731153D+00       0.6919602475986D+00     -0.3406400314662D+00
                    3      0.1662181564289D+00       0.3082129116158D+00      0.9366836849154D+00


                 VELOCITY EIGENVALUES           SQUARE ROOTS OF EIGENVALUES
                    1      0.1060074458171D-09            1     0.1029599174D-04
                    2      0.9602840659546D-11            2     0.3098845053D-05
                    3      0.9849043158003D-11            3     0.3138318524D-05


                 VELOCITY EIGENVECTORS
                    1      0.7340523232598D+00      -0.6790452962472D+00     -0.8041912797659D-02
                    2      0.6343833081846D+00       0.6899020919463D+00     -0.3487017663060D+00
                    3      0.2423324266655D+00       0.2508636864370D+00      0.9371992348554D+00




STATE TRANSITION MATRIX PARTITIONS OVER(   34.547,   36.000)          --TRANSPOSES SHOWN

                          X( 36.000)        Y( 36.000)        Z( 36.000)        VX( 36.000)       VY( 36.000)       VZ( 36.000)
          X( 34.547)   0.1000965990D+01 -0.1810193822D-02 -0.2929404784D-06  0.1550634221D-07 -0.2875091423D-07 -0.3166371862D-11
          Y( 34.547)  -0.1810205714D-02  0.1000264320D+01  0.2413440050D-06 -0.2875144318D-07  0.4069481775D-08  0.2606237424D-11
          Z( 34.547)  -0.2931017457D-06  0.2414754741D-06  0.9987711970D+00 -0.3171899158D-11  0.2610725732D-11 -0.1952789444D-07
         VX( 34.547)   0.1255633851D+06 -0.7545115749D+02 -0.7543754140D-02  0.1000979007D+01 -0.1797982418D-02 -0.1046297705D-06
         VY( 34.547)  -0.7545143457D+02  0.1255334671D+06  0.6203936108D-02 -0.1797997055D-02  0.1000245386D+01  0.8589545112D-07
```

```
    VZ( 34.547)  -0.7546654029D-02  0.6206296368D-02  0.1254715038D+06 -0.1047458123D-06  0.8598955532D-07  0.9987771061D+00

  SOLVE-FOR PARAMETERS

                 --NONE

  DYNAMIC CONSIDER PARAMETERS
                           0.2029424448D+05 -0.4345885069D+04 -0.4778164934D-03  0.3323481729D+00 -0.7125082400D-01 -0.8255466675D-08
                           0.7813996133D+02  0.3657676912D+03  0.2074452579D+05  0.1277897515D-02  0.5988549898D-02  0.3395839162D+00
                          -0.4334485720D+04 -0.2028929743D+05  0.3739737782D+03 -0.7088601178D-01 -0.3321875247D+00  0.6121878948D-02



  IGNORE PARAMETERS

                 --NONE

     **********     FINAL INSERTION HAS DURATION    0.1452809870D+01     **********


MATRIX 1 = PHI*P*PHI(TRANSPOSE)
  0.124777525598D+02 -0.757550477747D+01  0.280713265162D+01  0.268317568619D-04 -0.208961213245D-06 -0.122811120255D-06
 -0.757550477747D+01  0.117122849491D+02  0.408322065698D+01 -0.210323290225D-04  0.236327240469D-04  0.440407515547D-06
  0.280713265162D+01  0.408322065698D+01  0.162196343005D+02 -0.253501635059D-06  0.682788453757D-06  0.466797497555D-05
  0.268317568619D-04 -0.210323290225D-04 -0.253501635059D-06  0.632886490472D-10 -0.496135024047D-10 -0.523409756747D-12
 -0.208961213245D-04  0.236327240469D-04  0.682788453757D-06 -0.496135024047D-10  0.552467816614D-10  0.574769829143D-12
 -0.122811120255D-06  0.440407515547D-06  0.466797497555D-05 -0.523409756747D-12  0.574769829143D-12  0.966078323632D-11

TOTAL COVARIANCE MATRIX AT K+1
  0.124777525598D+02 -0.757550477747D+01  0.280713265162D+01  0.268317568619D-04 -0.208961213245D-04 -0.122811120255D-06
 -0.757550477747D+01  0.117122849491D+02  0.408322065698D+01 -0.210323290225D-04  0.236327240469D-04  0.440407515547D-06
  0.280713265162D+01  0.408322065698D+01  0.162196343005D+02 -0.253501635059D-06  0.682788453757D-06  0.466797497555D-05
  0.268317568619D-04 -0.210323290225D-04 -0.253501635059D-06  0.632886490472D-10 -0.496135024047D-10 -0.523409756747D-12
 -0.208961213245D-04  0.236327240469D-04  0.682788453757D-06 -0.496135024047D-10  0.552467816614D-10  0.574769829143D-12
 -0.122811120255D-06  0.440407515547D-06  0.466797497555D-05 -0.523409756747D-12  0.574769829163D-12  0.966078323632D-11

MATRIX 1 = PHI*P*PHI(TRANSPOSE)
  0.124777525598D+02 -0.757550477747D+01  0.280713265162D+01  0.268317568619D-04 -0.208961213245D-04 -0.122811120255D-06
 -0.757550477747D+01  0.117122849491D+02  0.408322065698D+01 -0.210323290225D-04  0.236327240469D-04  0.440407515547D-06
  0.280713265162D+01  0.408322065698D+01  0.162196343005D+02 -0.253501635059D-06  0.682788453757D-06  0.466797497555D-05
  0.268317568619D-04 -0.210323290225D-04 -0.253501635059D-06  0.632886490472D-10 -0.496135024047D-10 -0.523409756747D-12
 -0.208961213245D-04  0.236327240469D-04  0.682788453757D-06 -0.496135024047D-10  0.552467816614D-10  0.574769829143D-12
 -0.122811120255D-06  0.440407515547D-06  0.466797497555D-05 -0.523409756747D-12  0.574769829143D-12  0.966078323632D-11

TOTAL COVARIANCE MATRIX AT K+1
  0.124777525598D+02 -0.757550477747D+01  0.280713265162D+01  0.268317568619D-04 -0.208961213245D-04 -0.122811120255D-06
 -0.757550477747D+01  0.117122849491D+02  0.408322065698D+01 -0.210323290225D-04  0.236327240469D-04  0.440407515547D-06
  0.280713265162D+01  0.408322065698D+01  0.162196343005D+02 -0.253501635059D-06  0.682788453757D-06  0.466797497555D-05
  0.268317568619D-04 -0.210323290225D-04 -0.253501635059D-06  0.632886490472D-10 -0.496135024047D-10 -0.523409756747D-12
 -0.208961213245D-04  0.236327240469D-04  0.682788453757D-06 -0.496135024047D-10  0.552467816614D-10  0.574769829143D-12
 -0.122811120255D-06  0.440407515547D-06  0.466797497555D-05 -0.523409756747D-12  0.574769829143D-12  0.966078323632D-11

EXECUTION ERROR CORRELATION MATRIX AND STANDARD DEVIATIONS
  0.378348519D+03      0.100000000D+01
  0.218379467D+03     -0.259577493D+00  0.100000000D+01
  0.384212195D+03      0.270966307D-02  0.219751897D-01  0.100000000D+01
  0.619590296D-02      0.999999988D+00 -0.259728668D+00  0.270598571D-02  0.100000000D+01
  0.357609526D-02     -0.260031264D+00  0.999999890D+00  0.219710947D-01 -0.260182419D+00  0.100000000D+01
  0.628948008D-02      0.270966184D-02  0.219751904D-01  0.100000000D+01  0.270598448D-02  0.219710955D-01  0.100000000D+01

  CONTROL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST AFTER FINAL INSERTION
```

```
                STD DEV                    X              Y              Z              VX             VY             VZ
       X        0.37836501D+03        1.00000000
       Y        0.21840628D+03       -0.25962598     1.00000000
       Z        0.38423330D+03        0.00272871     0.02201994     1.00000000
      VX        0.61959081D-02        0.99996703    -0.25971211     0.00270573     1.00000000
      VY        0.35761030D-02       -0.26003481     0.99990521     0.02197034    -0.26018388     1.00000000
      VZ        0.62894809D-02        0.00270949     0.02197281     0.99994688     0.00270597     0.02197107     1.00000000


RSS POSITION ERRORS. . .  0.581804618597D+03
RSS VELOCITY ERRORS. . .  0.952551093963D-02


        SOLVE-FOR PARAMETERS

                 --NONE

        DYNAMIC CONSIDER PARAMETERS

                 --NONE

        MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                              0.00161417     0.00452650     0.00828438    -0.00000571     0.00004438     0.00002846
LAT  1                                0.00111481     0.00312812     0.00572247    -0.00000405     0.00003049     0.00001920
LONG 1                               -0.00167877    -0.00309562     0.00038813     0.00000295     0.00001354    -0.00000707
RADIUS 2                              0.00114773     0.00194374     0.00439577     0.00000276    -0.00000469    -0.00000886
LAT  2                                0.00081201     0.00137459     0.00310865     0.00000193    -0.00000337    -0.00000639
LONG 2                               -0.00160870    -0.00265909     0.00080125     0.00000030     0.00002016     0.00000044
RADIUS 3                              0.00049226    -0.00008594     0.00138807     0.00000056    -0.00003866    -0.00004336
LAT  3                               -0.00033966     0.00005842    -0.00095548    -0.00000040     0.00002663     0.00003004
LONG 3                               -0.00136355    -0.00260136     0.00123284     0.00000670     0.00001645     0.00000406

        NO SOLVE-FOR PARAMETERS

             POSITION EIGENVALUES             SQUARE ROOTS OF EIGENVALUES
                1       0.1477604415225D+06          1      0.3843962038D+03
                2       0.4306678446251D+05          2      0.2075253827D+03
                3       0.1476693882353D+06          3      0.3842777488D+03


             POSITION EIGENVECTORS
                1       0.9777818945019D+00      -0.2095631651932D+00       0.5083953030812D-02
                2       0.2096214853096D+00       0.9776156005356D+00      -0.1807126132988D-01
                3      -0.1183081071990D-02       0.1873545792473D-01       0.9998237759403D+00


             VELOCITY EIGENVALUES             SQUARE ROOTS OF EIGENVALUES
                1       0.3962757754307D-04          1      0.6295043887D-02
                2       0.1154110604256D-04          2      0.3397220341D-02
                3       0.3956667507537D-04          3      0.6290204693D-02


             VELOCITY EIGENVECTORS
                1       0.9775963920122D+00      -0.2101906667816D+00      -0.1118829400322D-01
                2       0.2099723799353D+00       0.9775410075480D+00      -0.1803269880773D-01
                3       0.1472732117892D-01       0.1527946857341D-01       0.9997747965672D+00


 KNOWLEDGE CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST AFTER FINAL INSERTION

                STD DEV                    X              Y              Z              VX             VY             VZ
       X        0.37836501D+03        1.00000000
```

```
      Y        0.21840628D+03     -0.25962598     1.00000000
      Z        0.38423330D+03      0.00272871     0.02201994     1.00000000
     VX        0.61959081D-02      0.99996703    -0.25971211     0.00270573     1.00000000
     VY        0.35761030D-02     -0.26003481     0.99990521     0.02197034    -0.26018388     1.00000000
     VZ        0.62894809D-02      0.00270949     0.02197281     0.99994688     0.00270597     0.02197107     1.00000000


RSS POSITION ERRORS. . .  0.581804619597D+03
RSS VELOCITY ERRORS. . .  0.952551093963D-02


        SOLVE-FOR PARAMETERS

                  --NONE

        DYNAMIC CONSIDER PARAMETERS

                  --NONE

        MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                           0.00161417     0.00452650     0.00828438    -0.00000571     0.00004438     0.00002846
LAT   1                            0.00111481     0.00312812     0.00572247    -0.00000405     0.00003049     0.00001920
LONG 1                            -0.00167877    -0.00309562     0.00038813     0.00000295     0.00001354    -0.00000707
RADIUS 2                           0.00114773     0.00194374     0.00439577     0.00000276    -0.00000469    -0.00000886
LAT   2                            0.00091201     0.00137459     0.00310865     0.00000193    -0.00000337    -0.00000639
LONG 2                            -0.00160870    -0.00265909     0.00080125     0.00000030     0.00002016     0.00000044
RADIUS 3                           0.00049226    -0.00008594     0.00138807     0.00000056    -0.00003866    -0.00004336
LAT   3                           -0.00033966     0.00005842    -0.00095548    -0.00000040     0.00002663     0.00003004
LONG 3                            -0.00136355    -0.00260136     0.00123284     0.00000670     0.00001645     0.00000406

        NO SOLVE-FOR PARAMETERS

                  POSITION EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
                     1       0.1477604415225D+06           1     0.3843962038D+03
                     2       0.4306678446251D+05           2     0.2075253827D+03
                     3       0.1476693882353D+06           3     0.3842777488D+03


                  POSITION EIGENVECTORS
                     1       0.9777818945019D+00     -0.2095631651932D+00       0.5083953030812D-02
                     2       0.2096214853096D+00      0.9776156005356D+00      -0.1807126132988D-01
                     3      -0.1183081071990D-02      0.1873545792473D-01       0.9998237759403D+00


                  VELOCITY EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
                     1       0.3962757754307D-04           1     0.6295043887D-02
                     2       0.1154110604256D-04           2     0.3397220341D-02
                     3       0.3956667507537D-04           3     0.6290204693D-02


                  VELOCITY EIGENVECTORS
                     1       0.9775963920124D+00     -0.2101906667816D+00      -0.1118829400322D-01
                     2       0.2099723799353D+00      0.9775410075480D+00      -0.1803269880773D-01
                     3       0.1472732117892D-01      0.1527946857341D-01       0.9997747965672D+00
```

CASE E-2

Long (118 day) Transfer Time Mission to the L_2 Point with Impulsive Insertion and Generalized Covariance Analysis

```
I N P U T   D A T A   F O R   P R O B L E M . . . .   118
  MODE TO BE EXECUTED. . .ERROR ANALYSIS

     LAUNCH DATE                 7  9 22 21  2.100 1974     JULIAN DATE . . .2442238.43127426

      FINAL DATE                11  4 22 21  3.000 1974     JULIAN DATE . . .2442356.43128468

     INITIAL TRAJECTORY TIME =       0.0

  INERTIAL FRAME IS   GEOCENTRIC ECLIPTIC

        INITIAL STATE VECTOR
     AT TRAJECTORY TIME      0.0

STATE           X-COMP          Y-COMP          Z-COMP          RADIUS          X-DOT          Y-DOT          Z-DOT       VELOCITY

INERTIAL -0.30534480D+04  0.5805989D+04 -0.2346189D+02  0.6560000D+04  -8.36006750   -4.37336030    5.77188219  11.06036315
HELIO-     0.4438201D+08 -0.1454605D+09 -0.6488726D+03  0.1520807D+09  19.64262685    4.20406799    5.77171304  20.90023083
ROT.GEO- -0.6444355D+04 -0.1226105D+04 -0.2346189D+02  0.6560000D+04   1.74293999   -9.27120995    5.77188219  11.05928559

     THE FOLLOWING QUANTITIES ARE TO BE AUGMENTED TO THE STATE VECTOR

     MEASUREMENT CONSIDER PARAMETERS
       RADIUS 1
       LAT   1
       LONG  1
       RADIUS 2
       LAT   2
       LONG  2
       RADIUS 3
       LAT   3
       LONG  3
```

```
          MEASUREMENT NO     1 AT TRAJECTORY TIME      0.042                                                                    PROBLEM. .    118

         RANGE-RATE WAS MEASURED FROM STATION 2 AT TRAJECTORY TIME       0.04200 DAYS

         INITIAL TRAJECTORY TIME       0.0
         FINAL   TRAJECTORY TIME       0.042
INITIAL
      AT TRAJECTORY TIME       0.0

 STATE         X-COMP         Y-COMP         Z-COMP          RADIUS          X-DOT          Y-DOT          Z-DOT       VELOCITY

 INERTIAL -0.3053448D+04  0.5805989D+04 -0.2346189D+02  0.6560000D+04  -8.36006750   -4.37336030   5.77188219  11.06036315
 HELIO-     0.4438201D+08 -0.1454605D+09 -0.6488726D+03  0.1520807D+09  19.64262685    4.20406799   5.77171304  20.90023083
 ROT.GEO- -0.6444355D+04 -0.1226105D+04 -0.2346189D+02  0.6560000D+04   1.74293999   -9.27120995   5.77188219  11.05928559
FINAL
      AT TRAJECTORY TIME       0.0420

 STATE         X-COMP         Y-COMP         Z-COMP          RADIUS          X-DOT          Y-DOT          Z-DOT       VELOCITY

 INERTIAL -0.1093977D+05 -0.1798819D+05  0.1108442D+05  0.2379323D+05   0.06630315   -5.54852751   1.56176517   5.76451768
 HELIO-     0.4447573D+08 -0.1454532D+09  0.1045842D+05  0.1521010D+09  28.06302100    3.04878712   1.56160610  28.27130815
 ROT.GEO-   0.1400147D+05 -0.1572299D+05  0.1108442D+05  0.2379323D+05   5.34221843   -1.56228173   1.56176518   5.76245118




STATE TRANSITION MATRIX PARTITIONS OVER(      0.0   ,     0.042)           --TRANSPOSES SHOWN

                               X(  0.042)          Y(  0.042)          Z(  0.042)          VX(  0.042)          VY(  0.042)          VZ(  0.042)
          X(  0.0   )   0.4642012886D+01 -0.1349131823D+01 -0.3011555602D+01  0.1279145672D-02  0.1568576165D-03 -0.1142716680D-02
          Y(  0.0   )  -0.4599592755D+01 -0.1202640978D+00  0.2040431068D+01 -0.1485194357D-02 -0.8726947403D-03  0.8358261822D-03
          Z(  0.0   )  -0.2075669239D+01  0.2858626333D+00 -0.6186114028D+00 -0.6699301473D-03 -0.5053815407D-04 -0.3779759937D-03
         VX(  0.0   )   0.5967782648D+04  0.4757035176D+03 -0.2325331683D+04  0.1935294756D+01  0.6832402010D+00 -0.1096972695D+01
         VY(  0.0   )  -0.5736538433D+03  0.2538312855D+04  0.1298069673D+03  0.2807660340D-02  0.5592982569D+00 -0.8552661904D-01
         VZ(  0.0   )  -0.2023196304D+04 -0.4366263167D+03  0.3131500501D+04 -0.9010596950D+00 -0.4528177400D+00  0.8842768568D+00

      SOLVE-FOR PARAMETERS

                  --NONE

      DYNAMIC CONSIDER PARAMETERS

                  --NONE
      IGNORE PARAMETERS

                  --NONE

DIAGONAL OF DYNAMIC NOISE MATRIX
                 0.0            0.0            0.0            0.0            0.0            0.0



OBSERVATION MATRIX PARTITIONS -- TRANSPOSES SHOWN
                                   RANGE-RATE(2)
              X                  0.7711566101D-04
              Y                 -0.4782526862D-04
              Z                 -0.2707523615D-04
             VX                 -0.3435909178D+00
```

```
                  VY                -0.8165957508D+00
                  VZ                 0.4638067805D+00

          SOLVE-FOR PARAMETERS

                    --NONE

          DYNAMIC CONSIDER PARAMETERS

                    --NONE

          MEASUREMENT CONSIDER PARAMETERS
          RADIUS 1                   0.0
          LAT  1                     0.0
          LONG 1                     0.0
          RADIUS 2                   0.9811608381D-05
          LAT  2                     0.2790069782D+00
          LONG 2                     0.4954467395D-01
          RADIUS 3                   0.0
          LAT  3                     0.0
          LONG 3                     0.0

          IGNORE PARAMETERS

                    --NONE


 MEASUREMENT NOISE MATRIX
                     0.16666667D-13



 GAIN MATRIX PARTITIONS
                    K-MATRIX
                                 -0.2781594498D+04
                                 -0.4859937499D+03
                                  0.3284389898D+04
                                 -0.1132166310D+01
                                 -0.5274142463D+00
                                  0.9928821271D+00

                    S-MATRIX

                              NOT DEFINED

 CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME    0.042 DAYS, JUST BEFORE  THE MEASUREMENT

                STD DEV               X               Y               Z               VX              VY              VZ
        X       0.23326443D+03    1.00000000
        Y       0.10495341D+03   -0.57224312      1.00000000
        Z       0.18726974D+03   -0.84285999      0.04857499      1.00000000
        VX      0.78176350D-01    0.97975032     -0.39774529     -0.93328023      1.00000000
        VY      0.29850788D-01    0.41294241      0.51059761     -0.83290128      0.58555299      1.00000000
        VZ      0.58357800D-01   -0.88763068      0.13436377      0.99570648     -0.96171879     -0.78316935      1.00000000


  RSS POSITION ERRORS. . .  0.3170132710960D+03
  RSS VELOCITY ERRORS. . .  0.1020179419580D+00
```

```
        SOLVE-FOR PARAMETERS

                  --NONE

        DYNAMIC CONSIDER PARAMETERS

                  --NONE

        MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                     0.0         0.0         0.0         0.0         0.0         0.0
LAT   1                      0.0         0.0         0.0         0.0         0.0         0.0
LONG 1                       0.0         0.0         0.0         0.0         0.0         0.0
RADIUS 2                     0.0         0.0         0.0         0.0         0.0         0.0
LAT   2                      0.0         0.0         0.0         0.0         0.0         0.0
LONG 2                       0.0         0.0         0.0         0.0         0.0         0.0
RADIUS 3                     0.0         0.0         0.0         0.0         0.0         0.0
LAT   3                      0.0         0.0         0.0         0.0         0.0         0.0
LONG 3                       0.0         0.0         0.0         0.0         0.0         0.0

        NO SOLVE-FOR PARAMETERS



CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME    0.042 DAYS, JUST AFTER   THE MEASUREMENT

                STD DEV                X           Y           Z           VX          VY          VZ
        X       0.17759680D+03     1.00000000
        Y       0.10157407D+03    -0.99809844  1.00000000
        Z       0.56414407D+02    -0.97944721  0.98987936  1.00000000
       VX       0.48192290D-01     0.99982095 -0.99888612 -0.98256786  1.00000000
       VY       0.82947139D-02    -0.99622495  0.99951895  0.99264257 -0.99726231  1.00000000
       VZ       0.22157340D-01    -0.99569656  0.99928914  0.99291404 -0.99668934  0.99990913  1.00000000


 RSS POSITION ERRORS. . .  0.2122274723800+03
 RSS VELOCITY ERRORS. . .  0.5368656095430-01


        SOLVE-FOR PARAMETERS

                  --NONE

        DYNAMIC CONSIDER PARAMETERS

                  --NONE

        MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                     0.0         0.0         0.0         0.0         0.0         0.0
LAT   1                      0.0         0.0         0.0         0.0         0.0         0.0
LONG 1                       0.00000053  0.00000016 -0.00000198  0.00000080  0.00000216 -0.00000152
RADIUS 2                     0.00000505  0.00000154 -0.00001876  0.00000757  0.00002048 -0.00001444
LAT   2                      0.00000631  0.00000193 -0.00002346  0.00000947  0.00002562 -0.00001806
LONG 2                       0.00000059  0.00000018 -0.00000220  0.00000089  0.00000240 -0.00000169
RADIUS 3                     0.0         0.0         0.0         0.0         0.0         0.0
LAT   3                      0.0         0.0         0.0         0.0         0.0         0.0
LONG 3                       0.00000053  0.00000016 -0.00000198  0.00000080  0.00000216 -0.00000152

        NO SOLVE-FOR PARAMETERS
```

```
**********************************************************************************************************

ACTUAL ESTIMATION ERROR STATISTICS

        DIAGONAL OF ACTUAL DYNAMIC NOISE COVARIANCE MATRIX
            0.0                0.0                0.0                0.0                0.0                0.0

        ACTUAL MEASUREMENT NOISE CORRELATION MATRIX AND STANDARD DEVIATIONS
                 0.12909945D-06        1.00000000

        ACTUAL MEASUREMENT RESIDUAL MEAN
            0.0

        ACTUAL MEASUREMENT RESIDUAL CORRELATION MATRIX AND STANDARD DEVIATIONS
                 0.54369413D-01        1.00000000

        ACTUAL ESTIMATION ERROR MEANS AT TIME    0.042 DAYS BEFORE  THE MEASUREMENT
                 X      0.0
                 Y      0.0
                 Z      0.0
                VX      0.0
                VY      0.0
                VZ      0.0

        ACTUAL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME   0.042 DAYS JUST BEFORE THE MEASUREMENT

                 STD DEV                 X             Y             Z             VX            VY            VZ
          X      0.23326432D+03      1.00000000
          Y      0.10495341D+03     -0.57224312    1.00000000
          Z      0.18726974D+03     -0.84285999    0.04857499    1.00000000
         VX      0.78176350D-01      0.97975032   -0.39774529   -0.93328023    1.00000000
         VY      0.29850788D-01      0.41204241    0.51059761   -0.83290128    0.58555299    1.00000000
         VZ      0.58352800D-01     -0.88703068    0.13436377    0.99570648   -0.96171879   -0.78316935    1.00000000


                 SOLVE-FOR PARAMETERS

        --NONE

                 DYNAMIC CONSIDER PARAMETERS

        --NONE

                 MEASUREMENT CONSIDER PARAMETERS
    RADIUS 1                             0.0           0.0           0.0           0.0           0.0           0.0

    LAT   1                              0.0           0.0           0.0           0.0           0.0           0.0

    LONG 1                               0.0           0.0           0.0           0.0           0.0           0.0

    RADIUS 2                             0.0           0.0           0.0           0.0           0.0           0.0

    LAT   2                              0.0           0.0           0.0           0.0           0.0           0.0

    LONG 2                               0.0           0.0           0.0           0.0           0.0           0.0

    RADIUS 3                             0.0           0.0           0.0           0.0           0.0           0.0

    LAT   3                              0.0           0.0           0.0           0.0           0.0           0.0

    LONG 3                               0.0           0.0           0.0           0.0           0.0           0.0
```

```
         IGNORE PARAMETERS

     --NONE



            SOLVE-FOR PARAMETERS

     NO SOLVE-FOR PARAMETERS

     ACTUAL ESTIMATION ERROR MEANS AT TIME     0.042 DAYS  AFTER  THE MEASUREMENT
             X     0.0
             Y     0.0
             Z     0.0
            VX     0.0
            VY     0.0
            VZ     0.0

     ACTUAL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME   0.042 DAYS JUST  AFTER THE MEASUREMENT

                 STD DEV                X              Y              Z              VX             VY             VZ
      X          0.17759680D+03      1.00000000
      Y          0.10157407D+03     -0.99809843     1.00000000
      Z          0.56414409D+02     -0.97944719     0.98987933     1.00000000
     VX          0.48192291D-01      0.99982095    -0.99888611    -0.98256785     1.00000000
     VY          0.82947141D-02     -0.99622490     0.99951892     0.99264245    -0.99726225     1.00000000
     VZ          0.22157340D-01     -0.99569655     0.99928912     0.99291404    -0.99668934     0.99990904     1.00000000

         SOLVE-FOR PARAMETERS

     --NONE

         DYNAMIC CONSIDER PARAMETERS

     --NONE

         MEASUREMENT CONSIDER PARAMETERS
 RADIUS 1                            0.0            0.0            0.0            0.0            0.0            0.0

 LAT   1                             0.0            0.0            0.0            0.0            0.0            0.0

 LONG 1                              0.00000533     0.00000163    -0.00001980     0.00000799     0.00002163    -0.00001524

 RADIUS 2                            0.00005046     0.00001541    -0.00018755     0.00007568     0.00020484    -0.00014436

 LAT   2                             0.00006311     0.00001928    -0.00023460     0.00009467     0.00025622    -0.00018057

 LONG 2                              0.00000592     0.00000181    -0.00002200     0.00000888     0.00002403    -0.00001694

 RADIUS 3                            0.0            0.0            0.0            0.0            0.0            0.0

 LAT   3                             0.0            0.0            0.0            0.0            0.0            0.0

 LONG 3                              0.00000533     0.00000163    -0.00001980     0.00000799     0.00002163    -0.00001524

         IGNORE PARAMETERS

     --NONE
```

```
      ERROR ANALYSIS MODE-    GUIDANCE     EVENT AT TRAJECTORY TIME 0.50000000D+01 DAYS          PROBLEM. .        118
**************************************************************************************************************************
      AT TRAJECTORY TIME      5.0000

 STATE         X-COMP         Y-COMP         Z-COMP          RADIUS          X-DOT          Y-DOT          Z-DOT        VELOCITY

 INERTIAL  0.2124195D+06 -0.5648053D+06  0.4769688D+05  0.6053116D+06   0.38280934    -0.72536502     0.00076788     0.82018168
 HELIO-    0.5652709D+08 -0.1418179D+09  0.4724530D+05  0.1526683D+09  27.57681946    10.19431159     0.00165488    29.40076467
 ROT.GEO-  0.6033131D+06 -0.1184964D+05  0.4769698D+05  0.6053116D+06   0.81327439    -0.02929974     0.00076619     0.81380237




STATE TRANSITION MATRIX PARTITIONS OVER(    4.600,    5.000)            --TRANSPOSES SHOWN

                            X(  5.000)        Y(  5.000)        Z(  5.000)       VX(  5.000)       VY(  5.000)       VZ(  5.000)
          X(   4.600)    0.9992226811D+00 -0.1186853643D-02  0.1013136429D-03 -0.4377980758D-07 -0.6726410496D-07  0.5697577751D-08
          Y(   4.600)   -0.1186858703D-02  0.1001973650D+01 -0.2728073384D-03 -0.6726486781D-07  0.1114904238D-06 -0.1529510495D-07
          Z(   4.600)    0.1013151426D-03 -0.2728102039D-03  0.9988051259D+00  0.5697803296D-08 -0.1529553624D-07 -0.6754669334D-07
         VX(   4.600)    0.3455128575D+05 -0.1337991395D+02  0.1133027840D+01  0.9992636447D+00 -0.1137340678D-02  0.9555781230D-04
         VY(   4.600)   -0.1338010604D+02  0.3458216665D+05 -0.3041151099D+01 -0.1137346157D-02  0.1001877751D+01 -0.2556913199D-03
         VZ(   4.600)    0.1133082747D+01 -0.3041259503D+01  0.3454655738D+05  0.9555942877D-04 -0.2556944133D-03  0.9988599798D+00

     SOLVE-FOR PARAMETERS

                  --NONE

     DYNAMIC CONSIDER PARAMETERS

                  --NONE
     IGNORE PARAMETERS

                  --NONE

        DIAGONAL OF DYNAMIC NOISE MATRIX

            0.0            0.0            0.0            0.0            0.0            0.0

 MATRIX 1 = PHI*P*PHI(TRANSPOSE)
   0.174758397133D+00  0.795248481237D-01  0.157897977405D+00  0.241034399047D-06  0.120588665096D-06  0.204292151700D-06
   0.795248481237D-01  0.514551237777D-01  0.199585879683D+00  0.122058301373D-06  0.592850459081D-07  0.213951730797D-06
   0.157897977405D+00  0.199585879683D+00  0.156047012096D+01  0.368859419592D-06  0.192528484856D-06  0.218280691414D-05
   0.241034399047D-06  0.122058301373D-06  0.368859419592D-06  0.370416496110D-12  0.187429637494D-12  0.545965499685D-12
   0.120588665096D-06  0.592850459081D-07  0.192528484856D-06  0.187429637494D-12  0.115475592140D-12  0.401748221506D-12
   0.204292151700D-06  0.213951730797D-06  0.218280691414D-05  0.545965499685D-12  0.401748221506D-12  0.435829483195D-11

 TOTAL COVARIANCE MATRIX AT K+1
   0.174758397133D+00  0.795248481237D-01  0.157897977405D+00  0.241034399047D-06  0.120588665096D-06  0.204292151700D-06
   0.795248481237D-01  0.514551237777D-01  0.199585879683D+00  0.122058301373D-06  0.592850459081D-07  0.213951730797D-06
   0.157897977405D+00  0.199585879683D+00  0.156047012096D+01  0.368859419592D-06  0.192528484856D-06  0.218280691414D-05
   0.241034399047D-06  0.122058301373D-06  0.368859419592D-06  0.370416496110D-12  0.187429637494D-12  0.545965499685D-12
   0.120588665096D-06  0.592850459081D-07  0.192528484856D-06  0.187429637494D-12  0.115475592140D-12  0.401748221506D-12
   0.204292151700D-06  0.213951730797D-06  0.218280691414D-05  0.545965499685D-12  0.401748221506D-12  0.435829483195D-11

      CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT EVENT TIME      5.000 DAYS
         BASED ON MEASUREMENTS UP TO TIME      4.600 DAYS

            STD DEV                 X              Y               Z              VX              VY              VZ
```

```
        X         0.41804114D+00      1.00000000
        Y         0.22683722D+00      0.83862829     1.00000000
        Z         0.12491878D+01      0.30236381     0.70434879     1.00000000
       VX         0.60861851D-06      0.94735956     0.88411315     0.48516335     1.00000000
       VY         0.33981700D-06      0.84887230     0.76910520     0.45354686     0.90624997     1.00000000
       VZ         0.20876529D-05      0.23408541     0.45179684     0.83700738     0.42969642     0.56630521     1.00000000


RSS POSITION ERRORS. . .  0.1336668860220+01
RSS VELOCITY ERRORS. . .  0.2200951367070-05


          SOLVE-FOR PARAMETERS

                     --NONE

          DYNAMIC CONSIDER PARAMETERS

                     --NONE

          MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                          -0.18498408    -0.42961397    -0.59123152    -0.27668251    -0.25360327    -0.47015130
LAT   1                           -0.12642380    -0.29749506    -0.40806583    -0.19198906    -0.17560267    -0.32416877
LONG 1                             0.90092480     0.60934337    -0.04481866     0.76014808     0.74093633    -0.04250656
RADIUS 2                          -0.16782225    -0.41506659    -0.50544319    -0.23844850    -0.21380582    -0.34297806
LAT   2                           -0.11795300    -0.29291494    -0.36063695    -0.16270211    -0.14818490    -0.24667467
LONG 2                             0.88596061     0.56289546    -0.04454567     0.72568075     0.60706804    -0.06141112
RADIUS 3                          -0.20106365    -0.43129428    -0.45098513    -0.26098142    -0.08932646    -0.17706014
LAT   3                            0.13970370     0.29827087     0.31304245     0.18211155     0.06410650     0.12559863
LONG 3                             0.84433425     0.55473400    -0.04635740     0.69917743     0.63189191    -0.05858801

          NO SOLVE-FOR PARAMETERS

                     POSITION EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
                        1       0.17751694487810+00           1     0.42132760280+00
                        2       0.32672017396810-02           2     0.57159441390-01
                        3       0.16058994912560+01           3     0.12672408970+01


                     POSITION EIGENVECTORS
                        1       0.92762645766000+00      0.33984884474720+00      -0.15495779352170+00
                        2      -0.35505207514260+00      0.93112430523070+00      -0.83339979275270-01
                        3       0.11596109721551D+00      0.13232645590600+00       0.98439957846460+00


                     VELOCITY EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
                        1       0.35804711549040-12           1     0.59837038320-06
                        2       0.13319514616730-13           2     0.11541020150-06
                        3       0.44728202900910-11           3     0.21149043220-05


                     VELOCITY EIGENVECTORS
                        1       0.89323113792710+00      0.41863700036160+00      -0.16395486014690+00
                        2      -0.42864760700100+00      0.90298573128300+00      -0.29631032915110-01
                        3       0.13564425254990+00      0.96746219706880-01       0.98602272069290+00

*****************************************************************************************************

      DIAGONAL OF ACTUAL DYNAMIC NOISE MATRIX

               0.0            0.0            0.0            0.0            0.0            0.0
```

```
MATRIX I = PHI*P*PHI(TRANSPOSE)
  0.165052928674D+02  0.749990613409D+01  0.127162855111D+02  0.215217209574D-04  0.105902820686D-04  0.116776451586D-04
  0.749990613409D+01  0.471412274884D+01  0.178929290045D+02  0.110128669020D-04  0.527293847670D-05  0.186419104321D-04
  0.127162855111D+02  0.178929290045D+02  0.126798438415D+03  0.279885286784D-04  0.113962030944D-04  0.140018996793D-03
  0.215217209574D-04  0.110128669020D-04  0.279885286784D-04  0.292928244787D-10  0.144153793308D-10  0.283418691845D-10
  0.105902820686D-04  0.527293847670D-05  0.113962030944D-04  0.144153793308D-10  0.795956756624D-11  0.133660831683D-10
  0.116776451586D-04  0.186419104321D-04  0.140018996793D-03  0.283418691845D-10  0.133660831683D-10  0.166287887965D-09

TOTAL COVARIANCE MATRIX AT K+1
  0.165052928674D+02  0.749990613409D+01  0.127162855111D+02  0.215217209574D-04  0.105902820686D-04  0.116776451586D-04
  0.749990613409D+01  0.471412274884D+01  0.178929290045D+02  0.110128669020D-04  0.527293847670D-05  0.186419104321D-04
  0.127162855111D+02  0.178929290045D+02  0.126798438415D+03  0.279885286784D-04  0.113962030944D-04  0.140018996793D-03
  0.215217209574D-04  0.110128669020D-04  0.279885286784D-04  0.292928244787D-10  0.144153793308D-10  0.283418691845D-10
  0.105902820686D-04  0.527293847670D-05  0.113962030944D-04  0.144153793308D-10  0.795956756624D-11  0.133660831683D-10
  0.116776451586D-04  0.186419104321D-04  0.140018996793D-03  0.283418691845D-10  0.133660831683D-10  0.166287887965D-09


*****************************************************************************************************************************

        ACTUAL ESTIMATION ERROR MEANS AT TIME    5.000 DAYS
              X     0.0
              Y     0.0
              Z     0.0
             VX     0.0
             VY     0.0
             VZ     0.0

        ACTUAL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME   5.000 DAYS

                 STD DEV                   X             Y             Z             VX            VY            VZ
          X      0.40626707D+01        1.00000000
          Y      0.21712031D+01        0.85044437    1.00000000
          Z      0.11260481D+02        0.27796601    0.73185331    1.00000000
         VX      0.54122846D-05        0.97877925    0.93717204    0.45924294    1.00000000
         VY      0.28212706D-05        0.92395575    0.86081044    0.35872240    0.94406243    1.00000000
         VZ      0.12895266D-04        0.22290168    0.66582434    0.96427232    0.40608557    0.36739151    1.00000000


                 SOLVE-FOR PARAMETERS

        --NONE

                 DYNAMIC CONSIDER PARAMETERS

        --NONE

                 MEASUREMENT CONSIDER PARAMETERS
  RADIUS 1                             -0.19034513   -0.44884073   -0.65588599   -0.31113312   -0.30546061   -0.76114191

  LAT   1                              -0.13008770   -0.31080904   -0.45269011   -0.21589422   -0.21151028   -0.52480646

  LONG 1                                0.92672592    0.63661367   -0.04971983    0.85479651    0.89244457   -0.06881514

  RADIUS 2                             -0.17268593   -0.43364230   -0.56071623   -0.26813847   -0.25752529   -0.55525737

  LAT   2                              -0.12137141   -0.30602393   -0.40007461   -0.18296066   -0.17848607   -0.39934895

  LONG 2                                0.91163675    0.58808705   -0.04941699    0.81603754    0.73120260   -0.09942029

  RADIUS 3                             -0.20689070   -0.45059624   -0.50030287   -0.29347704   -0.10759213   -0.28664792

  LAT   3                               0.14375247    0.31161956    0.34727539    0.20478684    0.07721514    0.20333535
```

```
LONG 3                                0.86880400   0.57956033   -0.05142684   0.78623421   0.76110252   -0.09484987

          IGNORE PARAMETERS

    --NONE


           SOLVE-FOR PARAMETERS

    NO SOLVE-FOR PARAMETERS

            POSITION EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
               1      0.1697447948167D+02          1     0.4120009646D+01
               2      0.4499483681884D-01          2     0.2121198643D+00
               3      0.1309983797132D+03          3     0.1144545236D+02


            POSITION EIGENVECTORS
               1      0.9291820292068D+00    0.3323580644345D+00    -0.1617370508095D+00
               2     -0.3500592143947D+00    0.9317529723406D+00    -0.9641029404310D-01
               3      0.1186562388438D+00    0.1462002583436D+00     0.9821131204926D+00


            VELOCITY EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
               1      0.2939228720563D-10          1     0.5421465411D-05
               2      0.6886634504815D-12          2     0.8298574881D-06
               3      0.1734593293535D-09          3     0.1317039595D-04


            VELOCITY EIGENVECTORS
               1      0.8675964254028D+00    0.4444550021853D+00    -0.2230161287010D+00
               2     -0.4547200618686D+00    0.8906146118771D+00     0.5939566073724D-02
               3      0.2012612927577D+00    0.9625676154663D-01     0.9747966597676D+00




STATE TRANSITION MATRIX PARTITIONS OVER(    0.500,    5.000)          --TRANSPOSES SHOWN

                          X(  5.000)        Y(  5.000)        Z(  5.000)       VX(  5.000)       VY(  5.000)       VZ(  5.000)
         X(  0.500)  -0.3394614271D+00 -0.1137367962D+01  0.1812912517D+00 -0.3461797250D-05 -0.3987135043D-05  0.5633565620D-06
         Y(  0.500)  -0.1389550143D+01  0.5398324373D+01 -0.9779128154D+00 -0.5595164953D-05  0.1637276532D-04 -0.2989140228D-05
         Z(  0.500)   0.2540885542D+00 -0.1115187057D+01 -0.4258667737D+00  0.1028013040D-05 -0.3866937865D-05 -0.3984069637D-05
        VX(  0.500)   0.3241650489D+06 -0.6994963057D+05  0.9312620639D+04  0.7375866755D+00 -0.3559129998D+00  0.4153237685D-01
        VY(  0.500)  -0.7465262217D+05  0.5737418708D+06 -0.3717461772D+05 -0.3912759913D+00  0.1894845666D+01 -0.1532506113D+00
        VZ(  0.500)   0.1067307230D+05 -0.3974435321D+05  0.3098605399D+06  0.5178011027D-01 -0.1726463640D+00  0.6469973895D+00
      SOLVE-FOR PARAMETERS

                 --NONE

      DYNAMIC CONSIDER PARAMETERS

                 --NONE
      IGNORE PARAMETERS
```

```
                    --NONE


********************************************************************************************************************************
                    * ASSUMED GUIDANCE EVENT *



        DIAGONAL OF DYNAMIC NOISE MATRIX
                      0.0                 0.0                  0.0                  0.0                  0.0                  0.0

     MATRIX 1 = PHI*P*PHI(TRANSPOSE)
        0.776630827873D+06 -0.339549484953D+06  0.353243221614D+05  0.183547547445D+01 -0.141204040239D+01  0.148371066316D+00
       -0.339549484953D+06  0.852303902851D+06  0.105653309582D+06 -0.107515853415D+01  0.288449304954D+01  0.959792863805D-01
        0.353243221614D+05  0.105653309582D+06  0.613878190465D+06  0.609102689557D-01  0.250348852901D+00  0.125871697015D+01
        0.183547547445D+01 -0.107515853415D+01  0.609102689557D-01  0.444456781100D-05 -0.421859252430D-05  0.338719980598D-06
       -0.141204040239D+01  0.288449304954D+01  0.250348852901D+00 -0.421859252430D-05  0.987951976137D-05  0.920854265901D-07
        0.148371066316D+00  0.959792863805D-01  0.125871697015D+01  0.338719980596D-06  0.920854265901D-07  0.259948908658D-05

     TOTAL COVARIANCE MATRIX AT K+1
        0.776630827873D+06 -0.339549484953D+06  0.353243221614D+05  0.183547547445D+01 -0.141204040239D+01  0.148371066316D+00
       -0.339549484953D+06  0.852393902851D+06  0.105653309582D+06 -0.107515853415D+01  0.288449304954D+01  0.959792863805D-01
        0.353243221614D+05  0.105653309582D+06  0.613878190465D+06  0.609102689557D-01  0.250348852901D+00  0.125871697015D+01
        0.183547547445D+01 -0.107515853415D+01  0.609102689557D-01  0.444456781100D-05 -0.421859252430D-05  0.338719980598D-06
       -0.141204040239D+01  0.288449304954D+01  0.250348852901D+00 -0.421859252430D-05  0.987951976137D-05  0.920854265901D-07
        0.148371066316D+00  0.959792863805D-01  0.125871697015D+01  0.338719980598D-06  0.920854265901D-07  0.259948908658D-05

       CONTROL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST BEFORE GUIDANCE CORRECTION AT TIME      5.0000000 DAYS

                      STD DEV                X                Y                Z               VX               VY               VZ
             X        0.88126660D+03      1.00000000
             Y        0.92320307D+03     -0.41734818       1.00000000
             Z        0.78350379D+03      0.05115940       0.14606453       1.00000000
            VX        0.21082144D-02      0.98793075      -0.55240869       0.03687522       1.00000000
            VY        0.31431703D-02     -0.50976721       0.99404110       0.10165684      -0.63662677       1.00000000
            VZ        0.16122931D-02      0.10442342       0.06448167       0.99642126       0.09065109       0.01817101       1.00000000


     RSS POSITION ERRORS. . .  0.149760239089D+04
     RSS VELOCITY ERRORS. . .  0.411382749504D-02


          SOLVE-FOR PARAMETERS

                    --NONE

          DYNAMIC CONSIDER PARAMETERS

                    --NONE

          MEASUREMENT CONSIDER PARAMETERS
     RADIUS 1                            -0.00056350      -0.00076079      -0.00519340      -0.00054715      -0.00041195      -0.00405841
     LAT   1                             -0.00037429      -0.00050293      -0.00344624      -0.00036397      -0.00027151      -0.00269303
     LONG 1                               0.00039500       0.00012508      -0.00033333       0.00018513       0.00007187      -0.00026422
     RADIUS 2                             0.00023414       0.00008368      -0.00013275       0.00018071       0.00012909       0.00046624
     LAT   2                              0.00019639       0.00007899       0.00000043       0.00015761       0.00009988       0.00038887
     LONG 2                               0.00055474       0.00022132       0.00077540       0.00034342       0.00008211       0.00053016
     RADIUS 3                             0.0              0.0              0.0              0.0              0.0              0.0
     LAT   3                              0.0              0.0              0.0              0.0              0.0              0.0
     LONG 3                               0.00044988       0.00016408       0.00020940       0.00025037       0.00007294       0.00012597
```

```
NO SOLVE-FOR PARAMETERS

          POSITION EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
             1       0.4227323958243D+06          1     0.6501787414D+03
             2       0.1161817093470D+07          2     0.1077876196D+04
             3       0.6582634318893D+06          3     0.8113343527D+03


          POSITION EIGENVECTORS
             1       0.6384095983414D+00        0.6176004383722D+00       -0.4593505015433D+00
             2      -0.6524557332060D+00        0.7508338869740D+00        0.1027131460830D+00
             3       0.4083316066049D+00        0.2341328099477D+00        0.8822965070506D+00


          VELOCITY EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
             1       0.1961122695620D-05          1     0.1400400905D-02
             2       0.1218082209170D-04          2     0.3490103450D-02
             3       0.2781631871572D-05          3     0.1667822494D-02


          VELOCITY EIGENVECTORS
             1       0.7757616072909D+00        0.4187829196797D+00       -0.4720326205232D+00
             2      -0.4790181840274D+00        0.8777638409738D+00       -0.8498167448562D-02
             3       0.4107742786793D+00        0.2327047607236D+00        0.8815401217823D+00
```

```
STATE TRANSITION MATRIX PARTITIONS OVER(    5.000,  118.000)          --TRANSPOSES SHOWN

                         X(118.000)         Y(118.000)          Z(118.000)          VX(118.000)         VY(118.000)          VZ(118.000)
        X(  5.000)   0.7792786776D+02 -0.7038554492D+01 -0.3168918166D+01  0.3527011762D-04  0.1961251239D-04 -0.8046710882D-06
        Y(  5.000)  -0.2316557271D+03  0.1803673507D+02  0.9199788518D+01 -0.1053772090D-03 -0.5617024954D-04  0.2435534498D-05
        Z(  5.000)   0.1629415152D+02 -0.1345506073D+01 -0.6301104144D+00  0.7425595998D-05  0.3940840521D-05  0.6033603177D-06
       VX(  5.000)   0.9701733026D+08 -0.8387629916D+07 -0.3827464571D+07  0.4389776940D+02  0.2310844075D+02 -0.1003640341D+01
       VY(  5.000)  -0.1638141302D+09  0.1288429220D+08  0.6453261886D+07 -0.7452515465D+02 -0.4015844403D+02  0.1676929545D+01
       VZ(  5.000)   0.2732189483D+07 -0.1738352927D+06 -0.1412512219D+07  0.1248187867D+01  0.6920409277D+00 -0.5346474582D+00

     SOLVE-FOR PARAMETERS

                --NONE

     DYNAMIC CONSIDER PARAMETERS

                --NONE
     IGNORE PARAMETERS

                --NONE
    (VARIATION MATRIX HAS BEEN COMPUTED AND PUNCHED)

      VARIATION MATRIX
         0.7741306391D+02    -0.2302866141D+03     0.1619411761D+02     0.9639737063D+08    -0.1628387241D+09     0.2718214338D+07
        -0.1642642669D+01     0.5044119770D+01    -0.3291690563D+00    -0.1977654431D+07     0.3498003364D+07    -0.1357256634D+07
         0.0                  0.0                  0.0                  0.0                  0.0                  0.0

       TARGET CONDITION CORRELATION MATRIX AND STANDARD DEVIATIONS BEFORE GUIDANCE CORRECTION
```

```
0.9073225779D+06      0.1000000000D+01     -0.9944436571D+00
0.1956779123D+05     -0.9944436571D+00      0.1000000000D+01

              EIGENVALUES  OF ABOVE MATRIX            SQUARE ROOTS OF EIGENVALUES
                 1      0.8236129176D+12            1     0.9075312213D+06
                 2      0.4241258210D+07            2     0.2059431526D+04


              EIGENVECTORS OF ABOVE MATRIX
                 1      0.9997700967D+00    -0.2144186959D-01
                 2      0.2144186959D-01     0.9997700967D+00


   GUIDANCE MATRIX -- VARIABLE TIME OF ARRIVAL GUIDANCE POLICY
      -0.2087474568D-06    0.6136818554D-06   -0.4433720825D-07   -0.2630783171D+00    0.4371250474D+00    0.5281864401D-01
       0.3518333018D-06   -0.1048928827D-05    0.7338936513D-07    0.4371250474D+00   -0.7407074436D+00    0.3133080869D-01
       0.6656711751D-09    0.1188519255D-[illegible]    0.1122180271D-07    0.5281864401D-01    0.3133080869D-01   -0.9962142393D+00


   VELOCITY CORRECTION CORRELATION MATRIX AND STANDARD DEVIATIONS
0.2438942671D-02                 0.1000000000D+01    -0.9989242254D+00      0.5584887498D-01
0.4126[illegible]D-02           -0.9989242254D+00     0.1000000000D+01     -0.1020887355D+00
0.1586242168D-02                 0.5584887498D-01    -0.1020887355D+00      0.1000000000D+01
```

```
DELTA-VEE STATISTICS ---

EIGENVALUES OF S ---          0.22992407D-04 KM2/SEC2       0.25027124D-05 KM2/SEC2       0.0              KM2/SEC2

TRACE OF S ---                0.25495120D-04 KM2/SEC2

SQUARE ROOT OF TRACE ---      0.50492692D-02 KM/SEC

EIGENVALUE RATIOS ---         1.00000000          0.10884952          0.0

EIGENVECTORS OF S ---         0.85844143D+00      0.50920777D+00      0.61528536D-01
(TRANSPOSE)                  -0.50811428D+00      0.86063985D+00     -0.33450375D-01
                             -0.69987100D-01     -0.25483405D-02      0.99754464D+00

MEAN ---                      0.42528045D-02 KM/SEC

STANDARD DEVIATION ---        0.27219063D-02 KM/SEC

DELTA-VEE(90) =               0.80577619D-02 KM/SEC
DELTA-VEE(99) =               0.12459726D-01 KM/SEC
DELTA-VEE(99.9) =             0.15863364D-01 KM/SEC
DELTA-VEE(99.99) =            0.18727871D-01 KM/SEC



      EXPECTED VALUE OF VELOCITY CORRECTION
         -0.2160910695D-02    0.3660133010D-02    -0.1422579029D-03

SIGPRO=    0.1000000000D-03    SIGRES=    0.1000000000D-09
SIGALP=    0.3430000000D-03    SIGBET=    0.3430000000D-03

EXECUTION ERROR CORRELATION MATRIX AND STANDARD DEVIATIONS
    0.7137743113D-04              0.1000000000D+01     0.4786445485D+00     -0.1298998455D-01
    0.5497562527D-04              0.4786445485D+00     0.1000000000D+01      0.2856665696D-01
    0.7873252760D-04             -0.1298998455D-01     0.2856665696D-01      0.1000000000D+01

                       EIGENVALUES              SQUARE ROOTS OF EIGENVALUES
                  1     0.6203616675746D-08             1     0.7876304131D-04
                  2     0.1908634599343D-08             2     0.4368792281D-04
                  3     0.6203616675746D-08             3     0.7876304131D-04


                       EIGENVECTORS
                  1     0.8612618481608D+00      0.5080266364218D+00      -0.1170322983190D-01
                  2    -0.5081142813509D+00      0.8606398489094D+00      -0.3345037453486D-01
                  3    -0.6921415307720D-02      0.3475610960908D-01       0.9993718561451D+00

CONTROL (AND KNOWLEDGE) CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST AFTER GUIDANCE CORRECTION AT TIME   5.000 DAYS

              STD DEV                 X              Y              Z              VX             VY             VZ
      X       0.41804114D+00     1.00000000
      Y       0.22683722D+00     0.83862829     1.00000000
      Z       0.12491878D+01     0.30236381     0.70434879     1.00000000
     VX       0.71380026D-04     0.00807762     0.00753835     0.00413672     1.00000000
     VY       0.54976676D-04     0.00524697     0.00475393     0.00280342     0.47866577     1.00000000
     VZ       0.78760201D-04     0.00620477     0.01197553     0.02218609    -0.01288783     0.02864886     1.00000000


 RSS POSITION ERRORS. . .  0.1336668860022D+01
 RSS VELOCITY ERRORS. . .  0.119669177894D-03
```

```
        SOLVE-FOR PARAMETERS

                 --NONE

        DYNAMIC CONSIDER PARAMETERS

                 --NONE

        MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                         -0.18498408    -0.42961397    -0.59123152    -0.00235912    -0.00156755    -0.01246204
LAT   1                          -0.12642380    -0.29749506    -0.40806583    -0.00163699    -0.00108542    -0.00859256
LONG  1                           0.90092480     0.60934337    -0.04481866     0.00448137     0.00457981    -0.00112670
RADIUS 2                         -0.16792225    -0.41506659    -0.50544319    -0.00203312    -0.00132156    -0.00909113
LAT   2                          -0.11795300    -0.29291494    -0.36063695    -0.00138727    -0.00091595    -0.00653847
LONG  2                           0.88596061     0.56289546    -0.04454567     0.00618748     0.00375236    -0.00162779
RADIUS 3                         -0.20106365    -0.43129428    -0.45098513    -0.00222525    -0.00055214    -0.00469323
LAT   3                           0.13970370     0.29827087     0.31304245     0.00155277     0.00039625     0.00332917
LONG  3                           0.84433425     0.55473400    -0.04635740     0.00596150     0.00390579    -0.00155296

        NO SOLVE-FOR PARAMETERS

                 POSITION EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
                   1        0.17751694887810+00         1     0.42132760280+00
                   2        0.32672017396810-02         2     0.57159441390-01
                   3        0.16058994912560+01         3     0.12672408970+01


                 POSITION EIGENVECTORS
                   1        0.92762645766000+00      0.33984884474720+00      -0.15495779352170+00
                   2       -0.35505207514260+00      0.93112430523070+00      -0.89339979275270-01
                   3        0.11596197215510+00      0.13232645590600+00       0.98439957846460+00


                 VELOCITY EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
                   1        0.62039720474310-08         1     0.78765297230-04
                   2        0.19086521414540-08         2     0.43688123570-04
                   3        0.62080879488710-08         3     0.78791420530-04


                 VELOCITY EIGENVECTORS
                   1        0.85201564363190+00      0.49657053935620+00      -0.16579268033640+00
                   2       -0.50810584347820+00      0.86064552500940+00      -0.33432500723230-01
                   3        0.12608713349470+00      0.11272523996350+00       0.98559375761120+00

        TARGET CONDITION CORRELATION MATRIX AND STANDARD DEVIATIONS AFTER  GUIDANCE CORRECTION
   0.82714611420+04              0.10000000000+01     -0.86151882660+00
   0.20194424830+03             -0.86151882660+00      0.10000000000+01

                 EIGENVALUES  OF ABOVE MATRIX            SQUARE ROOTS OF EIGENVALUES
                   1      0.68447342690+08            1     0.82732909220+04
                   2      0.10508216680+05            2     0.10250959310+03


                 EIGENVECTORS OF ABOVE MATRIX
                   1      0.99977879890+00    -0.21032197850-01
                   2      0.21032197850-01     0.99977879890+00

************************************************************************************************************************
```

```
        ACTUAL GUIDANCE EVENT


    MATRIX 1 = PHI*P*PHI(TRANSPOSE)
      0.7766877063610D+06 -0.3395000359500D+06  0.3559117052020D+05  0.1835587954400D+01 -0.1411955369950D+01  0.1488079099970D+00
     -0.3395000359500D+06  0.8523600966850D+06  0.1059775059870D+06 -0.1075051048230D+01  0.2884591974720D+01  0.9650136727670D-01
      0.3559117052020D+05  0.1059775059870D+06  0.6158999678410D+06  0.6152648969260D-01  0.2508862120840D+00  0.1261907146340D+01
      0.1835587954400D+01 -0.1075051048230D+01  0.6152648969260D-01  0.4444802385550D-05 -0.4218409324190D-05  0.3397223080620D-06
     -0.1411955369950D+01  0.2884591974720D+01  0.2508862120840D+00 -0.4218409324190D-05  0.9879709266780D-05  0.9298284561800D-07
      0.1488079099970D+00  0.9650136727670D-01  0.1261907146340D+01  0.3397223080620D-06  0.9298284561800D-07  0.2604611935340D-05

    TOTAL COVARIANCE MATRIX AT K+1
      0.7766877063610D+06 -0.3395000359500D+06  0.3559117052020D+05  0.1835587954400D+01 -0.1411955369950D+01  0.1488079099970D+00
     -0.3395000359500D+06  0.8523600966850D+06  0.1059775059870D+06 -0.1075051048230D+01  0.2884591974720D+01  0.9650136727670D-01
      0.3559117052020D+05  0.1059775059870D+06  0.6158999678410D+06  0.6152648969260D-01  0.2508862120840D+00  0.1261907146340D+01
      0.1835587954400D+01 -0.1075051048230D+01  0.6152648969260D-01  0.4444802385550D-05 -0.4218409324190D-05  0.3397223080620D-06
     -0.1411955369950D+01  0.2884591974720D+01  0.2508862120840D+00 -0.4218409324190D-05  0.9879709266780D-05  0.9298284561800D-07
      0.1488079099970D+00  0.9650136727670D-01  0.1261907146340D+01  0.3397223080620D-06  0.9298284561800D-07  0.2604611935340D-05
                  ACTUAL DYNAMIC NOISE SECOND MOMENT MATRIX DIAGONAL
           0.0                0.0                0.0                0.0                0.0                0.0

        ACTUAL DEVIATION MEANS
                X     0.0
                Y     0.0
                Z     0.0
               VX     0.0
               VY     0.0
               VZ     0.0

        ACTUAL CONTROL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST BEFORE GUIDANCE CORRECTION

                     STD DEV                X             Y             Z             VX            VY            VZ
          X          0.88129887D+03     1.00000000
          Y          0.92323350D+03    -0.41725837    1.00000000
          Z          0.78479295D+03     0.05145931    0.14626723    1.00000000
         VX          0.21082700D-02     0.98792905   -0.55232068    0.03718612    1.00000000
         VY          0.31432005D-02    -0.50971295    0.99403289    0.10170671   -0.63657621    1.00000000
         VZ          0.16138810D-02     0.10462399    0.06476650    0.99632447    0.09984500    0.01832986    1.00000000


        SOLVE-FOR PARAMETERS

        --NONE

        DYNAMIC CONSIDER PARAMETERS

        --NONE

        MEASUREMENT CONSIDER PARAMETERS
     RADIUS 1                               -0.00563479   -0.00760766   -0.05184867   -0.00547133   -0.00411949   -0.04054420

     LAT  1                                 -0.00374278   -0.00502912   -0.03440577   -0.00363959   -0.00271510   -0.02690383

     LONG 1                                  0.00394982    0.00125076   -0.00332779    0.00185127    0.00071873   -0.00263964

     RADIUS 2                                0.00234133    0.00083678   -0.00132535    0.00180703    0.00129085    0.00465785

     LAT  2                                  0.00196385    0.00078983    0.00000430    0.00157606    0.00099879    0.00388488

     LONG 2                                  0.00554724    0.00221309    0.00774122    0.00343408    0.00082114    0.00529636

     RADIUS 3                                0.0           0.0           0.0           0.0           0.0           0.0
```

```
LAT  3                                0.0            0.0            0.0            0.0            0.0            0.0

LONG 3                                0.00449861     0.00164077     0.00209057     0.00250358     0.00072941     0.00125845

      IGNORE PARAMETERS

      --NONE


                SOLVE-FOR PARAMETERS

      NO SOLVE-FOR PARAMETERS

                  POSITION EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
                      1      0.4229009384419D+06          1    0.6503083411D+03
                      2      0.1161860255304D+07          2    0.1077896217D+04
                      3      0.6601865771409D+06          3    0.8125186626D+03


                  POSITION EIGENVECTORS
                      1      0.6392550005019D+00     0.6182100178032D+00     -0.4573504326238D+00
                      2     -0.6523113002977D+00     0.7508881811360D+00      0.1032322959842D+00
                      3      0.4072382740330D+00     0.2323430939753D+00      0.8832744051792D+00


                  VELOCITY EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
                      1      0.1961466810278D-05          1    0.1400523763D-02
                      2      0.1218086301657D-04          2    0.3490109313D-02
                      3      0.2786793760828D-05          3    0.1669369270D-02


                  VELOCITY EIGENVECTORS
                      1      0.7763799064064D+00     0.4191403578068D+00     -0.4706969315664D+00
                      2     -0.4790114234137D+00     0.8777577999407D+00     -0.8470279009189D-02
                      3      0.4096123742852D+00     0.2320453616105D+00      0.8822543017676D+00

      ACTUAL TARGET STATE DEVIATION MEANS
          0.0                   0.0

      ACTUAL TARGET CONDITION CORRELATION MATRIX AND STANDARD DEVIATIONS BEFORE GUIDANCE CORRECTION
                0.90732404D+06        1.00000000
                0.19567932D+05       -0.99443311      1.00000000

                           EIGENVALUES                  SQUARE ROOTS OF EIGENVALUES
                      1      0.8236155591317D+12          1    0.9075326766D+06
                      2      0.4249347929227D+07          2    0.2061394656D+04


                  EIGENVECTORS
                      1      0.9997700989894D+00    -0.2144176221288D-01
                      2      0.2144176221288D-01     0.9997700989894D+00


       ACTUAL VELOCITY CORRECTION SECOND MOMENT MATRIX
                  0.5948499805D-05   -0.1005425357D-04    0.2155977428D-06
                 -0.1005425357D-04    0.1793055894D-04   -0.6680675501D-06
                  0.2155977428D-06   -0.6680675501D-06    0.2520897886D-05
```

```
          DELTA-VEE STATISTICS ---

          EIGENVALUES OF S ---            0.22992469D-04 KM2/SEC2       0.25074873D-05 KM2/SEC2       0.0            KM2/SEC2

          TRACE OF S ---                  0.25499957D-04 KM2/SEC2

          SQUARE ROOT OF TRACE ---        0.50497482D-02 KM/SEC

          EIGENVALUE RATIOS ---           1.00000000           0.10905690           0.0

          EIGENVECTORS OF S ---           0.85844143D+00       0.50920777D+00       0.61528536D-01
          (TRANSPOSE)                    -0.50811520D+00       0.86063982D+00      -0.33437297D-01
                                         -0.69980439D-01      -0.25596228D-02       0.99754508D+00

          MEAN ---                        0.42534184D-02 KM/SEC

          STANDARD DEVIATION ---          0.27218355D-02 KM/SEC

          DELTA-VEE(90) =                 0.80581298D-02 KM/SEC
          DELTA-VEE(99) =                 0.12459977D-01 KM/SEC
          DELTA-VEE(99.9) =               0.15863575D-01 KM/SEC
          DELTA-VEE(99.99) =              0.18728064D-01 KM/SEC


       ACTUAL STATISTICAL DELTA-V
          -0.2161226532D-02    0.3660661220D-02   -0.1422228161D-03

       ACTUAL EXECUTION ERROR MEANS
            0.0                 0.0                 0.0

       ACTUAL EXECUTION ERROR CORRELATION MATRIX AND STANDARD DEVIATIONS
                 0.71387654D-04       1.00000000
                 0.54983369D-04       0.47865082     1.00000000
                 0.78743917D-04      -0.01298503     0.02855577     1.00000000

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       MEANS OF ACTUAL DEVIATIONS
           0.0                 0.0                 0.0                 0.0                 0.0                 0.0

       MEANS OF ACTUAL ESTIMATION ERRORS
           0.0                 0.0                 0.0                 0.0                 0.0                 0.0

       ACTUAL CONTROL (AND KNOWLEDGE) CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS
              JUST AFTER GUIDANCE CORRECTION AT TIME     5.000 DAYS

                 STD DEV                   X              Y              Z             VX             VY             VZ
        X        0.40626707D+01       1.00000000
        Y        0.21712031D+01       0.85024437     1.00000000
        Z        0.11260481D+02       0.27796601     0.73185331     1.00000000
       VX        0.71592528D-04       0.07399420     0.07084876     0.03471806     1.00000000
       VY        0.55055703D-04       0.04734712     0.04411131     0.01838235     0.48031128     1.00000000
       VZ        0.79792808D-04       0.03602300     0.10760346     0.15583545    -0.00781635     0.03118593     1.00000000

       SOLVE-FOR PARAMETERS

       --NONE

       DYNAMIC CONSIDER PARAMETERS
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```
       --NONE

       MEASUREMENT CONSIDER PARAMETERS
   RADIUS 1                 -0.19034513   -0.44886073   -0.65588599   -0.02352118   -0.01565300   -0.12300767

   LAT   1                  -0.13008770   -0.31080906   -0.45269011   -0.01632127   -0.01083862   -0.08481364

   LONG 1                    0.92672592    0.63661367   -0.04971983    0.06462130    0.04573237   -0.01112117

   RADIUS 2                 -0.17268593   -0.43366230   -0.56071023   -0.02027085   -0.01319661   -0.08973480

   LAT   2                  -0.12137141   -0.30602393   -0.40007461   -0.01383154   -0.00914633   -0.06453854

   LONG 2                    0.91163675    0.58808705   -0.04941699    0.06169118    0.03746969   -0.01606725

   RADIUS 3                 -0.20689070   -0.45059626   -0.50030287   -0.02218641   -0.00551344   -0.04632499

   LAT   3                   0.14375267    0.31161956    0.34727539    0.01548157    0.00395681    0.03286090

   LONG 3                    0.86880600    0.57956033   -0.05142684    0.05943809    0.03900188   -0.01532863

       IGNORE PARAMETERS

       --NONE


                 SOLVE-FOR PARAMETERS

       NO SOLVE-FOR PARAMETERS

               POSITION EIGENVALUES              SQUARE ROOTS OF EIGENVALUES
                  1      0.16974479481670+02              1     0.41200096460+01
                  2      0.44994836818840-01              2     0.21211986430+00
                  3      0.13099837971320+03              3     0.11445452360+02


               POSITION EIGENVECTORS
                  1      0.92918202920680+00       0.33235806443450+00       -0.16173705080950+00
                  2     -0.35005921439470+00       0.93175297234060+00       -0.96410294843100-01
                  3      0.11865623884380+00       0.14620025834360+00        0.98211312049260+00


               VFLOCITY EIGENVALUES              SQUARE ROOTS OF EIGENVALUES
                  1      0.62347261023440-08              1     0.78960281800-04
                  2      0.19103686895300-08              2     0.43707764640-04
                  3      0.63784179472760-08              3     0.79864998260-04


               VELOCITY EIGENVECTORS
                  1      0.84356957631610+00       0.48902214378440+00       -0.22191825702800+00
                  2     -0.50747825907590+00       0.86108654711460+00       -0.31555901881630-01
                  3      0.17565929089870+00       0.13923828951430+00        0.97455451989820+00


       ACTUAL TARGET STATE DEVIATION MEANS
           0.0                 0.0

       ACTUAL TARGET CONDITION CORRELATION MATRIX AND STANDARD DEVIATIONS AFTER  GUIDANCE CORRECTION
   E(DTAU)         0.82743692D+04        1.00000000
   E(DTAU)         0.20262016D+03       -0.85886085       1.00000000
```

```
          EIGENVALUFS              SQUARE ROOTS OF EIGENVALUES
  1        0.6849547366025D+08              1     0.8276199228D+04
  2        0.1076632798308D+05              2     0.1037609174D+03


FIGENVECTORS
  1        0.9997788414939D+00      -0.2103017121093D-01
  2        0.2103017121093D-01       0.9997788414939D+00
```

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        MEASUREMENT NO   60 AT TRAJECTORY TIME   112.400                                                          PROBLEM. .   118

       RANGE-RATE WAS MEASURED FROM STATION 2 AT TRAJECTORY TIME    112.40000 DAYS

       INITIAL TRAJECTORY TIME   112.200
       FINAL   TRAJECTORY TIME   112.400
INITIAL
     AT TRAJECTORY TIME    112.2000

 STATE          X-COMP          Y-COMP          Z-COMP          RADIUS          X-DOT          Y-DOT          Z-DOT        VELOCITY

 INERTIAL  0.1218485D+07  0.7366942D+06 -0.1818024D+05  0.1423993D+07  -0.18919287   0.52646992   0.03573650   0.56057258
 HELIO-    0.1214477D+09  0.8799268D+08 -0.1931317D+05  0.1499742D+09 -18.16596535  24.51864452   0.03661769  30.51503837
 ROT.GEO-  0.1418856D+07 -0.1194706D+06 -0.1818024D+05  0.1423993D+07   0.13200367   0.25090444   0.03573156   0.28575296
FINAL
     AT TRAJECTORY TIME    112.4000

 STATE          X-COMP          Y-COMP          Z-COMP          RADIUS          X-DOT          Y-DOT          Z-DOT        VELOCITY

 INERTIAL  0.1215204D+07  0.7457867D+06 -0.1756223D+05  0.1425913D+07  -0.19058900   0.52590137   0.03579170   0.56051536
 HELIO-    0.1211331D+09  0.8841583D+08 -0.1867962D+05  0.1499686D+09 -18.25085826  24.45713527   0.03670887  30.51633400
 ROT.GEO-  0.1421148D+07 -0.1151407D+06 -0.1756223D+05  0.1425913D+07   0.13328469   0.25022979   0.03578647   0.28576289



STATE TRANSITION MATRIX PARTITIONS OVER(  112.200,  112.400)          --TRANSPOSES SHOWN

                      X(112.400)         Y(112.400)         Z(112.400)         VX(112.400)        VY(112.400)        VZ(112.400)
       X(112.200)   0.1000030649D+01   0.3676237247D-04 -0.7543130778D-06   0.3516928970D-08   0.4181909805D-08 -0.7764625574D-10
       Y(112.200)   0.3590877168D-04   0.9999650640D+00 -0.4244566298D-06   0.4181677227D-08 -0.4278553900D-09 -0.4731463572D-10
       Z(112.200)  -0.6856425898D-06 -0.4320108928D-06   0.9999733030D+00 -0.7764854471D-10 -0.4732245151D-10 -0.3088595536D-08
      VX(112.200)   0.1728057520D+05 -0.1244384766D+01   0.1081848145D+00   0.1000030224D+01   0.3597117029D-04 -0.6664340617D-06
      VY(112.200)   0.1620117187D+01   0.1727997397D+05 -0.9312438965D-01   0.3692800237D-04   0.9999966818D+00 -0.4303346941D-06
      VZ(112.200)  -0.1087341309D+00   0.8033752441D-01   0.1727984537D+05 -0.7074268069D-06 -0.4143503247D-06   0.9999733298D+00

    SOLVE-FOR PARAMETERS

                  --NONE

    DYNAMIC CONSIDER PARAMETERS

                  --NONE
    IGNORE PARAMETERS

                  --NONE

DIAGONAL OF DYNAMIC NOISE MATRIX
                  0.0             0.0             0.0             0.0             0.0             0.0


OBSERVATION MATRIX PARTITIONS -- TRANSPOSES SHOWN
                                   RANGE-RATE(2)
               X                 -0.1105396543D-06
               Y                  0.1822867468D-06
               Z                  0.1434851610D-06
              VX                  0.8503993610D+00
```

```
          VY              0.5259753582D+00
          VZ             -0.1307093741D-01

       SOLVE-FOR PARAMETERS

                 --NONE

       DYNAMIC CONSIDER PARAMETERS

                 --NONE

       MEASUREMENT CONSIDER PARAMETERS
       RADIUS 1               0.0
       LAT  1                 0.0
       LONG 1                 0.0
       RADIUS 2              -0.5611262073D-04
       LAT  2                 0.3103895104D-02
       LONG 2                 0.2806936663D+00
       RADIUS 3               0.0
       LAT  3                 0.0
       LONG 3                 0.0

       IGNORE PARAMETERS

                 --NONE



  MEASUREMENT NOISE MATRIX
                   0.16666667D-13



  GAIN MATRIX PARTITIONS
                 K-MATRIX
                                -0.1120593741D+07
                                 0.5417980944D+06
                                 0.4209276296D+07
                                -0.4438131037D+00
                                -0.6553644006D-02
                                 0.2373920864D+01

                 S-MATRIX

                           NOT DEFINED

  CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME  112.400 DAYS. JUST BEFORE  THE MEASUREMENT

                STD DEV             X             Y             Z             VX            VY            VZ
        X     0.23435789D+01     1.00000000
        Y     0.98072805D+00    -0.94616726    1.00000000
        Z     0.55140347D+01    -0.80898944    0.92119043    1.00000000
       VX     0.10034326D-05     0.99826364   -0.94438871   -0.80121360    1.00000000
       VY     0.34182112D-06    -0.28342696    0.01285934   -0.20916747   -0.25918264    1.00000000
       VZ     0.26722437D-05    -0.71914148    0.80935971    0.95260134   -0.69832791   -0.13796252    1.00000000


   RSS POSITION ERRORS. . .  0.607114223336D+01
   RSS VELOCITY ERRORS. . .  0.287482262354D-05
```

```
          SOLVE-FOR PARAMETERS

                --NONE

          DYNAMIC CONSIDER PARAMETERS

                --NONE

          MEASUREMENT CONSIDER PARAMETERS
      RADIUS 1                 -0.21469135   0.23540414   0.08122364  -0.25382433  -0.24927514  -0.10797541
      LAT  1                   -0.14742152   0.16181632   0.05573876  -0.17438826  -0.17139354  -0.07508599
      LONG 1                   -0.39932569   0.14624313  -0.15174796  -0.40469996   0.76034654  -0.20179839
      RADIUS 2                 -0.71803047   0.78832935   0.80868729  -0.69713763   0.05727998   0.79371482
      LAT  2                   -0.50889769   0.55846314   0.57306059  -0.49418939   0.04152870   0.56137389
      LONG 2                   -0.36151216   0.14936440  -0.16573006  -0.36729791   0.69042353  -0.23888027
      RADIUS 3                 -0.43747984   0.48836973   0.51539459  -0.44695138  -0.20491268   0.45050989
      LAT  3                    0.30266547  -0.33777202  -0.35675839   0.30937995   0.14305379  -0.31138644
      LONG 3                   -0.34811821   0.15042760  -0.18574418  -0.34421328   0.77213636  -0.24677522

          NO SOLVE-FOR PARAMETERS


  CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME  112.400 DAYS, JUST AFTER   THE MEASUREMENT

                STD DEV                    X            Y            Z            VX           VY           VZ
         X      0.23253178D+01       1.00000000
         Y      0.97051377D+00      -0.94546780   1.00000000
         Z      0.54038504D+01      -0.80648066   0.92034176   1.00000000
        VX      0.99674646D-06       0.99828320  -0.94385264  -0.79948592   1.00000000
        VY      0.34181686D-06      -0.28628365   0.01372156  -0.21242105  -0.26150411   1.00000000
        VZ      0.25996714D-05      -0.71514505   0.80609917   0.95086764  -0.69503248  -0.14062698   1.00000000


      RSS POSITION ERRORS. . .  0.596243227802D+01
      RSS VELOCITY ERRORS. . .  0.280510849458D-05

          SOLVE-FOR PARAMETERS

                --NONE

          DYNAMIC CONSIDER PARAMETERS

                --NONE

          MEASUREMENT CONSIDER PARAMETERS
      RADIUS 1                 -0.26248371   0.29129267   0.15740428  -0.29812705  -0.25111261  -0.02362728
      LAT  1                   -0.18028025   0.20024278   0.10811553  -0.20484827  -0.17265692  -0.01711498
      LONG 1                   -0.40208336   0.14734406  -0.15545354  -0.40706515   0.76037108  -0.20814856
      RADIUS 2                 -0.74564116   0.82207911   0.86069091  -0.72211498   0.05640653   0.85750450
      LAT  2                   -0.52848997   0.58240743   0.60995376  -0.51191419   0.04090873   0.60659618
      LONG 2                   -0.35348366   0.13834716  -0.18667510  -0.35972067   0.69086452  -0.26614060
      RADIUS 3                 -0.35684973   0.39612537   0.39002298  -0.37227682  -0.20157065   0.30379853
      LAT  3                    0.24699237  -0.27408008  -0.27020298   0.25781985   0.14074603  -0.21008593
      LONG 3                   -0.34281610   0.14270172  -0.20252046  -0.33909743   0.77246570  -0.26889068

          NO SOLVE-FOR PARAMETERS
```

```
*****************************************************************************************************************************

ACTUAL ESTIMATION ERROR STATISTICS

      DIAGONAL OF ACTUAL DYNAMIC NOISE COVARIANCE MATRIX
          0.0                 0.0                 0.0                 0.0                 0.0                 0.0

      ACTUAL MEASUREMENT NOISE CORRELATION MATRIX AND STANDARD DEVIATIONS
                0.12909945D-06      1.00000000

      ACTUAL MEASUREMENT RESIDUAL MEAN
          0.0

      ACTUAL MEASUREMENT RESIDUAL CORRELATION MATRIX AND STANDARD DEVIATIONS
                0.21125587D-05      1.00000000

      ACTUAL ESTIMATION ERROR MEANS AT TIME  112.400 DAYS BEFORE  THE MEASUREMENT
             X     0.0
             Y     0.0
             Z     0.0
            VX     0.0
            VY     0.0
            VZ     0.0

      ACTUAL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME 112.400 DAYS JUST BEFORE THE MEASUREMENT

                STD DEV                 X              Y              Z              VX             VY             VZ
       X        0.22411156D+02      1.00000000
       Y        0.95076690D+01     -0.95891206     1.00000000
       Z        0.54099918D+02     -0.81651166     0.92664027     1.00000000
      VX        0.96142756D-05      0.99854328    -0.95406652    -0.80684782     1.00000000
      VY        0.29351751D-05     -0.23802922     0.00508538    -0.25658875    -0.22033731     1.00000000
      VZ        0.25538333D-04     -0.72912262     0.84521486     0.97505620    -0.71067616    -0.23950364     1.00000000

             SOLVE-FOR PARAMETERS

      --NONE

             DYNAMIC CONSIDER PARAMETERS

      --NONE

             MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                            -0.22450699     0.24282234     0.08278570    -0.26491398    -0.29029787    -0.11298177

LAT   1                             -0.15416159     0.16691557     0.05681070    -0.18200733    -0.19959945    -0.07856740

LONG 1                              -0.41758277     0.15085163    -0.15466632    -0.42238141     0.88547532    -0.21115493

RADIUS 2                            -0.75085866     0.81317166     0.82423965    -0.72759575     0.06670643     0.83051600

LAT   2                             -0.53216438     0.57606177     0.58408147    -0.51578065     0.04836300     0.58740241

LONG 2                              -0.37804042     0.15407127    -0.16891732    -0.38334525     0.80404521    -0.24995613

RADIUS 3                            -0.45748132     0.50375953     0.52530646    -0.46647881    -0.23863476     0.47139812

LAT   3                              0.31650327    -0.34841609    -0.36361943     0.32289684     0.16659588    -0.32582410

LONG 3                              -0.36403409     0.15516796    -0.18931634    -0.35925205     0.89920536    -0.25821713
```

```
          IGNORE PARAMETERS

      --NONE



             SOLVE-FOR PARAMETERS

      NO SOLVE-FOR PARAMETERS

      ACTUAL ESTIMATION ERROR MEANS AT TIME  112.400 DAYS  AFTER  THE MEASUREMENT
                X      0.0
                Y      0.0
                Z      0.0
               VX      0.0
               VY      0.0
               VZ      0.0

      ACTUAL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME 112.400 DAYS JUST  AFTER THE MEASUREMENT

                 STD DEV                    X              Y              Z              VX             VY             VZ
        X        0.22263609D+02       1.00000000
        Y        0.94119830D+01      -0.95813460     1.00000000
        Z        0.53080926D+02      -0.81442383     0.92588513     1.00000000
       VX        0.95587065D-05       0.99835026    -0.95389858    -0.80581183     1.00000000
       VY        0.29344539D-05      -0.24530056     0.01187067    -0.25230479    -0.22706352     1.00000000
       VZ        0.24912712D-04      -0.72636667     0.84297348     0.97428038    -0.70840269    -0.23449488     1.00000000

             SOLVE-FOR PARAMETERS

      --NONE

             DYNAMIC CONSIDER PARAMETERS

      --NONE

             MEASUREMENT CONSIDER PARAMETERS
   RADIUS 1                           -0.27415055     0.30036556     0.16024384    -0.31087582    -0.29250596    -0.02465535

   LAT   1                            -0.18829331     0.20647974     0.11006593    -0.21360818    -0.20111765    -0.01785969

   LONG 1                             -0.41945510     0.15193338    -0.15825792    -0.42447244     0.88571048    -0.21720552

   RADIUS 2                           -0.77878330     0.84768439     0.87621773    -0.75299471     0.06570457     0.89481623

   LAT   2                            -0.55198020     0.60054766     0.62095730    -0.53380513     0.04765212     0.63299039

   LONG 2                             -0.36919525     0.14265625    -0.19004271    -0.37510337     0.80474647    -0.27772091

   RADIUS 3                           -0.37271093     0.40846348     0.39705898    -0.38819645    -0.23479751     0.31701741

   LAT   3                             0.25797064    -0.28261684    -0.27507743     0.26884497     0.16394658    -0.21922719

   LONG 3                             -0.35805353     0.14714644    -0.20617392    -0.35359822     0.89979078    -0.28059065

             IGNORE PARAMETERS

      --NONE
```

```
      ERROR ANALYSIS MODE-FINAL INSERTION  EVENT AT TRAJECTORY TIME 0.11800000D+03 DAYS          PROBLEM. .       11A
********************************************************************************************************************
      AT TRAJECTORY TIME     118.0000

 STATE         X-COMP         Y-COMP          Z-COMP          RADIUS          X-DOT          Y-DOT         Z-DOT        VELOCITY

 INERTIAL   0.1114926D+07  0.9959100D+06 -0.5362115D+01  0.1494957D+07  -0.22109491    0.50741756    0.03652809    0.55469797
 HELIO-     0.1117419D+09  0.9981373D+08 -0.5715374D+03  0.1498300D+09 -20.53970477   22.62046631    0.03757402   30.55431852
 ROT.GEO-   0.1494957D+07 -0.3211489D+00 -0.5362115D+01  0.1494957D+07   0.17314054    0.22309137    0.03652101    0.28474759




STATE TRANSITION MATRIX PARTITIONS OVER(  113.000,  118.000)          --TRANSPOSES SHOWN

                        X(118.000)         Y(118.000)        Z(118.000)         VX(118.000)        VY(118.000)         VZ(118.000)
       X(113.000)    0.1015262510D+01   0.2292075535D-01 -0.2229805541D-03  0.6511649886D-07  0.1060730792D-06 -0.7550426014D-09
       Y(113.000)    0.2289808798D-01   0.1000953735D+01 -0.1558723161D-03  0.1058278259D-06  0.9690311896D-08 -0.5424937704D-09
       Z(113.000)   -0.2239089081D-03  -0.1567522759D-03  0.9840352191D+00 -0.7660275530D-09 -0.5522942312D-09 -0.7253116951D-07
      VX(113.000)    0.4339090024D+06   0.3289628830D+04 -0.2299668884D+02  0.1012632231D+01  0.2275160956D-01 -0.1039670460D-03
      VY(113.000)    0.3291345703D+04   0.4322874847D+06 -0.1710360718D+02  0.2273199602D-01  0.1003060738D+01 -0.7901147092D-04
      VZ(113.000)   -0.2335324097D+02  -0.1699363518D+02  0.4297349013D+06 -0.1049393177D-03 -0.7984900731D-04  0.9845489285D+00

     SOLVE-FOR PARAMETERS

                  --NONE

     DYNAMIC CONSIDER PARAMETERS

                  --NONE
     IGNORE PARAMETERS

                  --NONE

       DIAGONAL OF DYNAMIC NOISE MATRIX

          0.0               0.0               0.0               0.0               0.0               0.0

MATRIX 1 = PHI*P*PHI(TRANSPOSE)
  0.441777921734D+04 -0.545544290588D+03  0.183601596597D+03  0.102720886792D-01 -0.110567498851D-02  0.449433305150D-03
 -0.545544290588D+03  0.147526370324D+05  0.185547051995D+02 -0.754125981588D-03  0.342063720488D-01  0.309525219310D-04
  0.183601596597D+03  0.185547051995D+02  0.146711975250D+05  0.455663711539D-03  0.347335004018D-04  0.335291077803D-01
  0.102720886792D-01 -0.754125981588D-03  0.455663711539D-03  0.239324868164D-07 -0.138950082977D-08  0.105378241435D-08
 -0.110567498851D-02  0.342063720488D-01  0.347335004018D-04 -0.138950082977D-08  0.793239791858D-07  0.806245711842D-10
  0.449433305150D-03  0.309525219310D-04  0.335291077803D-01  0.105378241435D-08  0.806245711842D-10  0.767915643375D-07

TOTAL COVARIANCE MATRIX AT K+1
  0.441777921734D+04 -0.545544290588D+03  0.183601596597D+03  0.102720886792D-01 -0.110567498851D-02  0.449433305150D-03
 -0.545544290588D+03  0.147526370324D+05  0.185547051995D+02 -0.754125981588D-03  0.342063720488D-01  0.309525219310D-04
  0.183601596597D+03  0.185547051995D+02  0.146711975250D+05  0.455663711539D-03  0.347335004018D-04  0.335291077803D-01
  0.102720886792D-01 -0.754125981588D-03  0.455663711539D-03  0.239324868164D-07 -0.138950082977D-08  0.105378241435D-08
 -0.110567498851D-02  0.342063720488D-01  0.347335004018D-04 -0.138950082977D-08  0.793239791858D-07  0.806245711842D-10
  0.449433305150D-03  0.309525219310D-04  0.335291077803D-01  0.105378241435D-08  0.806245711842D-10  0.767915643375D-07

    CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT EVENT TIME    118.000 DAYS
         BASED ON MEASUREMENTS UP TO TIME    113.000 DAYS

             STD DEV                   X              Y              Z              VX             VY             VZ
```

```
        X       0.66466377D+02      1.00000000
        Y       0.12146043D+03     -0.06757611    1.00000000
        Z       0.12112472D+03      0.02280561    0.00126121    1.00000000
       VX       0.15470128D-03      0.99899391   -0.04013425    0.02431743    1.00000000
       VY       0.28164513D-03     -0.05906405    0.99993079    0.00101815   -0.03189060    1.00000000
       VZ       0.27711291D-03      0.02440094    0.00091961    0.99892402    0.02458104    0.00103302    1.00000000


 RSS POSITION ERRORS. . .  0.18396090284 3D+03
 RSS VELOCITY ERRORS. . .  0.42432066923 5D-03


         SOLVE-FOR PARAMETERS

              --NONE

         DYNAMIC CONSIDER PARAMETERS

              --NONE

         MEASUREMENT CONSIDER PARAMETERS
 RADIUS 1                        -0.01143080    0.00182943    0.00663836   -0.00205554   -0.00058684   -0.00046611
 LAT  1                          -0.00785152    0.00125764    0.00455052   -0.00141224   -0.00040329   -0.00032831
 LONG 1                          -0.01723533    0.00197900   -0.00894055   -0.00295991    0.00049679   -0.00166440
 RADIUS 2                        -0.03155696    0.00620271    0.04647411   -0.00499416   -0.00072353    0.00652333
 LAT  2                          -0.02236751    0.00439550    0.03292390   -0.00354050   -0.00051170    0.00461284
 LONG 2                          -0.01516000    0.00184124   -0.01090393   -0.00260441    0.00046486   -0.00214858
 RADIUS 3                        -0.01530094    0.00267787    0.02018531   -0.00257624   -0.00062686    0.00217632
 LAT  3                           0.01059166   -0.00185102   -0.01398019    0.00178428    0.00043540   -0.00150422
 LONG 3                          -0.01462461    0.00199404   -0.01162506   -0.00244828    0.00057716   -0.00214879

         NO SOLVE-FOR PARAMETERS

              POSITION EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
                 1       0.43857582502 26D+04          1      0.66225057 57D+02
                 2       0.14782097081 89D+05          2      0.12158160 67D+03
                 3       0.14673768442 64D+05          3      0.12113533 11D+03


              POSITION EIGENVECTORS
                 1       0.99845623792 33D+00      0.52574605448 29D-01      -0.17917918797 30D-01
                 2      -0.50933771117 93D-01      0.99531266205 21D+00       0.82209827384 33D-01
                 3       0.22156080695 27D-01     -0.81170287795 55D-01       0.99645395903 04D+00


              VELOCITY EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
                 1       0.23876599895 91D-07          1      0.15452054 85D-03
                 2       0.79359945388 84D-07          2      0.28170900 84D-03
                 3       0.76811465054 99D-07          3      0.27714881 39D-03


              VELOCITY EIGENVECTORS
                 1       0.99948661265 55D+00      0.25075943368 44D-01      -0.19942622358 58D-01
                 2      -0.24651325189 07D-01      0.99947001768 51D+00       0.21260195554 22D-01
                 3       0.20465172581 13D-01     -0.20757668769 99D-01       0.99957505766 12D+00

*******************************************************************************************************

     DIAGONAL OF ACTUAL DYNAMIC NOISE MATRIX

           0.0            0.0            0.0            0.0            0.0            0.0
```

```
MATRIX 1 = PHI*P*PHI(TRANSPOSE)
  0.514777238921D+04 -0.778294982355D+03 -0.118198071165D+04  0.105568306685D-01 -0.104863517164D-02  0.703605408225D-04
 -0.778294982355D+03  0.148407771153D+05  0.503718359628D+03 -0.842541151617D-03  0.342100568665D-01  0.169295477710D-03
 -0.118198071165D+04  0.503718359628D+03  0.187020063542D+05 -0.542526114427D-04 -0.156816911110D-03  0.347952970213D-01
  0.105568306685D-01 -0.842541151617D-03 -0.542526114427D-04  0.240556411013D-07 -0.136837428495D-08  0.914608152569D-09
 -0.104863517164D-02  0.342100568665D-01 -0.156816911110D-03 -0.136837428495D-08  0.793930704768D-07  0.267281398176D-10
  0.703605408225D-04  0.169295477710D-03  0.347952970213D-01  0.914608152569D-09  0.267281398176D-10  0.772514657014D-07

TOTAL COVARIANCE MATRIX AT K+1
  0.514777238921D+04 -0.778294982355D+03 -0.118198071165D+04  0.105568306685D-01 -0.104863517164D-02  0.703605408225D-04
 -0.778294982355D+03  0.148407771153D+05  0.503718359628D+03 -0.842541151617D-03  0.342100568665D-01  0.169295477710D-03
 -0.118198071165D+04  0.503718359628D+03  0.187020063542D+05 -0.542526114427D-04 -0.156816911110D-03  0.347952970213D-01
  0.105568306685D-01 -0.842541151617D-03 -0.542526114427D-04  0.240556411013D-07 -0.136837428495D-08  0.914608152569D-09
 -0.104863517164D-02  0.342100568665D-01 -0.156816911110D-03 -0.136837428495D-08  0.793930704768D-07  0.267281398176D-10
  0.703605408225D-04  0.169295477710D-03  0.347952970213D-01  0.914608152569D-09  0.267281398176D-10  0.772514657014D-07


******************************************************************************************************************************

        ACTUAL ESTIMATION ERROR MEANS AT TIME  118.000 DAYS
              X     0.0
              Y     0.0
              Z     0.0
             VX     0.0
             VY     0.0
             VZ     0.0

        ACTUAL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS AT TIME 118.000 DAYS

                 STD DEV              X             Y             Z             VX            VY            VZ
      X          0.71747978D+02     1.00000000
      Y          0.12182273D+03    -0.08994432    1.00000000
      Z          0.13675528D+03    -0.12046382    0.03023537    1.00000000
     VX          0.15509881D-03     0.94807055   -0.04459173   -0.00255781    1.00000000
     VY          0.28176776D-03    -0.05187086    0.99663050   -0.00406965   -0.03131159    1.00000000
     VZ          0.27794148D-03     0.00352831    0.00499993    0.91542566    0.02121648    0.00034129    1.00000000


             SOLVE-FOR PARAMETERS

        --NONE

             DYNAMIC CONSIDER PARAMETERS

        --NONE

             MEASUREMENT CONSIDER PARAMETERS
 RADIUS 1                            -0.10589343    0.01823986    0.05879622   -0.02050268   -0.00586590   -0.00464723

 LAT   1                             -0.07273546    0.01253904    0.04030411   -0.01408624   -0.00403114   -0.00327330

 LONG 1                              -0.15966581    0.01973115   -0.07918685   -0.02952327    0.00496577   -0.01659441

 RADIUS 2                            -0.29233953    0.06184268    0.41162316   -0.04981358   -0.00723215    0.06503886

 LAT   2                             -0.20720968    0.04382430    0.29160833   -0.03531424   -0.00511479    0.04599086

 LONG 2                              -0.14044023    0.01835761   -0.09657652   -0.02597738    0.00464660   -0.02142178

 RADIUS 3                            -0.14174568    0.02669902    0.17878217   -0.02569639   -0.00626592    0.02169837

 LAT   3                              0.09811977   -0.01845514   -0.12382313    0.01779702    0.00435212   -0.01499732
```

```
LONG 3                                          -0.13548043     0.01988114    -0.10296360    -0.02442010     0.00576911    -0.02142387

            IGNORE PARAMETERS

      --NONE


             SOLVE-FOR PARAMETERS

      NO SOLVE-FOR PARAMETERS

               POSITION EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
                  1        0.4990947993451D+04            1     0.7064664177D+02
                  2        0.1481448725504D+05            2     0.1217147783D+03
                  3        0.1888512061026D+05            3     0.1374231444D+03


               POSITION EIGENVECTORS
                  1        0.9937820419400D+00       0.7428316748239D-01       0.8294132954340D-01
                  2       -0.6155794499015D-01       0.9872726022230D+00      -0.1466404729550D+00
                  3       -0.9277862106235D-01       0.1406229708428D+00       0.9857065017261D+00


               VELOCITY EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
                  1        0.2400610130881D-07            1     0.1549390245D-03
                  2        0.7942689446064 5D-07          2     0.2618277747D-03
                  3        0.7726718136422D-07            3     0.2779697490D-03


               VELOCITY EIGENVECTORS
                  1        0.9995471749029D+00       0.2470281205792D-01      -0.1718185734465D-01
                  2       -0.2467361624747D-01       0.9996937369672D+00       0.1909169908315D-02
                  3        0.1722374704234D-01      -0.1484366833723D-02       0.9998505582578D+00




STATE TRANSITION MATRIX PARTITIONS OVER(  113.000,  118.000)          --TRANSPOSES SHOWN

                         X(118.000)         Y(118.000)         Z(118.000)         VX(118.000)        VY(118.000)        VZ(118.000)
         X(113.000)   0.1015262510D+01  0.2292075535D-01 -0.2229805541D-03  0.6511649886D-07  0.1060730792D-06 -0.7550426014D-09
         Y(113.000)   0.2289808798D-01  0.1000953735D+01 -0.1558723161D-03  0.1058278259D-06  0.9690311886D-08 -0.5424937704D-09
         Z(113.000)  -0.2239089081D-03 -0.1567522759D-03  0.9840352191D+00 -0.7660275530D-09 -0.5522942312D-09 -0.7253116951D-07
        VX(113.000)   0.4339990024D+06  0.3289628830D+04 -0.2299668884D+02  0.1012632231D+01  0.2275160956D-01 -0.1039670460D-03
        VY(113.000)   0.3291345703D+04  0.4322874847D+06 -0.1710360718D+02  0.2273199602D-01  0.1003060738D+01 -0.7901147092D-04
        VZ(113.000)  -0.2335324097D+02 -0.1699363518D+02  0.4297349013D+06 -0.1049393177D-03 -0.7984900731D-04  0.9845489285D+00

      SOLVE-FOR PARAMETERS

               --NONE

      DYNAMIC CONSIDER PARAMETERS

               --NONE
      IGNORE PARAMETERS
```

```
          --NONE


**********************************************************************************************************************
          * ASSUMED GUIDANCE EVENT *



     DIAGONAL OF DYNAMIC NOISE MATRIX
             0.0              0.0              0.0              0.0              0.0              0.0

MATRIX 1 = PHI*P*PHI(TRANSPOSE)
  0.441777921734D+04 -0.545544290588D+03  0.183601596597D+03  0.102720886792D-01 -0.110567498851D-02  0.449433305150D-03
 -0.545544290588D+03  0.147526370324D+05  0.185547051995D+02 -0.754125981588D-03  0.342063720488D-01  0.309525219310D-04
  0.183601596597D+03  0.185547051995D+02  0.146711975250D+05  0.455663711539D-03  0.347335004018D-04  0.335291077803D-01
  0.102720886792D-01 -0.754125981588D-03  0.455663711539D-03  0.239324868164D-07 -0.138950082977D-08  0.105378241435D-08
 -0.110567498851D-02  0.342063720488D-01  0.347335004018D-04 -0.138950082977D-08  0.793239791858D-07  0.806245711842D-10
  0.449433305150D-03  0.309525219310D-04  0.335291077803D-01  0.105378241435D-08  0.806245711842D-10  0.767915643375D-07

TOTAL COVARIANCE MATRIX AT K+1
  0.441777921734D+04 -0.545544290588D+03  0.183601596597D+03  0.102720886792D-01 -0.110567498851D-02  0.449433305150D-03
 -0.545544290588D+03  0.147526370324D+05  0.185547051995D+02 -0.754125981588D-03  0.342063720488D-01  0.309525219310D-04
  0.183601596597D+03  0.185547051995D+02  0.146711975250D+05  0.455663711539D-03  0.347335004018D-04  0.335291077803D-01
  0.102720886792D-01 -0.754125981588D-03  0.455663711539D-03  0.239324868164D-07 -0.138950082977D-08  0.105378241435D-08
 -0.110567498851D-02  0.342063720488D-01  0.347335004018D-04 -0.138950082977D-08  0.793239791858D-07  0.806245711842D-10
  0.449433305150D-03  0.309525219310D-04  0.335291077803D-01  0.105378241435D-08  0.806245711842D-10  0.767915643375D-07

  CONTROL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST BEFORE GUIDANCE CORRECTION AT TIME    118.0000000 DAYS

               STD DEV              X             Y             Z             VX            VY            VZ
      X      0.66466377D+02     1.00000000
      Y      0.12146043D+03    -0.06727611    1.00000000
      Z      0.12112472D+03     0.02280561    0.00126121    1.00000000
     VX      0.15470128D-03     0.99899391   -0.04013425    0.02431743    1.00000000
     VY      0.28164513D-03    -0.05906405    0.99993079    0.00101815   -0.03189060    1.00000000
     VZ      0.27711291D-03     0.02440094    0.00091961    0.99892402    0.02458104    0.00103302    1.00000000


RSS POSITION ERRORS. . .  0.183960902843D+03
RSS VELOCITY ERRORS. . .  0.424320669235D-03

        SOLVE-FOR PARAMETERS

              --NONE

        DYNAMIC CONSIDER PARAMETERS

              --NONE

        MEASUREMENT CONSIDER PARAMETERS.
RADIUS 1                    -0.01143080    0.00182943    0.00663836   -0.00205554   -0.00058684   -0.00046611
LAT   1                     -0.00785152    0.00125764    0.00455052   -0.00141224   -0.00040329   -0.00032831
LONG 1                      -0.01723533    0.00197900   -0.00894055   -0.00295991    0.00049679   -0.00166440
RADIUS 2                    -0.03155696    0.00620271    0.04647411   -0.00499416   -0.00072353    0.00652333
LAT   2                     -0.02236751    0.00439550    0.03292390   -0.00354050   -0.00051170    0.00461284
LONG 2                      -0.01516000    0.00184124   -0.01090393   -0.00260441    0.00046486   -0.00214858
RADIUS 3                    -0.01530094    0.00267787    0.02018531   -0.00257624   -0.00062686    0.00217632
LAT   3                      0.01059166   -0.00185102   -0.01398019    0.00178428    0.00043540   -0.00150422
LONG 3                      -0.01462461    0.00199404   -0.01162506   -0.00244828    0.00057716   -0.00214879
```

```
NO SOLVE-FOR PARAMETERS

          POSITION EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
             1       0.43857582502560D+04          1       0.66225057570D+02
             2       0.14782087081890D+05          2       0.12158160670D+03
             3       0.14673768442640D+05          3       0.12113533110D+03


          POSITION EIGENVECTORS
             1       0.99845623792330D+00     0.52574605448290D-01     -0.17917918797300D-01
             2      -0.50933771117930D-01     0.99531266205210D+00      0.82209827384330D-01
             3       0.22156080695270D-01    -0.81170287795550D-01      0.99645395903040D+00


          VELOCITY EIGENVALUES            SQUARE ROOTS OF EIGENVALUES
             1       0.23876599895910D-07          1       0.15452054850D-03
             2       0.79359965388840D-07          2       0.28170900840D-03
             3       0.76811465054990D-07          3       0.27714881390D-03


          VELOCITY EIGENVECTORS
             1       0.99948661265550D+00     0.25075943368440D-01     -0.19942622358580D-01
             2      -0.24651325189070D-01     0.99947001768510D+00      0.21260195554220D-01
             3       0.20465172581130D-01    -0.20757668769990D-01      0.99957505766120D+00


  **********      FINAL INSERTION IS IMPULSIVE      **********


    EXPECTED VALUE OF VELOCITY CORRECTION
        0.1596500000D-01   -0.2853780000D+00   -0.3797100000D-01

 SIGPRO=   0.1000000000D-03    SIGRES=    0.1000000000D-09
 SIGALP=   0.3430000000D-03    SIGBET=    0.3430000000D-03

 EXECUTION ERROR CORRELATION MATRIX AND STANDARD DEVIATIONS
    0.5334243295D-02              0.1000000000D+01    0.7026032518D-01    0.5203454204D-02
    0.2954000478D-02              0.7026032518D-01    0.1000000000D+01   -0.1679598826D+00
    0.5307139763D-02              0.5203454204D-02   -0.1679598826D+00    0.1000000000D+01

                      EIGENVALUES                 SQUARE ROOTS OF EIGENVALUES
             1       0.28516087365850D-04          1       0.5340045633D-02
             2       0.83138280950000D-05          2       0.2883370960D-02
             3       0.28516087365850D-04          3       0.5340045633D-02


                      EIGENVECTORS
             1       0.99843555737150D+00     0.55912911720090D-01     -0.42904446601260D-03
             2      -0.55369552635200D-01     0.98974332552010D+00      0.13169040295090D+00
             3       0.77878377711640D-02    -0.13146062487060D+00      0.99129080177890D+00


  CONTROL CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST AFTER FINAL INSERTION

             STD DEV                 X            Y            Z            VX           VY           VZ
     X     0.66466377D+02      1.00000000
     Y     0.12146043D+03     -0.06757611   1.00000000
     Z     0.12112472D+03      0.02280561   0.00126121   1.00000000
     VX    0.53364861D-02      0.02896019  -0.00116347   0.00070495   1.00000000
     VY    0.29673966D-02     -0.00560596   0.09490664   0.00009664   0.06982600   1.00000000
     VZ    0.53143696D-02      0.00127236   0.00004795   0.05208797   0.00523135  -0.16696906   1.00000000
```

```
RSS POSITION ERRORS. . .  0.183960902843D+03
RSS VELOCITY ERRORS. . .  0.809481629545D-02


        SOLVE-FOR PARAMETERS

                  --NONE

        DYNAMIC CONSIDER PARAMETERS

                  --NONE

        MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                          -0.01143080     0.00182943     0.00663836    -0.00005959    -0.00005570    -0.00002430
LAT  1                            -0.00785152     0.00125764     0.00455052    -0.00004094    -0.00003828    -0.00001712
LONG 1                            -0.01723533     0.00197900    -0.00894055    -0.00008581     0.00004715    -0.00008679
RADIUS 2                          -0.03125696     0.00620271     0.04647411    -0.00014478    -0.00006867     0.00034015
LAT  2                            -0.02236751     0.00439550     0.03292390    -0.00010264    -0.00004857     0.00024053
LONG 2                            -0.01516000     0.00184124    -0.01090393    -0.00007550     0.00004412    -0.00011204
RADIUS 3                          -0.01530094     0.00267787     0.02018531    -0.00007468    -0.00005950     0.00011348
LAT  3                             0.01059166    -0.00185102    -0.01398019     0.00005172     0.00004133    -0.00007844
LONG 3                            -0.01462461     0.00199404    -0.01162506    -0.00007097     0.00005478    -0.00011205

        NO SOLVE-FOR PARAMETERS

                  POSITION EIGENVALUES             SQUARE ROOTS OF EIGENVALUES
                     1      0.4385758250256D+04           1     0.6622505757D+02
                     2      0.1478208708189D+05           2     0.1215816067D+03
                     3      0.1467376844264D+05           3     0.1211353311D+03


                  POSITION EIGENVECTORS
                     1      0.9984562379233D+00      0.5257460544829D-01     -0.1791791879730D-01
                     2     -0.5093377111793D-01      0.9953126620521D+00      0.8220982738433D-01
                     3      0.2215608069527D-01     -0.8117028779555D-01      0.9964539590304D+00


                  VELOCITY EIGENVALUES             SQUARE ROOTS OF EIGENVALUES
                     1      0.2854002506464D-04           1     0.5342286502D-02
                     2      0.8393096109651D-05           2     0.2897084079D-02
                     3      0.2859292968275D-04           3     0.5347235705D-02


                  VELOCITY EIGENVECTORS
                     1      0.9981987333246D+00      0.5798379287944D-01     -0.1540027767638D-01
                     2     -0.5546025870482D-01      0.9897362393851D+00      0.1317054902127D+00
                     3      0.2287899677848D-01     -0.1306141501181D+00      0.9911692566335D+00


 KNOWLEDGE CORRELATION MATRIX PARTITIONS AND STANDARD DEVIATIONS JUST AFTER FINAL INSERTION

                 STD DEV                 X              Y              Z              VX             VY             VZ
          X      0.66466377D+02     1.00000000
          Y      0.12146043D+03    -0.06757611     1.00000000
          Z      0.12112472D+03     0.02280561     0.00126121     1.00000000
         VX      0.53364861D-02     0.02896019    -0.00116347     0.00070495     1.00000000
         VY      0.29673966D-02    -0.00560596     0.09490664     0.00009664     0.06982600     1.00000000
         VZ      0.53143696D-02     0.00127236     0.00004795     0.05208797     0.00523135    -0.16696906     1.00000000
```

```
RSS POSITION ERRORS. . .  0.183960902843D+03
RSS VELOCITY ERRORS. . .  0.809481629545D-02


        SOLVE-FOR PARAMETERS

                  --NONE

        DYNAMIC CONSIDER PARAMETERS

                  --NONE

        MEASUREMENT CONSIDER PARAMETERS
RADIUS 1                             -0.01143080     0.00182943     0.00663836    -0.00005959    -0.00005570    -0.00002430
LAT   1                              -0.00785152     0.00125764     0.00455052    -0.00004094    -0.00003828    -0.00001712
LONG 1                               -0.01723533     0.00197900    -0.00894055    -0.00008581     0.00004715    -0.00008679
RADIUS 2                             -0.03155696     0.00620271     0.04647411    -0.00014478    -0.00006867     0.00034015
LAT   2                              -0.02236751     0.00439550     0.03292390    -0.00010264    -0.00004857     0.00024053
LONG 2                               -0.01516000     0.00184124    -0.01090393    -0.00007550     0.00004412    -0.00011204
RADIUS 3                             -0.01530094     0.00267787     0.02018531    -0.00007468    -0.00005950     0.00011348
LAT   3                               0.01059166    -0.00185102    -0.01398019     0.00005172     0.00004133    -0.00007844
LONG 3                               -0.01462461     0.00199404    -0.01162506    -0.00007097     0.00005478    -0.00011205

        NO SOLVE-FOR PARAMETERS

              POSITION EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
                 1       0.4385758250256D+04          1     0.6622505757D+02
                 2       0.1478208708187D+05          2     0.1215816067D+03
                 3       0.1467376844264D+05          3     0.1211353311D+03


              POSITION EIGENVECTORS
                 1       0.9984562379233D+00       0.5257460544829D-01      -0.1791791879730D-01
                 2      -0.5093377111793D-01       0.9953126620521D+00       0.8220982738433D-01
                 3       0.2215608069527D-01      -0.8117028779555D-01       0.9964539590304D+00


              VELOCITY EIGENVALUES          SQUARE ROOTS OF EIGENVALUES
                 1       0.2854002506464D-04          1     0.5342286502D-02
                 2       0.8393096109651D-05          2     0.2897084070D-02
                 3       0.2859292968275D-04          3     0.5347235705D-02


              VELOCITY EIGENVECTORS
                 1       0.9981987333246D+00       0.5798379287944D-01      -0.1540027767638D-01
                 2      -0.5546025870482D-01       0.9897362393851D+00       0.1317054902127D+00
                 3       0.2287899677848D-01      -0.1306141501181D+00       0.9911692566335D+00
```